Book of Abstracts

ICACS-25

25th International Conference
on **Atomic Collisions in Solids**

October 21-25, 2012

&

SHIM 2012

8th International Symposium
on **Swift Heavy Ions in Matter**

October 24-27, 2012

Kyoto, Japan

京都

ICACS-25 & SHIM2012

	21 (Sun)	22 (Mon)	23 (Tue)	24 (Wed)	25 (Thu)	26 (Fri)	27 (Sat)
	ICACS			Joint		SHIM	
9:00		Opening (ICACS) IC-I-01 R.C. Monreal IC-O-01 V. Esaulov IC-O-02 M.L. Martiarena	IC-I-09 H. Yurimoto IC-O-08 J.A. Scheer IC-O-09 L. Houssiau	Opening (SHIM) JO-I-01 S. Klein JO-O-01 K.K. Andersen JO-O-02 Yu.L. Pivovarov	Lindhard lecture IC-L-01 G. Schiwietz	SH-I-01 S. Klaumunzer SH-O-01 V. Stegailov SH-O-02 O.H. Pakarinen	SH-I-07 M.E. Toimil-Molares SH-O-11 M. Tomut SH-O-12 O. Ochedowski
10:00		Coffee	Coffee	Coffee	Coffee	Coffee	Coffee
11:00		IC-I-02 A.A. Correa IC-I-03 D. Primetzhofer IC-O-03 P. Sigmund	IC-I-10 L. Begrambekov IC-O-10 J.M. Layet IC-O-11 H. Gnaser	JO-I-02 W. Weber JO-O-03 A.I. Titov JO-O-04 L. Desgranges	JO-I-06 G. Rizza JO-O-10 U.B. Singh JO-I-07 H. Rothard	SH-I-02 S. Ghosh SH-O-03 T. Tamegai SH-O-04 R.K. Pandey	SH-I-08 M. Lang SH-O-13 F. Pellemoine SH-O-14 K. Takayama
12:00	IC-T-01 N. Arista	IC-O-04 P.L. Grande	IC-O-12 M. Szymonski IC-O-13 L. Repetto	JO-O-05 J.B. Malherbe	JO-O-11 C. Trautmann	SH-O-05 D. Severin SH-O-06 J.-M. Costantini	SH-O-15 K.-F. Wei SH-O-16 Y. Yoshida
13:00	Lunch	Lunch	Lunch	Lunch	Outing (Joint)	Lunch	Lunch
14:00	IC-T-02 C. Lemell	IC-I-04 J. Seifert IC-I-05 T. Suzuki	IC-I-11 R. Schuch IC-I-12 A. Cassimi	JO-I-03 B. Rethfeld JO-O-06 P. Kluth		SH-I-03 T. Kamada SH-I-04 E. Surdutovich	
15:00	Coffee	IC-I-06 T. Pradeep IC-O-05 O. Grizzi	IC-O-14 T. Kobayashi Coffee	JO-O-07 R. Ritter JO-O-08 J. Xue		SH-O-07 D. Dauvergne SH-O-08 C. Champion	
16:00	IC-T-03 H. Winter	Coffee	IC-I-13 J. Matsuo	Coffee		Coffee	
17:00	Coffee IC-T-04 D.W. Moon	IC-I-07 A. Hatakeyama IC-I-08 J. Schreiber IC-O-06 T. Schenkel	IC-O-15 K. Moritani IC-O-16 H.M. Urbassek IC-O-17 K. Narumi IC-O-18 E. Kolodney	JO-I-04 O. N. Rosmej JO-I-05 Y. Zhao JO-O-09 M. Pajek		SH-I-05 K. Suzuki SH-I-06 K. Murai SH-O-09 Y. Ngono-Ravache SH-O-10 T. Wiss	
18:00		IC-O-07 A. Yogo					
19:00	Welcome Reception (ICACS)	Exhibition with snacks & beverages	Poster (ICACS) and Welcome Reception (SHIM)	Poster (Joint)	Banquet (Joint)	Poster (SHIM)	
20:00				Special Session SH-S-01 M. Toulemonde SH-S-02 R. Neumann			
20:45							

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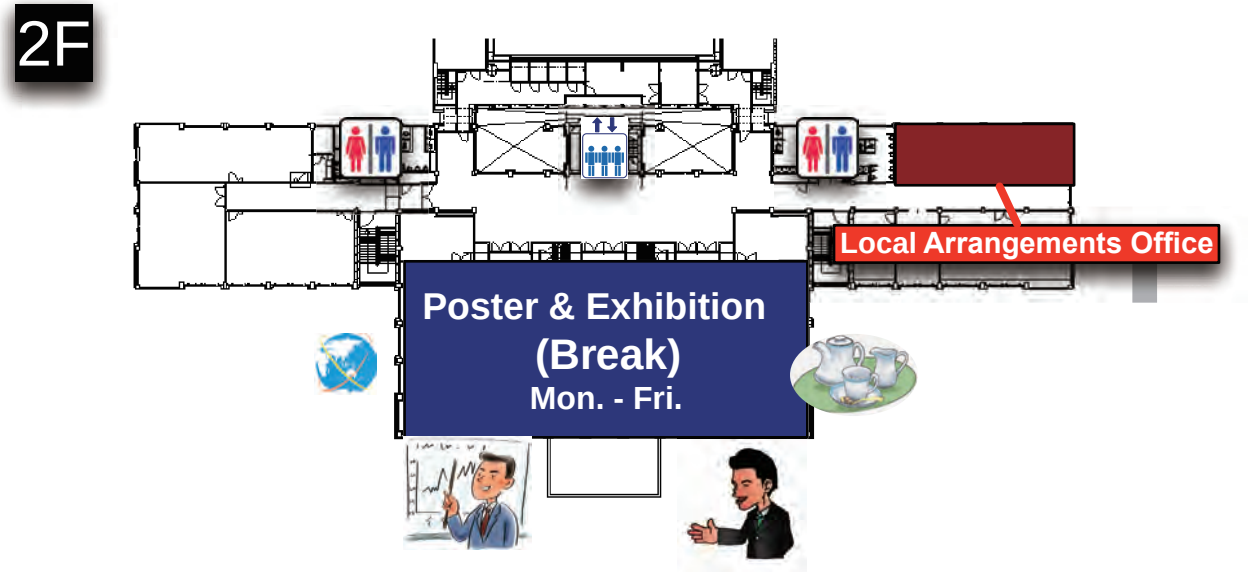
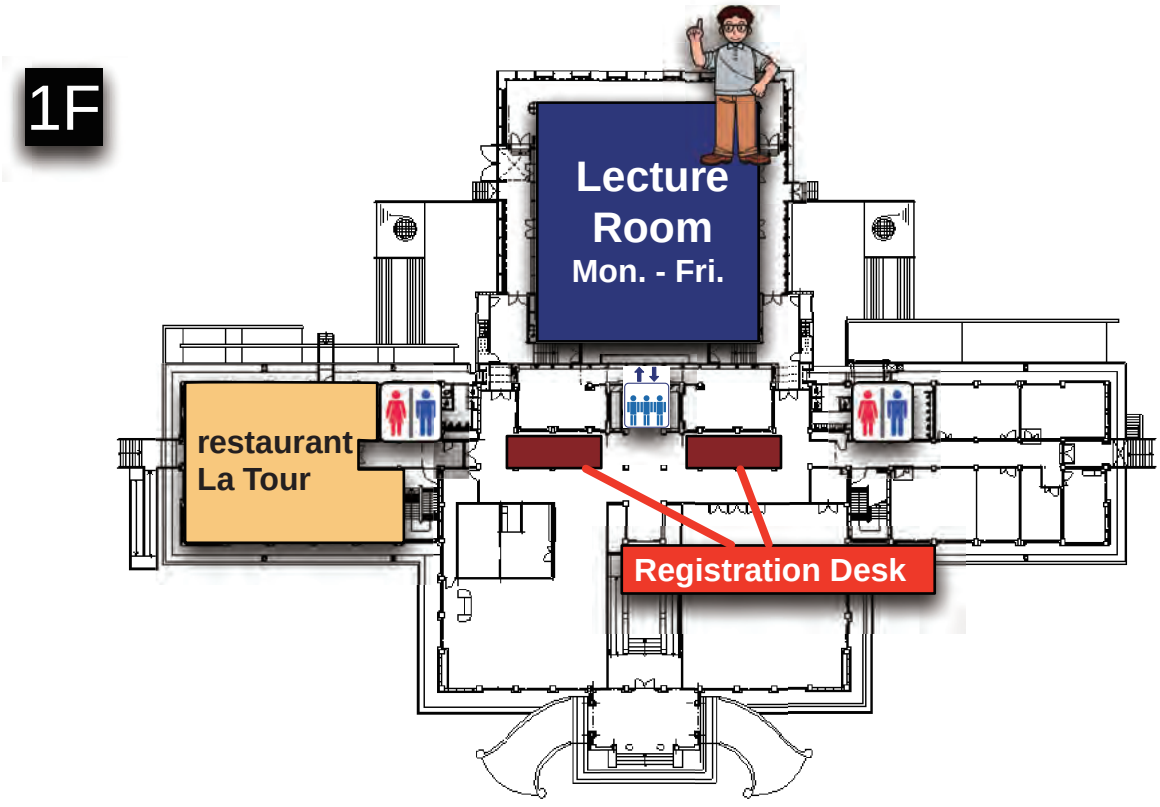
Floor Plan (Mon. - Fri.)

Clock Tower Centennial Hall





Campus Guide

SOCIAL PROGRAM

Social program includes Mixer, Banquet and Excursion. Thanks to generous subsidies from our sponsors, the registered participants and accompanying persons are invited to the social events free of charge. Excursion and Banquet will take place jointly between ICACS-25 and SHIM2012.

1. Welcome Reception: Oct. 21 (Sun) for ICACS-25, Oct. 23 (Tue) for SHIM2012

Welcome Reception for all delegates and registered accompanying persons with ICACS-25 will be held at the 2nd floor of the Kyoto University Clock Tower Centennial Hall from 18:00 on Oct. 21 (Sun). For participants in SHIM2012, the Welcome Reception will be held on Oct. 23 (Tue) at the poster and exhibition room in the Kyoto University Clock Tower Centennial Hall from 18:00 in conjunction with the poster session of ICACS-25.

2. Excursion: Afternoon on Oct. 25 (Thu)

In the afternoon on Oct. 25 (Thu), you can enjoy the excursion around Kyoto. The bus will depart from the conference site soon after the end of the morning session. Please pick the boxed lunch up when you get on the bus.

We will arrange the following three impressive options;

EX-1: Ukyo (right side of Kyoto) area, visiting *Ryoan-ji*, *Daitoku-ji* and *Kinkaku-ji (Golden Pavilion)* temples

EX-2: Higashiyama (east mountain side of Kyoto) area, visiting *Yasaka-jinjya* shrine, *Kodai-ji* and *Kiyomizu-dera* temples

EX-3: Fushimi (south of Kyoto) area, visiting *Sanjusangen-do* temple, *Fushimi Inari-taisya* shrine and *Gekkeikan Okura Sake Museum*

Please take a bus for the pre-registered option.

3. Banquet: Evening on Oct. 25 (Thu)

Banquet will take place at the Hyatt Regency Kyoto on Oct. 25 (Thu) at 18:00, following the excursion. Excursion buses will bring you to the banquet site directly. You may enjoy the Japanese drum play collaborated with the piano play as well as fine foods and beverages. After the banquet, buses for several major hotels will be arranged.

LUNCH TICKET

Lunch ticket will be offered to participants. The lunch ticket will be commonly available at Central Cafeteria, Cafe Restaurant ″Camphora″ and Yoshida Cafeteria (Yoshida Cafeteria is closed on Saturday). Please note that the lunch ticket will cover up to JPY800, and you have to pay the excess by yourself at the cashier of the Cafeteria.

On Sunday (Oct. 21, tutorial session will be held), the boxed lunch will be served in the conference room.

BUFFET SUPPER AT EXHIBITION AND POSTER SESSION

A buffet style meal and beverages will be available at Exhibition and Poster Session room every evening from Monday thru Friday except for Thursday evening.

Sunday 21st October

11:00 - 12:10	*Tutorial IC-T-01*	Chair P. Bauer	**N. Arista** (Centro Atómico Bariloche, Argentina) "The stopping of light ions in solids"
12:10 - 13:30	Lunch		
13:30 - 14:40	*Tutorial IC-T-02*	Chair H. Rothard	**C. Lemell** (Vienna University of Technology, Austria) "Modeling of highly charged ion - surface interactions"
14:40 - 15:00	Coffee Break		
15:00 - 16:10	*Tutorial IC-T-03*	Chair O. Grizzi	**H. Winter** (Humboldt University, Germany) "Scattering of fast atoms and ions from surfaces under channeling conditions"
16:10 - 16:30	Coffee Break		
16:30 - 17:40	*Tutorial IC-T-04*	Chair Y. Kido	**D.W. Moon** (Korea Research Institute of Standards and Science, Korea) "Surface ion microscopy (MEIS & SIMS) for nanotechnology & biotechnology"
18:00-19:30	Welcome Reception (ICACS)		

Monday 22nd October

9:00 - 9:10	Opening (ICACS)		
9:10 - 9:40	*IC-I-01*		**C. Monreal** (University of Autonoma, Spain) "Auger neutralization at metal surfaces"
9:40 - 10:00	*IC-O-01*	Chair H. Winter	**V. Esaulov** (ISMO, France) "Electron transfer processes on Au nano clusters and chains supported on HOPG and alumina films and size effects"
10:00 - 10:20	*IC-O-02*		**M.L. Martiarena** (CONICET, Argentina) "Size effects on the charge exchange process:Li^+ neutralization on Au wires and clusters"
10:20 - 10:50	Coffee Break		
10:50 - 11:20	*IC-I-02*		**A. A. Correa** (Lawrence Livermore National Laboratory, USA) "First principles theory of nonadiabatic forces in ion-solid interactions
11:20 - 11:50	*IC-I-03*		**D. Primetzhofer** (Uppsala University, Sweden) "Excitation thresholds in electronic stopping of low- and medium-energy ions"
11:50 - 12:10	*IC-O-03*	Chair J. O'Connor	**P. Sigmund** (University of Southern Denmark, Denmark) "Wakes, plasmons and Fermi gas in the theory of stopping of atomic and molecular ions"
12:10 - 12:30	*IC-O-04*		**P. L. Grande** (UFRGS, Brazil) "Depth profiling of thin films using coulomb explosion"
12:30 - 14:00	Lunch		
14:00 - 14:30	*IC-I-04*		**J. Seifert** (Humboldt University, Germany) "Surface structure determination via fast atom diffraction"
14:30 - 15:00	*IC-I-05*		**T. Suzuki** (National Institute for Materials Science, Japan) "Polarized $^4He^+$ ion-surface collisions"
15:00 - 15:30	*IC-I-06*	Chair V. Esaulov	**T. Pradeep** (Indian Institute of Technology Madras, India) "Collisions of 1-10 eV ions at ice surfaces"
15:30 - 15:50	*IC-O-05*		**O. Grizzi** (Centro Atómico Bariloche, Argentina) "Thiol terminated 1,4-Benzenedimethanethiol films grown on Au, Ag and Cu surfaces studied by direct recoiling spectroscopy"
15:50 - 16:20	Coffee Break		
16:20 - 16:50	*IC-I-07*		**A. Hatakeyama** (Tokyo University of Agriculture and Technology, Japan) "Okorokov effect in a magnetic lattice for a slow atomic beam"
16:50 - 17:20	*IC-I-08*		**J. Schreiber** (Ludwig Maximilians University Munich, Germany) "(Heavy) ion acceleration by laser pulses"
17:20 - 17:40	*IC-O-06*	Chair G. Schiwietz	**T. Schenkel** (Lawrence Berkeley National Laboratory, USA) "Intense, short pulse ion beams for studies of warm dense matter and point defect dynamics in solids"
17:40 - 18:00	*IC-O-07*		**A. Yogo** (Japan Atomic Energy Agency, Japan) "Radiobiology with laser-accelerated proton beams"
18:00 - 20:00	Exhibition with Snacks & Beverages		

Tuesday 23rd October

9:00 - 9:30	*IC-I-09*		**H. Yurimoto** (Hokkaido University, Japan) "Science of asteroid sample return mission "HAYABUSA"
9:30 - 9:50	*IC-O-08*	Chair J. Malherbe	**J.A. Scheer** (University of Bern, Switzerland) "Ionization at insulating surfaces: a review about a successful technique to measure energetic neutral atoms (ENA) in space"
9:50 - 10:10	*IC-O-09*		**L. Houssiau** (University of Namur, Belgium) "Why is low energy Cs^+ efficient for depth-profiling both organics and inorganics?"
10:10 - 10:40	Coffee Break		
10:40 - 11:10	*IC-I-10*		**L. Begrambekov** (National Research Nuclear University, Russia) "Hydrogen and oxygen trapping and retention in irradiated metals and graphite materials in plasma"
11:10 - 11:30	*IC-O-10*	Chair A. Titov	**J.M. Layet** (Aix-Marseille University, France) "H^- production by surface ionization on carbon materials in H_2 plasma"
11:30 - 11:50	*IC-O-11*		**H. Gnaser** (University of Kaiserslautern, Germany) "Atomic relocation in ion-irradiated ultra-thin magnetic films visualized with sub-nm spatial resolution"
11:50 - 12:10	*IC-O-12*		**M. Szymonski** (Jagiellonian University, Poland) "Anisotropic mass transport on ion-bombarded titanium dioxide surfaces"
12:10 - 12:30	*IC-O-13*		**L. Repetto** (Università di Genova, Italy) "Anisotropic dewetting of ion irradiated solid films"
12:30 - 14:00	Lunch		
14:00 - 14:30	*IC-I-11*	Chair F. Aumayr	**R. Schuch** (Stockholm university, Sweden) "Tailoring of keV-HCI beams by transmission through insulating nanocapillaries"
14:30 - 15:00	*IC-I-12*		**A. Cassimi** (CIMAP, France) "MeV ion micro-beam shaped by glass capillaries"
15:00 - 15:20	*IC-O-14*		**T. Kobayashi** (RIKEN, Japan) "Material deposition by ion irradiation in liquid"
15:20 - 15:50	Coffee Break		
15:50 - 16:20	*IC-I-13*		**J. Matsuo** (Kyoto University, Japan) "Secondary ion emission with energetic cluster beam"
16:20 - 16:40	*IC-O-15*	Chair B. Dev	**K. Moritani** (University of Hyogo, Japan) "Soft-sputtering of protein molecules using large cluster ion beams"
16:40 - 17:00	*IC-O-16*		**H.M. Urbassek** (University of Kaiserslautern, Germany) "Sputtering and reflection under cluster bombardment of solids"
17:00 - 17:20	*IC-O-17*		**K. Narumi** (Japan Atomic Energy Agency, Japan) "Cluster effect on damage accumulation in a Si crystal bombarded with 10-540-keV C_{60} ions"
17:20 - 17:40	*IC-O-18*		**E. Kolodney** (Technion-Israel Institute of Technology, Israel) "Postcollision multifragmentation in keV cluster-surface impact"
18:00 - 20:00	Poster (ICACS) Welcome Reception (SHIM)		

Wednesday 24th October

9:00 - 9:10	Opening (SHIM)		
9:10 - 9:40	*JO-I-01*		**S. Klein** (Lawrence Berkeley National Laboratory, USA) "Particle interactions with matter at TeV energies and above: the cosmic-ray experience"
9:40 - 10:00	*JO-O-01*	Chair T. Azuma	**K. K. Andersen** (Aarhus University, Denmark) "Direct measurement of the formation length of photons"
10:00 - 10:20	*JO-O-02*		**Yu. L. Pivovarov** (National Research Tomsk Polytechnic University, Russia) "Influence of stopping on transition radiation of relativistic heavy ions crossing a target"
10:20 - 10:50	Coffee Break		
10:50 - 11:20	*JO-I-02*		**W. Weber** (University of Tennessee, USA) "Effects of nuclear and electronic energy loss on damage formation and recovery"
11:20 - 11:40	*JO-O-03*	Chair H. Gnaser	**A. I. Titov** (St Petersburg State Polytechnic University, Russia) "Molecular effect on swelling and surface topography of GaN irradiated by PF_n^+ ions"
11:40 - 12:00	*JO-O-04*		**L. Desgranges** (CEA/DEN, France) "A possible new mechanism for defect formation in irradiated UO_2"
12:00 - 12:20	*JO-O-05*		**J.B. Malherbe** (University of Pretoria, South Africa) "SEM analysis of ion implanted SiC"
12:20 - 14:00	Lunch		
14:00 - 14:30	*JO-I-03*		**B. Rethfeld** (University of Kaiserslautern, Germany) "Ultrashort electron dynamics in solids irradiated with a laser or swift heavy ion"
14:30 - 14:50	*JO-O-06*	Chair M. Lang	**P. Kluth** (The Australian National University, Australia) "Ion tracks: new insights using small-angle x-ray scattering experiments"
14:50 - 15:10	*JO-O-07*		**R. Ritter** (Vienna University of Technology, Austria) "Nanopores in 1 nm thick carbon-nanomembranes drilled by slow highly charged ions"
15:10 - 15:30	*JO-O-08*		**J. Xue** (Peking University, China) "Nanoscale engineering of graphene with heavy ion beams"
15:30 - 16:00	Coffee Break		
16:00 - 16:30	*JO-I-04*		**O.N. Rosmej** (GSI, Germany) "X-ray spectroscopy of the heavy ion interaction with matter"
16:30 - 17:00	*JO-I-05*	Chair R. Schuch	**Y. Zhao** (Institute of Modern Physics, CAS, China) "Inner shell processes in the collisions of highly charged ions near Bohr velocity"
17:00 - 17:20	*JO-O-09*		**M. Pajek** (Jan Kochanowski University, Poland) "X-ray emission in fast collisions of heavy ions with solids"
17:30 - 19:20	Poster (Joint)		
19:30 - 20:45	Special Session "The history of swift heavy ions in matter"		
	SH-S-01	Chair C. Trautmann & A. Iwase	**M. Toulemonde** (CIMAP-GANIL, France) "Interactions of swift heavy ions with matter"
	SH-S-02		**R. Neumann** (Materials Research Department, GSI Helmholtz Centre for Heavy Ion Research, Germany) "Applications on the nanoscale"

Thursday 25th October

9:00 - 10:00	Lindhard lecture		
	IC-L-01	Chair P. Sigmund	**G. Schiwietz** (Helmholtz-Zentrum Berlin, Germany) "Short-time processes triggered by fast ions in solids"
10:00 - 10:20	Coffee Break		
10:20 - 10:50	*JO-I-06*		**G. Rizza** (Ecole Polytechnique, France) "Beyond the ion-beam shaping mechanism: toward plasmonic applications"
10:50 - 11:10	*JO-O-10*	Chair M. Toulemonde	**U.B. Singh** (Inter-University Accelerator Centre, India) "Synthesis of semi-embedded Au nanostructures by ion irradiation: combined effect of sputtering, viscous flow and ion recoil implantation"
11:10 - 11:40	*JO-I-07*		**H. Rothard** (CIMAP, France) "Heavy ion sputtering of LiF, astrophysical ices and silicates"
11:40 - 12:00	*JO-O-11*		**C. Trautmann** (GSI Helmholtz Centre for Heavy Ion Research, Germany) "Microscopic analysis of particles sputtered with heavy ions in the electronic stopping regime"
12:00	Outing (Joint)		
18:00 - 20:00	Banquet (Joint)		

Friday 26th October

9:00 - 9:30	*SH-I-01*		**S. Klaumunzer** (Helmholtz-Center for Materials and Energy, Germany) "Ion tracks in non-amorphizable non-radiolytic materials - a revision of the thermal spike concepts"
9:30 - 9:50	*SH-O-01*	Chair P. Grande	**V. Stegailov**(Joint Institute for High Temperatures of Russian Academy of Sciences, Russia) "Computer simulation of SHI effects in materials"
9:50 - 10:10	*SH-O-02*		**O.H. Pakarinen** (University of Helsinki, Finland) "Role of ion track density evolution in void formation in amorphous Ge and in metal nanoparticle shaping"
10:10 - 10:40	Coffee Break		
10:40 - 11:10	*SH-I-02*		**S. Ghosh** (Indian Institute of Technology Delhi, India) "Swift heavy ion induced thermal spike engineering of thin films modification and evolution of nanostructures"
11:10 - 11:30	*SH-O-03*	Chair J. C. Rizza	**T. Tamegai** (The University of Tokyo, Japan) "Effects of 2.6 GeV U irradiation in co-doped $BaFe_2As_2$"
11:30 - 11:50	*SH-O-04*		**R.K. Pandey** (University of Allahabad, India) "Swift heavy ion induced sputtering in barium fluoride thin films"
11:50 - 12:10	*SH-O-05*		**D. Severin** (GSI Helmholtz Centre for Heavy Ion Research, Germany) "From grain fragmentation to grain rotation: swift heavy ion bombardment of single crystalline NiO"
12:10 - 12:30	*SH-O-06*		**J. -M. Costantini** (CEA-DEN, France) "Paramagnetic trigonal center production in yttria stabilized zirconia by electronic excitations"
12:30 - 14:00	Lunch		
14:00 - 14:30	*SH-I-03*		**T. Kamada** (NIRS, Japan) "High energy heavy ion therapy -recent activities at HIMAC NIRS-"
14:30 - 15:00	*SH-I-04*		**E. Surdutovich** (Oakland University, USA) "DNA damage due to thermomechanical effects caused by heavy ions propagating in tissue "
15:00 - 15:20	*SH-O-07*	Chair A. Itoh	**D. Dauvergne** (Institut de Physique Nucléaire de Lyon, France) "Online monitoring of the ion range during ion therapy by means of prompt secondary radiations"
15:20 - 15:40	*SH-O-08*		**C. Champion** (University of Bordeaux 1, France) "Water versus DNA: a theoretical description of the ionizing processes induced by proton impact"
15:40 - 16:10	Coffee Break		
16:10 - 16:40	*SH-I-05*		**K. Suzuki** (SUNTRY Flowers Limited, Japan) "Innovative technology in flower breeding using heavy-ion beams"
16:40 - 17:10	*SH-I-06*		**K. Murai** (Fukui Prefectural University, Japan) "A large scale mutant panel of wheat developed by heavy-ion beam mutagenesis and its application for genetic research"
17:10 - 17:30	*SH-O-09*	Chair T. Kambara	**Y. Ngono-Ravache** (CIMAP-CEA, France) "The study of energy transfers towards radiation-induced defects in polymers submitted to ionizing radiation"
17:30 - 17:50	*SH-O-10*		**T. Wiss** (Institute for Transuranium Elements, Germany) "Response of nuclear ceramics to heavy ion impact"
18:00 - 20:00	Poster (SHIM)		

Saturday 27th October

9:00 - 9:30	*SH-I-07*	Chair J. M. Costantini	**M.E. Toimil-Molares** (GSI Helmholtz Centre for Heavy Ion Research, Germany) "Thermoelectric and plasmonic nanowires fabricated by ion-track technology and electrodeposition"
9:30 - 9:50	*SH-O-11*		**M. Tomut** (GSI Helmholtz Centre for Heavy Ion Research, Germany) "Non-graphitizing carbon phase induced by swift heavy ion irradiation of graphite"
9:50-10:10	*SH-O-12*		**O. Ochedowski** (Universität Duisburg-Essen, Germany) "Detecting swift heavy ion modification with graphene"
10:10-10:40	Coffee Break		
10:40-11:10	*SH-I-08*		**M. Lang** (University of Michigan, USA) "Nanoscale manipulation of the properties of solids at high pressures and irradiated by swift heavy ions"
11:10 - 11:30	*SH-O-13*	Chair R. Neumann	**F. Pellemoine** (Michigan State University, USA) "Annealing of radiation damage in graphite during swift heavy ion irradiation at high temperature"
11:30 - 11:50	*SH-O-14*		**K. Takayama** (KEK, Japan) "Heavy ion beam factory for material science based on the KEK digital accelerator"
11:50 - 12:10	*SH-O-15*		**K. -F. Wei** (Chinese Academy of Sciences, China) "Acoustic wave excited in materials by swift heavy ion irradiation"
12:10 - 12:30	*SH-O-16*		**Y. Yoshida** (Shizuoka Institute of Science and Technology, Japan) "On-line Mössbauer study of ^{57}Mn^{57}Fe in Si materials after nuclear projectile fragmentation and implantation at RIBF"
12:30 - 14:00	*Lunch*		

ORAL PRESENTATIONS

ICACS-25

&

SHIM2012

IC-T-01

The stopping of light ions in solids

Néstor R. Arista

División Colisiones Atómicas

Centro Atómico Bariloche and Instituto Balseiro, S.C. Bariloche, Argentina

This tutorial will include a review of several developments, current directions and questions related the phenomenon of energy loss of light ions in solids. The topics to be discussed include the following: (a) review of various basic models for the electronic stopping mechanisms: linear and perturbative models, self-consistent and non-linear models, Density Functional method, and related experimental results. (b) charge state effects, partial stopping powers and related issues; protons, antiprotons, positrons and muons; experimental evidences. (c) band structure and threshold effects at low energies: metals and insulators; experiments and models. What have we learned in the last years?.

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Modeling of HCI-surface interaction

Christoph Lemell*

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As a true many particle problem, the simulation of the interaction of highly charged ions with solid surfaces poses big challenges to theory. A large variety of simulation methods ranging from classical to full ab-initio calculations have to be combined to model experiments in this field.

Starting from experimental results I will work out prototypical pathways to the final simulation results and present details about the methods used. Emphasis will be put on understanding the advantages but, even more important, the limitations of the various methods.

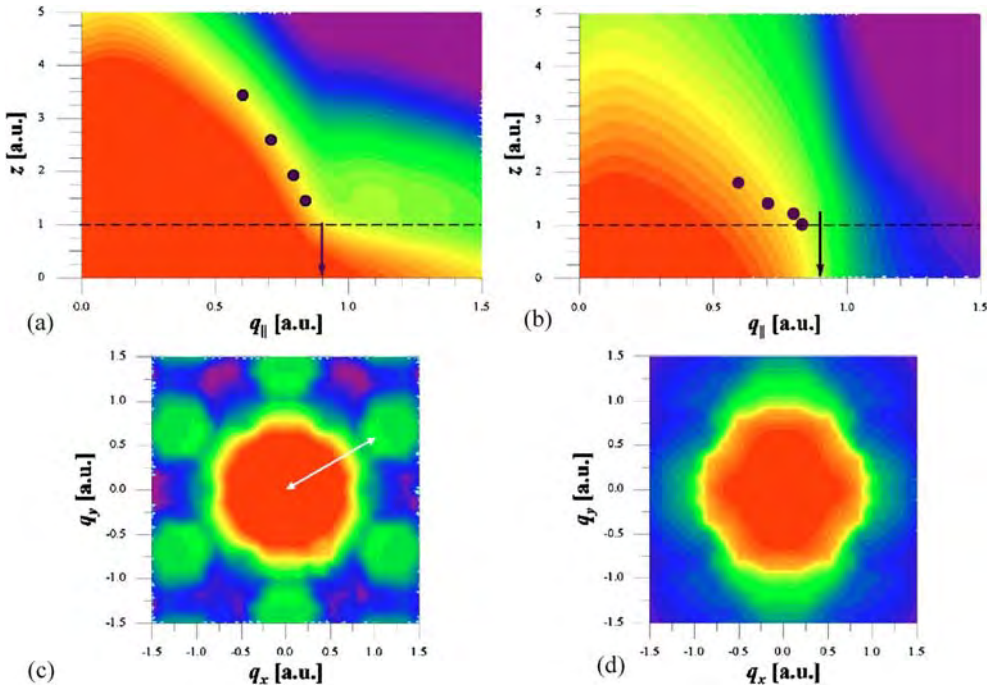

Figure 1: momentum distributions as a function of the distance from the topmost atomic layer of an Al(111) (left panels and an Al(110) surface (right panels). Black dots indicate experimental estimates for local Fermi momenta [1]. Panels c and d show q_x-q_y distributions for both faces taken at z=1 a.u. above the topmost atomic layer. [from (2)]

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Scattering of fast atoms and ions from surfaces under channeling conditions

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Scattering of fast atoms and ions from surfaces under glancing angles of incidence proceeds in the regime of “surface channeling” where projectiles are steered in terms of small angle collisions by atoms of the topmost layer of the surface. Collisions with the solid under these conditions are characterized by defined trajectories for the ensemble of scattered projectiles which is the basis for a detailed model description of the interaction mechanisms [1]. An important issue of channeling is the presence of the two vastly different regimes of motion during the scattering process: (1) a “fast” motion parallel to the surface (“planar channeling”) or strings of surface atoms (“axial channeling”) which proceeds with the kinetic energy of the incident projectiles, whereas (2) the motion normal to the surface plane or atomic strings is several orders of magnitude smaller; i.e. amounts for keV projectiles to about eV-energies.

In the talk an overview will be presented concerning the different aspects and techniques which demonstrate the substantial potential of surface channeling for studies on the ion-surface interactions and on the structure of surfaces [2]. As examples will be discussed the production of polarized beams, studies on resonant charge transfer, energy loss phenomena, resonant coherent excitation, interactions with insulators, scattering of clusters, investigation of growth and structure of ultra-thin films, as well as the recently discovered Fast Atom Diffraction for quantum scattering of fast atoms under axial surface channeling conditions [3].

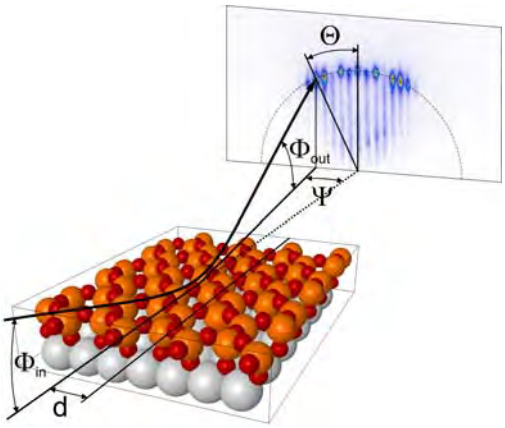

Figure 1. Scattering geometry for (axial) surface channeling experiment.

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Surface Ion Microscopy (MEIS & SIMS)

for Nanotechnology & Biotechnology

DaeWon Moon

Korea Research Institute of Standards and Science

Energetic ions in the energy range from ~ 100 eV to ~ 100 keV are useful to understand the surface and interface composition and structure of nanothin films and biosystems using scattering and sputtering processes. Two ion beam analysis techniques actively studied for nanotechnology (NT) and biotechnology (BT) applications are medium energy ion scattering (MEIS) and secondary ion mass spectrometry (SIMS)

In this lecture, I'd like to present the basic principles, instruments, and major applications of MEIS and SIMS for semiconductors, displays, nanoparticles, biosurfaces, cells and tissues. Rather than listing up many application results, I will try to discuss the present status and challenges of MEIS and SIMS for practical and useful applications in NT and BT.

MEIS is based on binary scattering and electronic stopping near sub surface region down to ~ 10 nm range. With channeling, MEIS is excellent for compositional and structural depth profiling of nm thin films. However, MEIS has not been widely used due to the lack of imaging or small spot analysis capability, the high cost of analysis, the large instrument size, and etc. Recent progresses to make MEIS more practically useful techniques such as HRRBS and TOF-MEIS will be discussed.

SIMS is still a unique & mandatory technique for dopant depth profiling in semiconductors due to its extremely high sensitivity, nano 3D imaging capability. However, the intrinsic destructive feature and serious matrix effect are the major problems for more reliable and wide applications in NT such as ultrashallow junction profiling and nanostructured materials. For last more than 10 years, the SIMS community has been trying to make SIMS a useful tool for bio-organic analysis with a partial success. Cluster ion beam technology almost solved the ion beam damage issues in polymer and bio specimens. However, the sensitivity of SIMS for high molecular weight molecules in polymer and biospecimen is still poor. Improvement of secondary ionization efficiency of organic and bio-molecues by orders of magnitude will be the major challenge in bio-SIMS in the near future. Recent development of bio-SIMS using cluster ion beam will be discussed.

Finally, visions of various cutting-edge ion beam techniques will be discussed to meet the rapidly increasing demands from NT and BT with other complementary techniques.

Auger neutralization at metal surfaces

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In this talk I will review the more recent advances in the theory of Auger neutralization of noble gas ions scattered off metal surfaces. The progress is related to different kinds of crystal effects, such as an influence of the band structure or the surface orientation on the neutralization efficiency, that account for some characteristics of the measured ions yields, either at normal incidence or under grazing scattering conditions. I will also present our latest theoretical and experimental results on the probabilities of He^+ ions to survive Auger neutralization when scattered at Cu, Ag and Au surfaces. I emphasize what we understood to be the key quantities to govern Auger neutralization and outline the challenges remaining to be met. This opens new perspectives for the further development of our theoretical and experimental work.

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IC-O-01

Electron Transfer Processes on Au Nano Clusters and Chains Supported on HOPG and Alumina Films and Size Effects

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Effects of cluster size in reactivity of supported clusters have been noted in several studies. We investigate here how electron transfer processes are affected as a function of growth of clusters on different surfaces on the example of neutralization of Li^+ ions and in particular if the substrate plays some role. This extends an earlier study (1) of Li ion neutralization on semiconducting TiO_2 to HOPG and alumina. Previously Li^+ neutralization in scattering on Au clusters and thin films supported on TiO_2 was found to display significantly more efficient neutralization on small clusters, with a decrease with increasing cluster size. These results closely follow the size-effects observed in the reactivity of these systems. In this study we observed again a much more efficient neutralization on small clusters. In case of HOPG on pristine surface with large planes and few defects, clusters agglomerate along step edges forming nanochains as observed by STM. On the nanochains (or wires) neutralization was found to be even more efficient. In case of Au clusters on alumina films, grown by oxidation of a NiAl crystal, we again observe this effect. We also note differences in the electron transfer probability for small clusters on these different substrates. In case of alumina some differences were noted for differently prepared substrates, presumably due to differences in the nature of the oxide support. These results will be presented and discussed.

References

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Size effects on the charge exchange process: Li+ neutralization on Au wires and clusters

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Electron transfer processes on surfaces, that play an important role in surface chemistry and influence charge states of ions or atoms scattered on surfaces, have been quite extensively investigated in the past[1]. Recently a renewed activity has developed in this field involving nano-scaled structures. Recent experimental studies of alkali neutralization on supported Ag and Au clusters, performed in the quest of quantum size effects, show that alkali neutralization occurs much more efficiently on small clusters than on films or bulk metal surfaces[2]. A study of size effects on electron transfer is then interesting and necessary. A prerequisite for this is the knowledge of the characteristic of the neutralization on bulk surfaces.

Recently, to understand the anomalous ion energy dependence of the Li neutral fraction for Au, we presented a theoretical study of such systems using DFT and a linearized rate equation approach [3]. This work allowed us to follow the Li charge state evolution for the (111) surfaces of Ag, Au, and Cu, and for the Ag covered Au(111) surface. Since the understanding of the simpler case of neutralization on bulk surfaces was an essential prerequisite, we have started with investigation into nanostuctured systems.

We present here a theoretical study of the neutralization of the Li charge in front of wires and cluster of Au(111). We have carried out DFT calculations within the supercell approach by using the ab-initio total energy and molecular dynamics program VASP[4]. By considering different Au geometries (perfect surface, wire and cluster), and comparing the Li atom number of valence electrons and of the projected density of state as a function of the Li - Au distances, we analyse the size effects on the charge exchange process.

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First Principles Theory of Nonadiabatic Forces in Ion-Solid Interactions

Alfredo A. Correa[(1)1], J. Kohanoff[(2)], E. Artacho [(3)], D. Sanchez-Portal[(4)], and A. Caro[(5)]

[(1)] Lawrence Livermore National Laboratory, USA, [(2)] Queen's University, Belfast, [(3)]Nanogune and DIPC, San Sebastıan, Spain ; Ikerbasque, Bilbao, Spain ; and Cavendish Laboratory, UK [(4)] CCSIC-UPV/EHU and DIPC, San Sebastian, Spain, [(5)] Los Alamos National Laboratory, USA.

The Born-Oppenheimer (BO) approximation is the keystone for molecular dynamics simulations of radiation damage processes; however, actual materials response involves nonadiabatic energy exchange between nuclei and electrons. Therefore, interatomic forces have components that are history-dependent, and in particular dependent on the velocity of the projectile ion. A first principles atomistic description of the ion-solid interaction that simultaneously goes beyond BO, the dielectric linear response, and homogeneous electron gas approximation was so far an elusive task. In this presentation, we will report recent advances that allows us to have a coherent quantitative description of energy loss mechanism, fully non-adiabatic forces and momentum transfer in a chemically specific way. The approach is based on Time-Dependent Density Functional Theory, ab initio pseudo-potentials and coupled electron-ion dynamics. For example, in the case of a fast proton channeling in aluminum, we find that forces and momentum transfer of host atoms near ion channel deviate significantly from the adiabatic case when velocities approach the maximum of the stopping curve.

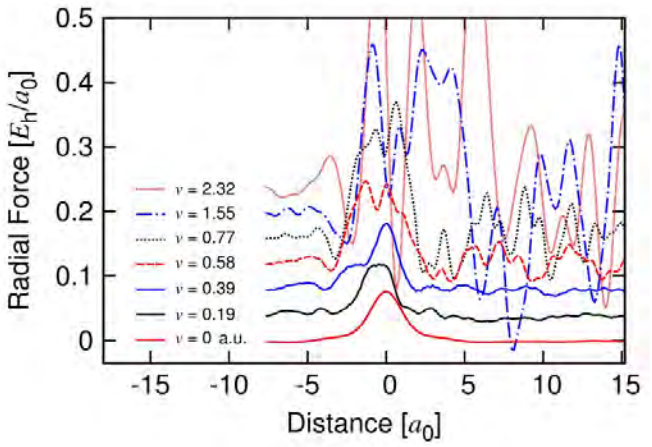

Figure 1. Proton in aluminum: Radial force exerted on host atom (first neighbor to channel trajectory) vs. parallel distance to projectile at different projectile velocities v; $x = 0$ is the point of maximum proximity. The nonadiabatic curves have been shifted vertically for visualization purposes.

References

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Excitation Thresholds in Electronic Stopping of Low- and Medium-Energy Ions

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The road to success for conventional ion beam analysis is paved by good quantitative predictions and qualitative explanations for the observed electronic stopping cross section $\varepsilon \sim dE/dx$ of the materials for ions at high energies. In contrast, at medium and low ion energies, i.e. at energies below the stopping power maximum, ε is much less understood, and in many cases even not well known quantitatively, with typically increasing uncertainties towards lower energies. The scatter of data is large, and only model systems have been well characterized. One description commonly employed, and - for metals - expected to be valid to a large degree is a free electron gas (FEG). In a FEG, ε is expected to be proportional to the ion velocity [1]. Effects like a changing density of the FEG due to a decrease of the maximum possible energy transfer between ion and target electrons lead to a more complicated velocity scaling, which has been observed experimentally [2],[3],[4] and can be understood considering the density of states of the target materials.

Recent experiments, have been devoted to study and compare the velocity scaling of ε for H and He ions in ultrathin Al, Au and Pt films for low and intermediate ion velocities [5],[6]. For He, a distinct deviation from $\varepsilon \sim v$ is observed for all investigated materials, even if only one of them, Au, features a distinct excitation thresholds for electrons in the conduction band. These findings represent interesting complementary results to earlier studies, and cannot be straightforward explained by considering the unperturbed electronic properties of the investigated target materials. Instead changes induced in the electronic structure of the projectile when passing the material of interest may be used to explain at least qualitatively some of the observed phenomena.

References

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Wakes, Plasmons and Fermi Gas in the Theory of Stopping of Swift Atomic and Molecular Ions

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It is wellknown that the stopping force on a charged particle or aggregate can be expressed by the induced polarization, the wake field. Existing estimates of wake fields most often refer to a Fermi gas, the excitation spectrum of which is known to exhibit a characteristic plasmon peak.

In the stopping literature one may find numerous studies in which wakes, plasmons and Fermi gases play central roles, and others in which those concepts are barely mentioned at all. This does not necessarily imply different predictions concerning measurable quantities.

However, the implied coupling between wake, plasmon and Fermi gas needs caution in the analysis of

1) Stopping of Aggregates and

2) Gas-solid and metal-insulator differences.

We have studied these aspects on the basis of a dielectric function describing a gas of *bound* electrons [1]. Wake effects can be identified by varying the density of the stopping medium. We find that

a) Enhanced stopping of swift molecular compared to atomic ions, found long ago, is predicted to be *increasingly* pronounced as the density *decreases* [2],

b) This implies that the wake field, which has frequently been identified as the *cause* of the enhancement, actually *weakens* the effect [3].

c) Pronounced differences are predicted between conductors and insulators in the charge-state dependence of the wake potential.

d) The common origin of these observations is that over the range of distances relevant to stopping, the primary effect of the wake is to *screen* the ion potential.

References

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Depth profiling of thin films using Coulomb explosion

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Depth profiling measurements of thin films made by backscattering spectrometry expresses depth in units of length assuming the knowledge of the density of the target otherwise "depth" stands as an abbreviation for the number of atoms per unit area (density) over the distance traversed (length) in the target [1]. A method to determine the absolute depth without the knowledge of the density is useful since the density is a physical quantity which can presents different values for the same material.

In this work we explore the Coulomb explosion with occurs when energetic H_2^+ ionic clusters interact with thin layers of dielectric materials ($LaScO_3$, HfO_2 and $LaAlO_3$, thickness < 100 Å). The Coulomb explosion is connected with the excitation pattern of the target electrons generated by the simultaneous interaction of fragment ions moving in a correlated way within the solid. The molecules dissociate after passing the first monolayer and get stripped of all their electrons. The moving ionic fragments repel each other via mutual quasi-Coulomb forces and excite the electronic medium coherently. The Coulomb explosion leads to a broadening of the energy-loss distribution of the ionic fragments, and can be evaluated through the energy straggling. The information obtained by Coulomb explosion of H_2^+ clusters in this approach can provide the *dwell time* of the ionic fragments in the thin layers after the breakup, and thus the *absolute traversed distance.* For this purpose, high-energy resolution backscattering experiments (MEIS: Medium Energy Ion Scattering) were carried out as a function of the incoming projectile energy, covering an energy range between 100 and 200 keV/nucleon. Our results show that the study of the Coulomb explosion and the dwell time of H_2^+ molecules traversing ultra-thin films constitute a powerful technique to determine absolute thicknesses and densities of amorphous targets. The experimental values of the Coulomb broadening agree well with calculations considering a screened repulsive potential between the ionic fragments. The thicknesses and densities of different films obtained from the Coulomb broadening are in excellent agreement with those values provided by other techniques like XRR and TEM, thus corroborating the present methodology.

References

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Surface Structure Determination via Fast Atom Diffraction

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We demonstrate the potential of grazing scattering of fast atoms for surface structure determination. Under axial surface channeling conditions, i.e. directions along low indexed strings of surface atoms, projectiles are scattered out of the incident scattering plane normal to the surface. Then, at the maximum of azimuthal deflection an intensity enhancement, the so called "collisional rainbow", is present. For sufficiently small angles of incident ($\Phi_{in} \sim 1°$) and projectile energies ($E \sim 1$ keV), diffraction patterns can be observed in the angular distribution of scattered atoms and molecules [1,2]. In "Fast Atom Diffraction" (FAD), in analogy to established diffraction techniques as LEED, RHEED, HAS, or SXRD, from the splitting of diffraction spots the unit cell size and symmetry and from relative intensities atomic positions in the topmost layer can be deduced [3]. In combination with new triangulation methods based on the transition between axial and planar surface channeling structural models can be tested.

For the system of one monolayer of SiO_2/Mo(112) it could be unambiguously distinguished between two competing structural models. The positions of atoms can be determined with an accuracy of a few 0.01 Å [4]. The adsorption of oxygen on a Mo(112) surface was studied in-situ by detection of scattered He-atoms. From the intensity of specularly reflected atoms the formation of well-ordered adsorbate phases is monitored. For scattering along axial channels the diffraction patterns provide information on the evolving surface geometry. For the c(2x4) and pg(2x1) adsorbate structure we demonstrate that not only a periodic lattice but also a separated pair of oxygen strings can be the origin of diffraction. The interference of matter waves from the two equivalent rows within the unit cell can be analyzed in analogy to Young-type interference in a double-slit experiment [5].

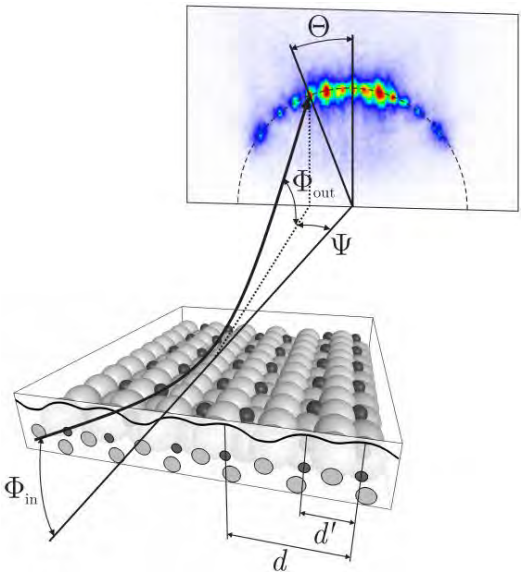

Figure 1. Sketch of scattering geometry for FAD

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Polarized $^4He^+$ ion-surface collisions

T. Suzuki*, Y. Yamauchi, and S. Hishita

National Institute for Materials Science

We investigated electron-spin-polarized $^4He^+$ ion scattering on various nonmagnetic surfaces at kinetic energies below 2 keV (spin-polarized ion scattering spectroscopy (SP-ISS) [1]). It was observed that the scattered He^+ ion yield depends on the He^+ ion spin. We interpret this spin-dependent scattering in terms of the spin-orbit coupling that acts transiently on the He^+ 1s electron spin in the He^+-target binary collision. This interpretation qualitatively explains the relationship between the spin-dependent scattering and the scattering geometry, incident velocity, and magnetic field arrangement. This is the first study to report spin-orbit coupling caused by projectile electron spin in ion scattering. [2]

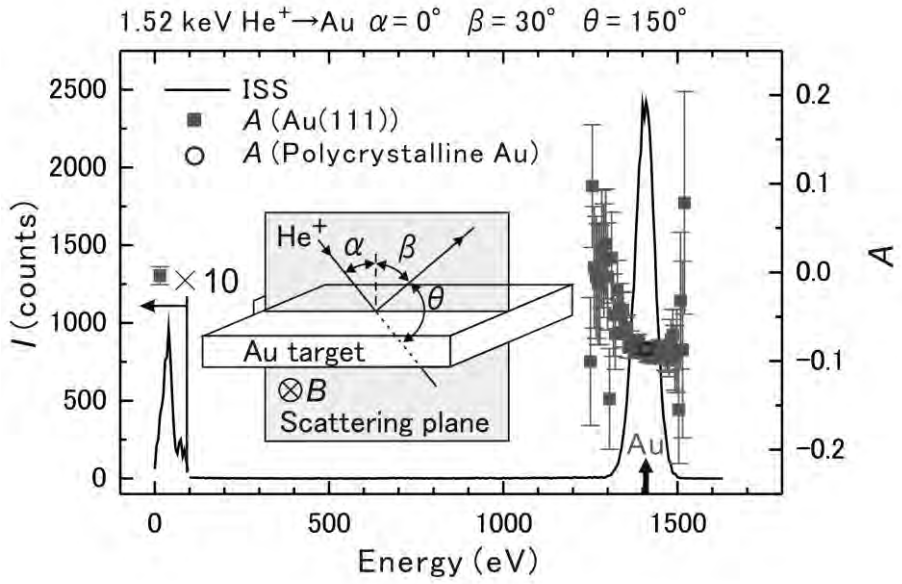

Figure 1. ISS spectrum of the Au(111) surface with the calculated He^+-Au binary collision energy (arrow). Filled squares represent the spin asymmetries (*A*) of Au(111); an open circle indicates that of polycrystalline Au. The error of the spin asymmetry corresponds to statistics. The inset shows the scattering geometry. The scattering plane is perpendicular to both the Au surface and the magnetic field ***B***.

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Collisions of 1-10 eV ions at ice surfaces

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Collision of ultra low energy mass selected ions in the range of 1-10 eV on molecular surfaces can lead to a number of interesting phenomena[1]. On water ice, several processes phenomena such as diffusion, phase transition and reaction have been probed.[2-5] The most recent in the category of reactions is the formation of molecular ion of dihydrogen (H_2^+) by 1 eV collisions of protons (H^+) on amorphous water ice surfaces.[6] The reaction is also observed on crystalline ice surfaces, but with lower efficiency. Collisions of D^+ on amorphous H_2O and D_2O ices yield D_2^+ on the former, subsequent to isotope exchange on the H_2O surface. Ultra-low-energy collision-induced dihydrogen ion production is also observed from alkanol surfaces, with decreasing efficiency as the alkyl chain length increases. There is no corresponding reaction on solid hexane. This endothermic reaction, with implications for interstellar chemistry and plasma etching processes, is proposed to occur as a result of stabilization of the other reaction product, a hydroxyl radical ($OH^{\bullet}$), on water surfaces through hydrogen-bonding interactions with the surface. These results point to an interesting chemistry involving ultra-low-energy ions on molecular solids. A brief review of our previous work in the area will also be presented.

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IC-O-05

Thiol Terminated 1,4-Benzenedimethanethiol Films Grown on Au, Ag and Cu Surfaces studied by Direct Recoiling Spectroscopy

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Dithiol films deposited on metallic surfaces are promising systems for developing sensors. In most of the cases studied up to now, the dithiol films are grown by dipping an already prepared surface in a solution containing the appropriate dithiol [1]. This has been shown to work well for Au surfaces, however in more reactive surfaces a vacuum approach is desirable to obtain cleaner film-substrate interfaces. In the vacuum approach [2-5], at low exposures the dithiol molecule tends to adsorb with both S atoms bonded to the substrate. The question whether the molecule will stand up or not at higher exposures is open and the adsorption conditions to obtain this Self Assembled Monolayer (thiol exposed film) depend on the substrate-molecule interaction. Direct Recoil Spectroscopy (DRS) [5] has the appropriate surface and element sensitivity to test the thiol termination of the films, and the low damage imparted to the organic film allows carrying on detailed studies of the film stability with surface temperature. In this work we present a TOF-DRS study of 1,4-benzenedimethanethiol films grown in vacuum on Au, Ag and Cu surfaces. We discuss the thiol termination and compare the corresponding spectra to those for the same substrates under pure S exposures. DFT calculations for these systems are used to obtain the shape of the molecule in front of the surface, to study the energetics of its adsorption and to understand the main features of the TOF-DRS spectra. Different implementations of the Van der Waals correction within the VASP[6] code are tested to study how this term affect the system description. Studies performed at temperatures below room temperature suggest formation of a multilayer. This thicker film is identified from the multiple scattering of Ar or Kr projectiles at high incidence angles, i.e., involving collisions with both molecule and substrate. Thermal desorption by TOF-DRS allows the study of the stability of the thiol termination with temperature, determination of the temperature at which the multilayer desorbs, and identification of the final molecule products remaining after annealing.

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Okorokov Effect in a Magnetic Lattice for a Slow Atomic Beam

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We study resonance transitions in the internal states of atoms passing through a static periodic field. This motion-induced resonance occurs when the frequency of the field oscillation that the atoms experience equals the transition frequency. The principle of the resonance is the same as that of the "Okorokov effect" [1] or "resonant coherent excitation" (RCE) [2], which has been studied extensively using fast ion beams passing through crystals for resonances at high frequencies up to 10^{18} Hz or keV. We are interested in its extension to very low energy experiments, such as resonances in the rf or microwave region. The motion-induced resonance is strongly velocity-dependent in nature, and it is particularly worth noting that the internal excitation is supposed to occur at the expense of the atomic kinetic energy [3]. These features are not attainable with the standard rf or microwave resonance technique, and we expect that the motion-induced resonance will find useful applications as a new type of control method for slow atoms.

Our study started with a proof-of-principle experiment in an energy range of neV or 10^5 Hz [4], quite different from traditional RCE experiments. Magnetic resonance was induced between the Zeeman sublevels of Rb atoms with a velocity of $v \sim 10^2$ m/s in a periodic magnetic field ("magnetic lattice") with a period of $a \sim 1$ mm. We used a thin cell containing a Rb vapor, to which a periodic field was applied with a pair of arrays of parallel current-carrying wires. In the next experiment, an effusive atomic beam of Rb ($v \sim 10^2$ m/s) passed through a magnetic lattice produced by a stack of planar arrays of parallel current-carrying wires ($a \sim 1$ mm) [5]. This experimental configuration realized a longer coherent interaction of atoms with the periodic field, resulting in sharp resonance lines, whose widths were primarily determined by the transit time through the lattice. We also observed Rb spin nutation, which was a first direct demonstration of coherent population transfer induced by atomic motion through a periodic field [6].

Experiments using magnetic lattices with smaller periods (1 μm ~ a < 1 mm) are currently underway.

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(Heavy) Ion Acceleration by Laser Pulses

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After more than one decade of successful operation at the Max Planck Institute for Quantum Optics, the Advanced Titanium-Sapphire Laser (ATLAS) system has been dismantled and is currently transferred to its new, temporary home, the Laboratory for Extreme Photonics (LEX). This move will allow us to upgrade the peak power from currently 60 TW to 300 TW before it can take on its final upgrade to 3 PW at the Centre for Advanced Laser Applications (CALA), possibly constituting one of the world's most powerful laser systems. The opportunities are manifold. GeV-electron bunches with a few femtosecond pulse duration will be available routinely and in turn enable for the generation of even shorter light, UV, X- and Gamma-ray pulses. The high laser pulse energy (60J) paired with the short duration (20fs) will allow to access light intensities of up to 1023W/cm2 and address fundamental questions of modern physics.

One major prospect is the generation of ion bunches with energies beyond 100 MeV/u, sufficiently high to approach and investigate their applicability in tumour therapy constituting one of the grand goals of our research. One of the most exciting aspects of laser acceleration is the high bunch density not far from a solid even for heavy ions with energies of a few MeV/u. Such bunches are discussed to serve in nonlinear nuclear effects such as coherent energy loss or even fission-fusion reactions for the production of neutron rich nuclei.

In this talk, I will explain various concepts of laser-driven ion acceleration that have been employed and studied over the past years. At present, the application of nanometer thin foils seems to be most promising both in terms of achieving highest energy and conversion efficiency. The demands on the quality and control of the laser pulses, mainly in terms of the suppression of prepulses, are enormous. Despite of these difficulties, we could demonstrate first biological studies with tumour cells irradiated by laser accelerated proton bunches with single shot doses of several Gray delivered within 1 nanosecond. This demonstration has been a major mile stone of our research. Moreover, the combined efforts in laser, target and detector development disclosed a number of new and partially surprising insights that constitute my excitement for this field of physics and motivate for the future challenges and possibilities that await us.

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Intense, short pulse ion beams for studies of warm dense matter and point defect dynamics in solids

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A novel, induction type, heavy ion linear accelerator, the Neutralized Drift Compression eXperiment (NDCX-II) is scheduled to come online at Berkeley Lab in the Fall of 2012. This new user facility is designed to deliver intense (~1 to 50 nC/pulse), sub-ns pulses of 1.2-3.5 MeV lithium ions at a rate of about 2 pulses per minute [1]. When focused to a mm-diameter spot, the beam can volumetrically heat a few micrometer thick metal foil targets up to ~30,000 K (~2-3 eV), generating hundreds of Mbar of pressure. The duration of the ion beam pulse is shorter then the hydro response time of a typical sample, making NDCX-II an ideal driver for warm-dense-matter studies. For studies of radiation effects in solids, the beam intensity can be controlled by defocussing while the short pulse duration is maintained. Incident lithium ions generate collision cascades when they impinge on solid targets. While collision cascades ensue on a ps time scale, diffusion and recombination of vacancies and interstitials can stretch over much longer time scales. The sub-ns excitation pulse with tunable intensity enables "pump-probe" type experiments for *in situ* studies of point defect dynamics and time resolved studies on the formation dynamics of specific defects such as color centers. Diagnostics capabilities include x-ray diffraction and time resolved detection of transmitted ions and emitted light (e. g. from color centers in diamond). In our presentation we will describe the ion beam user facility concept and capabilities and discuss experimental research opportunities in the fields of warm dense matter and radiation effects in solids.

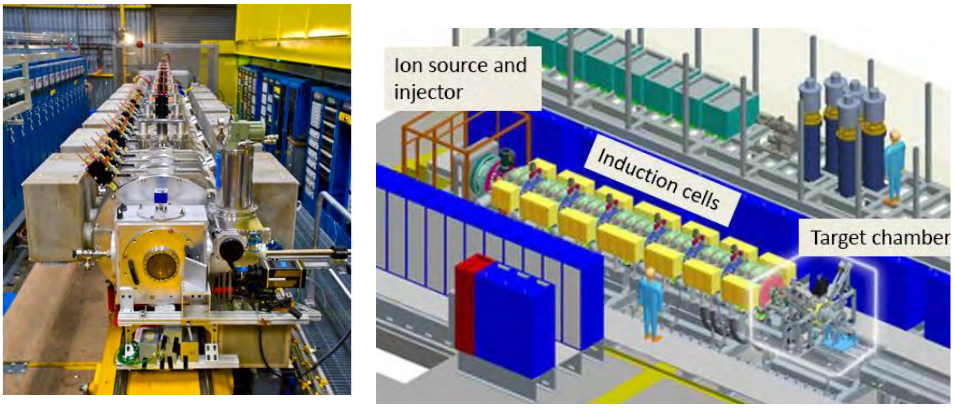

Figure 1 : Photo (left) and schematic (right) of the NDCX-II induction linac at Berkeley Lab.

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This work was supported by the Office of Science of the US Department of Energy under contract no. DE-AC02–05CH11231.

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Radiobiology with Laser-accelerated Proton Beams

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Recently, high-intensity laser ion acceleration has been suggested as a potential, cost-saving alternative technology to conventional accelerators for radiotherapy. When a laser pulse of intensity well above 10^{18} W/cm^2 interacts with a thin foil target, a laser-field-driven force generates a strong accelerating field exceeding 1MV/μm, which exceeds the field in conventional ion accelerators by as much as six orders of magnitude. In this work, investigations of the biological effects of the high bunch current and short bunch duration, that are typical of laser-acceleration, are reported [1,2,3].

The experiment was performed using the J-KAREN laser system at JAEA. Laser pulses of 1 J energy and 45 fs duration are focused to an intensity of 5×10^{19} W/cm^2 onto a polyimide foil target of 7.5-μm-thickness which is continuously fed by a servomotor. Laser pulses are delivered at a repetition rate of 1 Hz. The emitted proton spectrum is continuous up to a maximum energy of 4 MeV. Energy selection for transport to cancer cells is determined by four pairs of dipole magnets (DMs), which is about 40 cm in length. Each DM consists of a pair of permanent magnets generating a central magnetic field of 0.78 T. The second and third magnetic fields are oriented antiparallel to the first and fourth ones. Proton energy is selected by a pinhole in the middle plane located between the second and third DMs.

We have successfully obtained 2.25 MeV proton beams with an energy spread of 0.66 MeV (FWHM) and single bunch duration of 20 ns. The beams were extracted from vacuum into air through a thin-foil window and used to irradiate in-vitro cell samples from a human salivary gland tumor (HSG cells). The dose given in a single proton bunch was 0.2 Gy, hence, the single bunch dose rate is estimated to be 10^7 Gy/s. At the 1 Hz repetition-rate cell samples were irradiated with successive proton bunches with integrated dose levels up to 8 Gy (40 shots).

Using a colony formation assay, we determined the value of relative biological effectiveness (RBE) of this proton irradiation for cell inactivation. X-rays delivered from a 4-MV clinical linac were used as reference radiation. RBE at the 10% surviving rate was evaluated to be 1.20 ± 0.11 for the laser-accelerated protons having a volume-averaged LET of 17.1 ± 2.8 keV/μm. This is the first RBE estimation for laser-accelerated ions. We compare our results with published ion beam RBE using conventional accelerators.

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Science of asteroid sample return mission "HAYABUSA"

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Of the ~40,000 meteorites we know of, only 14 have had their pre-impact orbits ascertained. The aphelia of these 14 orbits are located within the Main Asteroid Belt between Martian and Jovian orbits, which suggests that meteorites are an asteroidal origin. However, telescopic spectroscopy of asteroidal surfaces had raised serious doubts on the hypothesis. One of the primary scientific purposes of Hayabusa mission was demonstration of this hypothesis. The Hayabusa spacecraft made two touchdowns on the surface of asteroid 25143 Itokawa on November 20th and 26th, 2005. After recoveries from serious accidents on the way home from Itokawa, the spacecraft made the reentry into the terrestrial atmosphere on June 12th, 2010 and the sample capsule was successfully recovered in Australia on June 13th, 2010.

More than 1,500 grains were found in the sample capsule and identified as rocky particles. Although their sizes are mostly less than 10 micrometers, some larger grains of about 100 micrometers or larger were also included. About 50 particles among the larger grains were subjected to one set of preliminary examinations. The preliminary examinations started from January 21st, 2011. The examinations include X-ray CT analysis, X-ray diffraction analysis, petrology, mineral chemistry, oxygen isotope analysis, trace element analysis and noble gas analysis.

In order to determine extraterrestrial origin of the particles in the capsule, isotope analysis of oxygen for individual particles is essential because extraterrestrial materials usually show different isotope ratios from terrestrial materials. However, the degree of difference is less than 1%. A precise analysis technique by SIMS was newly developed and applied.

The SIMS characterization of Itokawa particles certified that Itokawa was composed of similar materials of ordinary chondrites [1]. This is the first direct link showing that S-type asteroids is one of the sources of the ordinary chondrites, which are the most abundant meteorite species fallen into the Earth. From this citification, we confirm that insights based on meteorite research are the right way to study origin of our solar system. New insights for the early solar system are expected by further detail measurements of Itokawa particles.

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Ionization at Insulating Surfaces – A Review about a successful Technique to measure Energetic Neutral Atoms (ENA) in Space

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In space science many applications of remote sensing of plasma populations require a high detection efficiency of Energetic Neutral Atoms (ENA) because the sources of these ENAs are very faint [1]. This requires sophisticated detection techniques and not before long measurements of ENAs were quite impossible due to the technical limitations onboard of a spacecraft. The reason is neutral particles have to be ionized before they can be analyzed and ionizing techniques, which work fine in a laboratory on earth, can be very difficult, if not impossible, to implement in an instrument, which shall work on a satellite in space.

In the mid 1990ies reports about unexpected high yields of negative ions upon scattering of positive and neutral particles from various surfaces led to a new type of neutral particle sensing mass spectrometers, which use the effect of surface ionization and work now successfully on several space missions, which are IMAGE [2] and IBEX [3] (NASA) and the CENA instrument (ESA & ISRO) from the Indian mission to moon, i.e. Chandrayaan-1 [4]. Furthermore, another instrument of such kind, called ENA, is part of the scientific payload of the Mercury Magnetospheric Orbiter (MMO) satellite of the BepiColombo mission to Mercury. BepiColombo is a joint mission of ESA and JAXA and the MMO module is lead by JAXA. Launch is scheduled for August 2015.

However, it took many years to find good working so-called Conversion Surfaces (CS) [5] and this report will summarize our tests with possible candidates for conversion surfaces, with special emphasis on ionization efficiency and scattering properties. Furthermore, we will report about the current status and finally explain why the quest for the perfect conversion surface is still going on.

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Why Is Low Energy Cs^+ Efficient For Depth-Profiling Both Organics And Inorganics?

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Depth-profiling a material without modifying its chemistry has always been a challenge. This holds especially true for organic materials, which are very sensitive to etching beams and tend to degrade rapidly. However, new polyatomic ion sources (C_{60}^+, Ar_n^+) have been developed over the last decade, allowing real molecular depth profiling thanks to their huge sputtering yield. In 2007, our group has also shown that, surprisingly, low energy (~250 eV) Cs^+ ions could also be used to depth profile polymers[1]. We have extended the study to many different organic materials, including amino acid thin films, analyzed in the energy range 150-1000 eV. This paper aims at reviewing recent advances in understanding how low energy Cs^+ ions interact with organics in such a way that the chemical structure is preserved, contrary to all other monoatomic ions. It is indeed a special case of atomic collisions in solids where atoms are extremely reactive, inducing major chemical effects.

Cs^+ beams have been extensively used in SIMS on inorganic materials, thanks to the strong negative ionization enhancement they bring about, but also for the creation of MCs_n^+ clusters, where M is a matrix element. We will show that a similar negative ionization enhancement, along with MCs_n^+ cluster formation, also occurs on polymers and small organic molecules, making low energy Cs^+ a versatile ion source. In both organics and inorganics, the interest of Cs lies in its strong reactivity, being the most electropositive element. Implanted Cs atoms reduce the surrounding molecules, creating anionic sites, therefore enhancing the negative ionization. Moreover, Cs reacts preferentially with free radicals, preventing cross-linking reactions, thus allowing molecular depth-profiling. Our model is supported by recent XPS data, showing changes in the charge state of phenylalanine molecules irradiated by Cs^+ (a decrease of the N 1s NH_3^+ contribution along with an increase of the O 1s COO^- contribution). XPS also allows measuring the surface Cs concentration (up to 8%). Optical Emission Spectroscopy (OES) data from the surface were also acquired, proving the existence of neutral Cs species at the surface.

Every ion source has its pros and cons. Ar_n^+ clusters sources are extremely efficient on organic materials but are of limited use on inorganics. On the other hand, Cs^+ ions allow depth profiling on all types of materials, although with a much lower sputtering yield.

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Hydrogen and Oxygen Trapping and Retention in Metals and Graphite Materials Irradiated in Plasma

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The plasma facing materials are subjected to irradiation with ions and neutrals in a wide energy range including practically zeroth energies. Last years the features of trapping of low energy hydrogen and oxygen in plasma irradiated metals (NI, W, stainless steel, etc.) and carbon materials (pirolytic graphite, fine grain graphite, carbon fiber composite (CFC)) have been studded in details. Special attention was paid to hydrogen and oxygen interaction with stainless steel (SS) representing the metals (alloys) with oxide layer on the surface.

The report presents the newly discovered features and mechanisms of hydrogen and oxygen trapping and desorption from carbon materials and metals under plasma irradiation.

Carbon materials. Dependence of hydrogen trapping on material structure, charge state of impinging particles, plasma ion flux and energy, irradiation dose, presence of oxygen impurity in plasma, specimen temperature are discussed. Experimental results allowed elaboration of "potential" mechanism of hydrogen trapping. This mechanism considers trapping as the process proceeded at the expense of energy of inelastic interaction of particles with the surface. It plays the main role in trapping of low energy hydrogen particles and explains features of hydrogen trapping in carbon materials irradiated in plasma.

Conditions of methane formation in carbon materials irradiated in the hydrogen plasma, its thermal desorption and interrelations between hydrogen trapping and "chemical" sputtering are described. Oxygen trapping in carbon materials irradiated in H_2+O_2 plasma and its removal due to hydrogen plasma irradiation are the subject of special consideration.

Metals. The processes on oxidized surface of SS are described. It is shown; in particular, that irradiation with hydrogen atoms of not annealed SS submersed in H_2+O_2 gas mixture initiates formation of H_2O molecules on SS surface. Hydrogen released from SS as well as hydrogen of surrounding atmosphere take part in H_2O formation. The similar result was observed when SS was irradiated with ions of (H_2+O_2) plasma.

The parallel measurements of hydrogen and oxygen trapping in SS and Ni exposed in oxygen contaminated hydrogen plasma were performed to clarify the role of oxide surface layer in this process. Among them there were measurements of dependence of trapping on ion energy, irradiation dose, oxygen concentration in plasma. The results demonstrate that oxide layer appears to be the reason of significant increase of the rate of hydrogen trapping and of amount of retained hydrogen in SS. The main fraction of hydrogen trapping in SS is provided by the "water" molecules sorbed on irradiated surface through the mechanism of "potential" trapping. Oxygen atoms trapped in SS are practically fully concentrated within oxide surface layer and bond with chromium atoms.

Oxygen concentration in plasma influenced on hydrogen trapping in SS. Hydrogen trapping in Ni proceeded by the kinetic energy of implanting particles ("kinetic" mechanism.) and did not depend on oxygen concentration in plasma.

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H^- production by surface ionization on carbon materials in H_2 plasma

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The ITER (International Thermonuclear Experimental Reactor) project aims at demonstrating power production by magnetic confinement nuclear fusion. In such a device, neutral beam injection (NBI), which uses high power beams of fast neutral atoms of hydrogen isotopes to heat the plasma, is necessary to reach high performances. The ITER NBI system requires beam energy at 1 MeV where the neutralization of positive ions becomes very inefficient and only the negative ions can be neutralized with sufficient yield. Hence the development of high current negative ion sources (50A D- beam for ITER) is crucial. The use of cesium (Cs) injection to enhance surface ionization in the negative-ion source is nowadays the only way to meet ITER requirements in terms of D- current. However, cesium injection has severe drawbacks, and the development of Cs-free negative-ion sources would be highly valuable. The present work deals with negative-ion production by surface ionization on carbon materials in Cs-free hydrogen plasma.

In beam experiments, surface ionization mechanisms are most often studied by measuring angle and energy distribution functions of all particles (positive and negative ions, electrons, neutrals) emitted or scattered by a well characterized surface. In plasma experiments, such analyses cannot be performed easily due to the presence of multiple charged and neutral species, to the presence of electric fields modifying angle and energy distributions and to strong surface modifications induced by particle bombardment. In the present works, energy distributions of H^- negative ions emitted by a carbon sample in hydrogen plasma are measured by an energy-resolved mass spectrometer. In order to get information on the energy distributions on the surface, the trajectories of the negative ions between the sample and the spectrometer, as well as the negative-ion transmission inside the spectrometer are computed. The measured distribution functions are then modeled using a test surface-distribution-function. It appears that the distribution functions given by SRIM and arising from the impact of H^+ onto a-CH material are appropriate to reproduce measured negative-ion distribution functions, suggesting few dependence of the electron capture probability with angle and energy of the outgoing particle.

A comparative study between HOPG (Highly Oriented Pyrolitic Graphite) and BDD (Boron Doped Diamond) has revealed the possible influence of the electro-affinity of diamond on the electron capture. Although HOPG and BDD behaves similarly at low surface temperature, the negative-ion yield is completely different at high temperature (400°C) where it increases by a factor 5 on diamond and decreases by a factor 3 on graphite. Surface modifications after plasma treatment at low and high temperature have been studied by Raman spectroscopy, allowing giving a possible interpretation of this result.

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Atomic relocation in ion-irradiated ultra-thin magnetic films visualized with sub-nm spatial resolution

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The relocation of atoms in solids caused by ion irradiation has been studied by 3D Atom Probe Tomography (APT) [1]. This technique enables the determination of atomic positions with sub-nm spatial resolution. This is illustrated using a MBE-grown trilayer system of Fe(10 nm)/Cr(0.7 nm)/Fe(10 nm) [2]. It is well documented [3] that the magnetic properties of such films can be modified by ion-beam exposure. The specimen was bombarded by 30 keV Ga^+ ions at low fluences ($\leq 3\times10^{15}$ Ga^+/cm^2), and the compositional changes induced thereby were monitored by APT. In the pristine specimen the presence of the 0.7-nm Cr layer could be verified. Upon irradiation, this layer is broadened to ~ 1.7 nm at a fluence of 3×10^{14} Ga^+/cm^2. Fig. 1 illustrates these results by means of a representation of the positions of the Cr and Fe atoms before and after ion bombardment.

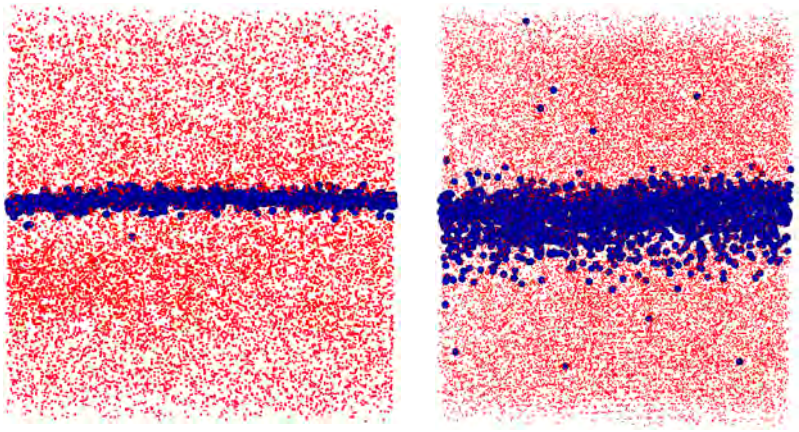

Fig. 1. The distribution of Cr (blue spheres) and Fe (red dots) atoms in a Fe/Cr/Fe layer system in the pristine state (left panel) and upon irradiation with 30 keV Ga^+ ions at a fluence of 3×10^{14} Ga^+/cm^2 (right panel), obtained by 3D atom probe tomography. The width of the displayed region is 10 nm.

These data indicate that 3D APT is a promising tool for the examination, with sub-nm resolution, of atomic relocation processes in solids induced by ion bombardment. Future experiments and possible limitations are discussed.

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Anisotropic Mass Transport on Ion-Bombarded Titanium Dioxide Surfaces

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Basic processes responsible for nanoscale morphology changes of single crystal anisotropic TiO_2 (110) surfaces irradiated by keV energy ion beams (Ar^+, Xe^+) have been investigated by means of the scanning tunnelling microscopy. We have found that the ripple morphology pattern developed on TiO_2 (110) surface under ion irradiation shows a remarkable temperature-dependent rotation. At 300 K the ripples are oriented perpendicular to the ion beam direction whereas at the other studied temperatures (150 K, 620 K and 720 K) they are aligned along the beam direction. We have demonstrated that the formation of the nanostructures is determined by the interplay between the effects of preferential erosion of the monatomic step edges at grazing incidence and directional surface diffusion along the favoured crystallographic orientation. Density-functional theory (DFT) calculations reveal that the highly mobile surface species responsible for the development of the nanoripples are TiO dimers. The observations highlight a unique character of the anisotropic mass transport on irradiated oxide surfaces invoking dimer (metal oxide) mediated diffusion.

Anisotropic dewetting of ion irradiated solid films

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When solid matter is brought to a molten state, forces acting on a molecular scale can induce self-organization processes of scientific and technological relevance. In the case of thin films, the concurring action of surface tension and Van der Waals forces can be responsible for the amplification of surface fluctuations and produce the mechanism of spinodal dewetting. We have recently demonstrated that a spinodal like phenomenon, modified by the presence of sputtering, can be induced also when the melting agent is ion bombardment [1]. Here we show that by recognizing the real forces acting on the system we are able to perform a modified experiment were the symmetry is broken and deterministic structures are created thus showing that the process can be exploited for nanofabrication purposes.

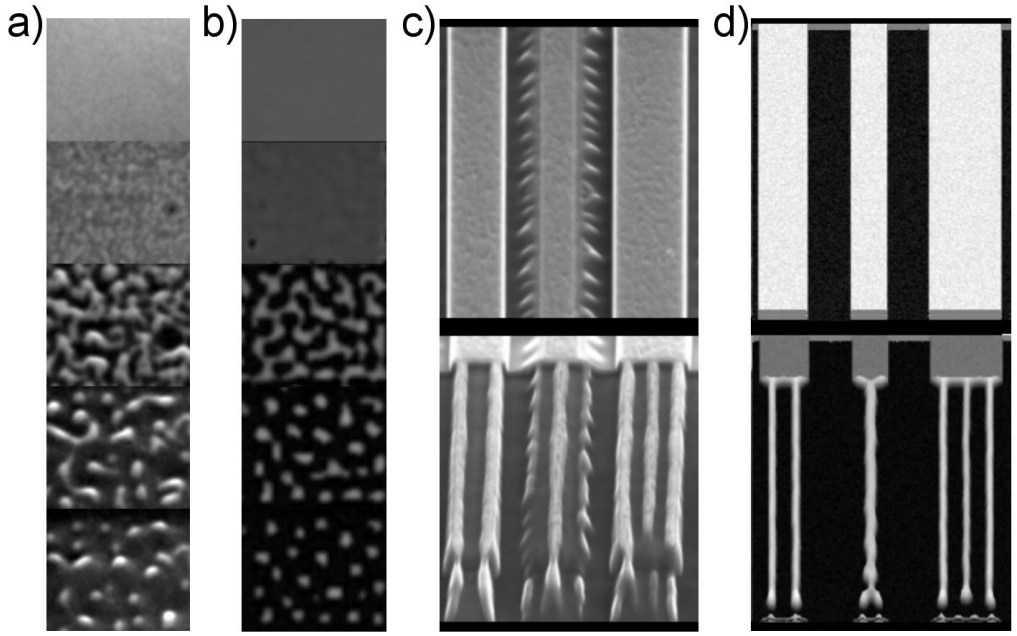

Figure 1. 30 keV Ga ions irradiation of Cr films. a) Experimental sequence of isotropic dewetting. b) Simulation sequence of isotropic dewetting. c) Experimental sequence of anisotropic dewetting. d) Simulation sequence of anisotrpic dewetting.

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Tailoring of keV-HCI Beams by Transmission through Insulating Nanocapillaries

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Charged particles, in particular slow highly charged ions, have shown to be guided through nanocapillaries in various insulating materials by self-organized charge patches on the inner walls of the channels due to initial ion impact [1-3]. The time dependent formation of the guiding potential has been demonstrated by measurements[2,3]. In contrast to previous guiding experiments, we are utilizing capillaries of rhombic and rectangular cross-sections (Fig.1). The capillaries were fabricated by chemical track etching of the irradiated mica sheets. The irradiation was performed at the GSI UNILAC with 11.1 MeV/u Pb- and Xe-ions for muscovite and phlogopite mica, respectively. Ion-beam transmission measurements were performed at the ECR and S-EBIT sources of Stockholm University using Ne^{7+}-ions of kinetic energy between 1-10 keV/q.

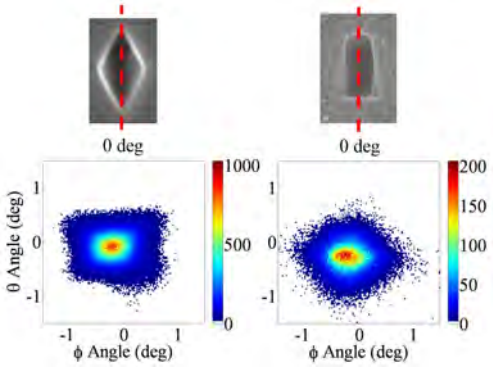

Figure 1: Cross sections of rhombic (muscovite) and rectangular (phlogopite) nanocapillaries and the corresponding angular distributions of 7-keV-Ne^{7+} ions.

Surprisingly, we found that the ion beam profiles are tailored by the geometrical shape of the nanocapillaries: rectangular cross sections produce rhombic shaped ion transmission profiles with the long axis aligned along the short sides of the rectangles (Fig. 1) and, vice versa, rhombic cross sections produce rectangular shaped ion transmission profiles with the long side aligned along the short axes of the rhombi (Fig. 1). More details on this novel beam shaping mechanism are described in this contribution and in publications [4-6].

Support by Swedish Research Council (VR) and European network ITSLEIF is gratefully acknowledged.
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MeV ion micro-beams shaped by glass capillaries

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The application of microscopic ion beams focused by tapered glass capillary received extensive attention in recent years [1], due to a surprisingly high increase of the beam current density, so called focusing factor, with reported values up to ~10^4 [2]. The well accepted scenario for Slow Highly Charged Ion (SHCI) is a self-organization charge-up guiding, which leads to charge patches on the walls of tapered glass capillary [3, 4]. However, the physics mechanism for fast heavy ions transmission in glass capillary cannot be the same and is still under discussion. Nevertheless, as it is a convenient method for producing micro-beam, capillaries are applied in more and more fields [5]. In order to improve our understanding of the transmission features, we performed experiments on the IRRSUD beam line of GANIL facility (Caen France) for 71 MeV Xe^{19+} and 26.5 MeV Kr^{10+} projectiles transmitted through 2 different tapered glass capillariy shapes, in association with a 2-D PSD for beam cross section measurement. In contrast to the charge-up guiding in the SHCI [5], the transmission for high energy ions has been observed to be dominated by collimation of the beam through the exit aperture (20 μm). A scattered contribution was also clearly visible as a diffuse ring around the central part of the beam. A simple simulation based of Rutherford scattering reproduces quite well the experimental observations. Furthermore, energy loss spectra measurements have shown the correlation between the scattering angle and the ion energy loss (Fig. 1).

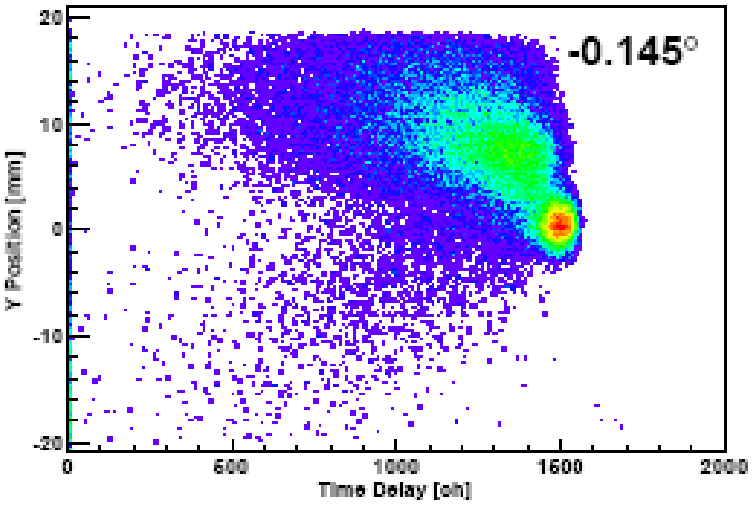

Figure 1. Density plot showing how the energy loss (Time delay) depend on the scattering angle (Y position) for the 71 MeV Xe^{19+} transmitted ions.

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Material Deposition by Ion Irradiation in Liquid

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Ion irradiation in liquid or at liquid-solid interface is quite promising because it can be applied to surface modification processes [1], novel material production, surface corrosion tests in radiation fields and radiation tests of living subject [2]. In this study, we deposited metals on insulating substrates by ion irradiation in liquid using tapered glass capillaries aiming for a fast and fine patterning process.

The capillaries were produced by pulling both ends of heated glass tubes. They have a lid of glass or plastic film so that the irradiation can be performed in liquid (Fig.1). 3MeV H^+ ion beam of a tandem accelerator is focused and guided by small angle scatterings with inner wall of tapered glass capillaries with inserted in a liquid container. The substrates were set perpendicular to the beam at the distance of 100 μm. The irradiation was performed in electroless nickel plating solution containing nickel sulfate and hypophosphorous acid as a reducing agent. Usually, heat-activation (>350K) and palladium catalyst coating are required for nickel deposition.

At the irradiated area, metallic nanoparticles were deposited on the surface without heat-activation or catalysts (Fig.2). The EDX analysis showed the particles consist of nickel containing about 10% of phosphor. The deposited layer had a poor adhesion to the substrates and was easily removed by scratching. The nanoparticles spread on substrates broader than the irradiated area especially toward the downward direction. They diffused over the substrate or grew up at the outer side of the irradiated area and then stuck. The mechanisms of particle growth will be investigated by changing the irradiation conditions.

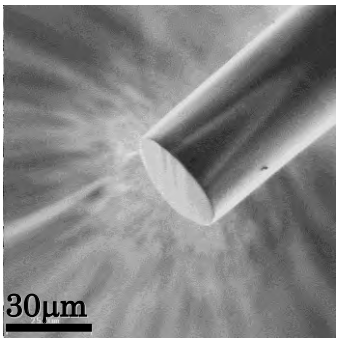

Figure 1. A tip of the glass capillary with a lid shaped by FIB（internal diameter:10μm）

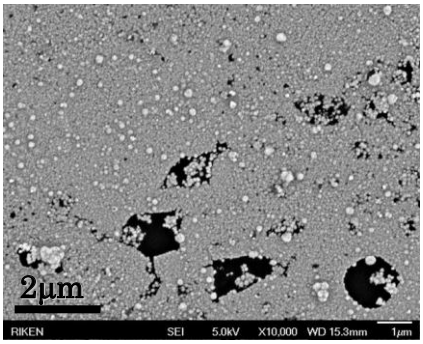

Figure 2. Ni-P nanoparticles covering polyimide substrate formed by proton irradiation

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Secondary ion emission with energetic cluster beam

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Secondary particle emission provides unique opportunities for further insight on ion collisions with matter. In particular, molecular ion emission from organic or biological molecules is of interest, not only for fundamental studies on excitation of molecules, but also for practical applications. For example, secondary ion mass spectrometry (SIMS) has been widely used for organic and biological material analysis. However, secondary ion yields for organic molecules are very low because of collisions with incident ions. It has been reported that cluster ions can enhance the yields of secondary ions, because of the high-density energy deposition and multiple collisions near surfaces. Clusters such as SF_5, C_{60}, Au_3, Bi_3 and Ar_n were found to be quite useful for SIMS of organic materials [1]. Moreover, the velocity of cluster ions is quite low, because the kinetic energy of ion is shared with constituent atoms in the cluster, and therefore cluster ion beam is actually an equivalent low-energy ion beam. This also provides a unique opportunity to sputter materials with little damage formation on the surface.

We have proposed to use large (N>500, where N is the number of atoms) cluster ion beams, which are generated with adiabatic expansion through a small nozzle. Shallow junction formation, surface smoothing, nanofabrication and thin-film formation have been demonstrated with various gas cluster beams. SIMS analysis and molecular depth profiling of soft materials were demonstrated using large Ar cluster ion beams [2–4]. However, there are still many open questions. One of the fundamental issues are cluster-size effects, because the cluster size distribution can range from a few hundred to several tens of thousands atoms. However, measuring the cluster size effects is very difficult because after size selection significant degradation in beam intensity occurs. Recently, we found a way to overcome the difficulties and successfully measured the effect of cluster size on sputtering and secondary ion emission using size-selected cluster ion beams and observed significant lowering of the sputtering threshold energy.

Both experimental and molecular dynamic (MD) simulation results will be presented to propose a possible collision model for large cluster ions, together with the enhancement effect on the yield and lowering of the threshold energy for sputtering.

This work was partially supported by JST, CREST.

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Soft-sputtering of protein molecules using large cluster ion beams

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A gas cluster ion beam (GCIB) provides an extremely low-energy projectile compared to conventional polyatomic projectiles, since each gas cluster ion typically contains several thousands atoms, and the energy per atom (E_{atom}) should be only several eV. Therefore, the damage of organic molecules can be substantially suppressed, causing the soft sputtering of the protein molecules.

We have investigated the damage formation on highly orientated pyrolytic graphite (HOPG) and the sputtering of DNA molecules adsorbed on HOPG by Ar-GCIB.[1] This study has suggested that E_{atom} was the most important variable to the damage formation on the sample. Moreover, it has been indicated that adjusting E_{atom} of the GCIB can suppress damage on the sample. Motivated by these experimental results, we have developed a size-selected gas-cluster SIMS apparatus[2,3], where E_{atom} can be controlled from several tens eV to below 1 eV by selecting the cluster size and the acceleration voltage of the gas-cluster ion. On applying this instrumentation to several protein and peptide molecules, we demonstrated that the fragmentation is substantially suppressed when E_{atom} was decreased below ~5 eV and intact ions of some protein molecules, for example, insulin (molecular weight: 5,808) and chymotripsin (molecular weight: ~25,000), were detected without using any matrix.[4,5] We have focused on the dependence of the emission of intact ions and fragment ions on the incident direction of the cluster ions as well as accumulated dosage of the cluster ions.[6] The bombardment at a lower angle of incidence significantly enhanced the emission of intact ions. However, the yields of intact ion should be enhanced still more for practical use. In this presentation, results of the biomolecule measurement in SIMS by various gas cluster ion projectiles will be presented.

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Sputtering and reflection under cluster bombardment of solids

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Using molecular-dynamics simulation, we study the sputtering induced by energetic impacts of projectile clusters containing up to N = 10000 atoms. Both a metallic target and a van-der-Waals-bonded material are studied. We focus on self-bombardment at perpendicular incidence. The total emission yield is composed of the sputter yield of the target material and the reflection yield of reflected projectile cluster atoms. The dependence of these yields on the impact energy shows a slow transition from the reflection- to the sputter-dominated emission. Similarities and differences between the emission yield of metals and of van-der-Waals-bonded materials are discussed.

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Cluster Effect on Damage Accumulation in a Si Crystal Bombarded with 10-540-keV C_{60} Ions

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When a solid target is bombarded with a molecular/cluster ion in the velocity region where nuclear collisions are dominant, cluster effect on sputtering, displacement of target atoms, *etc.* is observed [1, 2]. The effect on displacement of lattice atoms by molecular-ion bombardment has been reported by many groups: most of them investigated the effect in connection with nonlinear effect on the collision cascade or spike effect. Impact of large cluster such as C_{60} would lead to huge cluster effect. On the other hand, the recent development of application studies using keV C_{60}-ion bombardment such as surface-sensitive analyses and secondary-ion mass spectroscopy (SIMS) of high-polymer materials and/or biomaterial has been based on the belief that little damage in the target is induced by its bombardment. However, there have been few studies on the damage accumulation by C_{60} impact. In this study we have investigated damage accumulation in bombardment of a Si crystal with 10-540-keV C_{60} ions.

Pieces of Si(100) wafer treated with an RCA method were irradiated with 10-540-keV C_{60} ions at room temperature. The areal density of displaced lattice atoms was determined from the area of a surface damage peak of backscattering yields of 2-MeV He^+ ions. The number of displaced Si atoms per C_{60} ion, N_{D60}, has been derived from the fluence dependence of the areal density of displaced Si atoms. Figure 1 shows the result as a function of the energy of C_{60} ions. Comparing with that by C-ion bombardment calculated with SRIM2008, N_{D1}, large nonlinear effect on the displacement of Si atoms has been found. The effect is the maximum around 100 keV, where the number ratio, $N_{D60}/(60\times N_{D1})$ is more than 50. Together with result obtained from irradiation at liquid-nitrogen temperature, cluster effect on damage accumulation will be discussed in connection with how dense the collision cascade is.

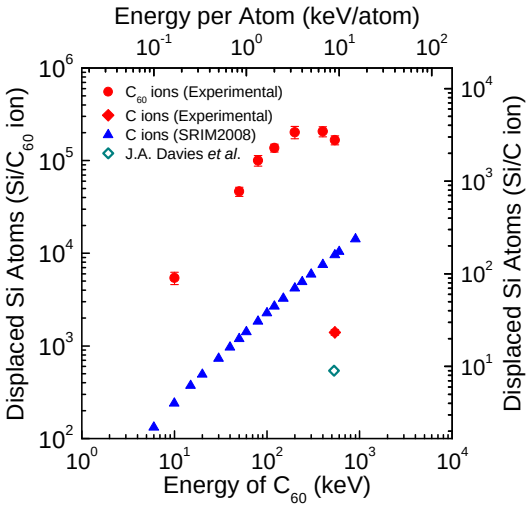

Figure 1. Energy dependence of the number of displaced Si atoms per C_{60} ion. For comparison, those by a monatomic C ion calculated with SRIM2008 and measured in the present study and reference [2] are shown.

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Postcollision Multifragmentation in keV cluster-surface impact

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When a large molecule or cluster is impacting a solid target at high velocity (typically a few hundreds of eV collision energy) it experiences a strong deformation which eventually leads to a variety of fragmentation phenomena , manifested by the abundances pattern of the outgoing fragments ,their kinetic energy distributions and angle distributions . Up to a certain impact energy and vibrational excitation (well below its total cohesion energy) the energized cluster is assumed to recoil intact and undergo a statistical unimolecular delayed emission of its subunits. At higher impact and internal energies, multifragmentation (multiparticle break-up) dynamics will start to dominate, eventually reaching complete disintegration of the system into its smallest units (the shattering limit). We have observed and characterized different intermediate multifragmentation modes by scattering C_{60}^{-} ions from surfaces (gold and nickel) at a few hundreds of eV impact energies [1-3]. By analyzing kinetic energy and angle distributions of outgoing C_n^{-} (2=15) fragments for different incidence angles and impact energies we distinguish between multifragmentation events which occur at the surface ("during-collision') and events which occur away from the surface ("post-collision") [1,2]. By measuring and analyzing also positively charged fragments, we show that the multifragmentation dynamics is independent of the charge transfer dynamics [3]. The postcollision multifragmentation is characterized by velocity correlated emission of all outgoing fragments and gradual narrowing of incidence angle dependences of the C_n^{-} fragment yield as a function of the fragment size *n*. A predicted $1/\sqrt{n}$ narrowing law is found to be in good agreement with the experimental results [2]. Molecular dynamics (MD) simulations will also be reported, providing microscopic insight into the nature of the postcollision multifragmentation process [4]. Finally, we will present results related with the collisional formation of the larger C_{60-2n}^{+} (n=1-5) ionic cage fragments [5].

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JO-I-01

Particle Interactions with Matter at TeV energies and above: the cosmic-ray experience

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Lawrence Berkeley National Laboratory, and
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Cosmic-rays are the highest energy particles observed by man; particles with energies up to $3*10^{20}$ eV have been observed. Cosmic neutrinos have been observed with energies up to about 1 PeV. In this talk, I will discuss electron and photon and muon interactions with matter, focusing on the special features that become important at very high energies: Landau-Pomeranchuk-Migdal and dielectric suppression of bremsstrahlung and pair production, the growing importance of photonuclear and electronuclear interactions, and, ultimately, at the highest energies, coherent photonuclear interactions with bulk matter. Then, I will discuss muon energy loss, and present some of the ways that large Cherenkov telescopes use these interactions to measure neutrino energy. Finally, I will briefly discuss data from the Auger observatory which sheds light on proton interactions at EeV (above 10^{18} eV) interactions.

Direct measurement of the formation length of photons

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We report the first observation of a shoulder in the radiation spectrum from GeV electrons in a structured target consisting of two thin and closely spaced foils. The position of the shoulder depends on the target spacing and is directly connected to the finite formation length of a low-energy photon emitted by an ultrarelativistic electron. The formation length corresponds to the distance it takes for the emitted photon to be separated by a reduced wavelength from the emitting electron. With the present setup it is possible to control the separation of the foils on a micrometer scale and hence measure interference effects caused by the macroscopic dimensions of the formation length. Several theoretical groups have predicted this effect using different methods. Our observations have a preference for the modified theory by Blankenbecler but disagree with the results of Baier and Katkov.

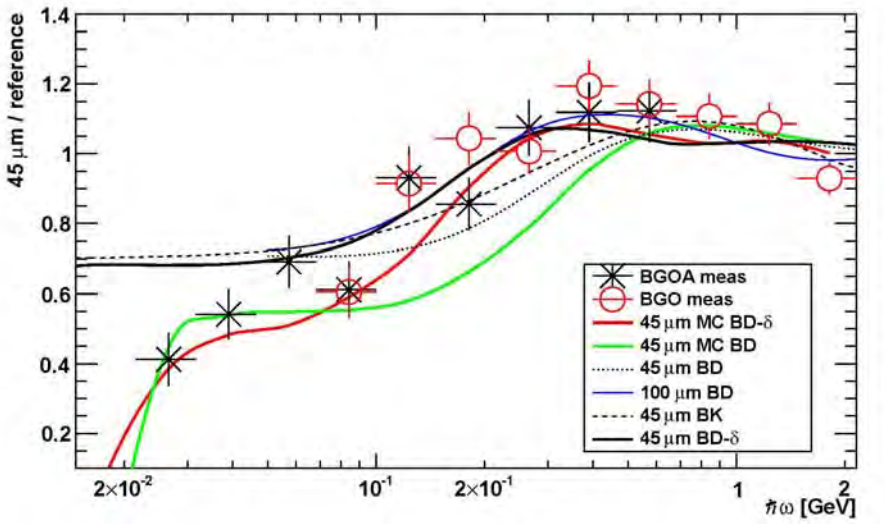

Figure 1. The ratio between the radiation spectra of a 45 micrometer structured target and a reference target.

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Influence of Stopping on Transition Radiation of Relativistic Heavy Ions Crossing a Target

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When the relativistic heavy ions (RHI) penetrate through the thin solid amorphous target with a constant velocity, two types of electromagnetic radiation may appear: Cherenkov radiation (CR) (optically transparent target) and transition radiation (TR). The bremsstrahlung is strongly suppressed (compared to relativistic electrons) due to large mass of RHI. In fact, the velocity of RHI slightly decreases due to ionization energy loss (stopping) and it changes the spectral-angular distributions both of CR and TR.

The influence of the stopping on the spectral-angular properties of CR has been investigated recently in [1-4] (see, also our Abstract to this Conference, “Stopping of Relativistic Heavy Ions and its Influence on Angular Distributions of Cherenkov Radiation”).The results of calculations show that the stopping of RHI in radiator leads to additional broadening of CR ring and forming of new CR angular distribution which is different compared with Tamm-Frank distribution.

Here, we present theoretical analysis and results of calculations of spectral-angular properties of TR taking into account RHI stopping in a radiator. The physical reason for appearance of new peculiarities is connected with interference of two waves emitted at entrance and exit of the radiator of finite thickness. These waves are emitted by RHI crossing the boundary vacuum-target and target-vacuum with slightly different velocities, which may change the condition of constructive interference compared to a case of relativistic electrons, see, e.g. [5].

The key parameters here are the plasma frequency, photon energy, attenuation length and thickness of the target, and stopping of RHI, which in turn is a complicated function of the energy, charge and mass of RHI.

The possible applications of the considered effect of stopping on TR from RHI are discussed.

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Effects of Nuclear and Electronic Energy Loss on Damage Formation and Recovery

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The interaction of ions with solids results in energy loss to both atomic nuclei and electrons. At low energies, nuclear energy loss dominates, and irradiation damage occurs primarily by ballistic collisions. At high energies for swift heavy ions, electronic energy loss dominates and can lead to latent track formation or recovery of existing irradiation damage. At intermediate energies, both nuclear and electronic energy losses are significant and can lead to synergistic or competitive processes that that affect irradiation damage. We have integrated experimental and computational approaches to investigate the separate and combined effects of nuclear and electronic energy loss on damage formation and recovery in several materials. Experimentally, it has been shown that that there is a synergy between the nuclear and electronic energy loss on damage formation in amorphous SiO_2 at intermediate ion energies [1]. Large scale molecular dynamics simulations, which include ballistic collisions and/or local electronic heating based on the inelastic thermal spike model, have been employed to investigate the separate and combined effects of nuclear and electronic energy loss on damage production; these simulations demonstrate conclusively the additive effect on nuclear and electronic energy loss on damage production. On the other hand, electronic energy loss in $Ca_2La_8(SiO_4)_6O_2$ leads to competitive damage recovery processes that decrease damage production [2]. In SiC, irradiation with intermediate energy ions leads to defect formation and amorphization [3]; however, it has been shown that swift heavy ions can induce some recovery of such irradiation damage [4]. New experimental results and molecular dynamics simulations reveal that swift heavy ions induce defect recovery and recrystallization in SiC that are well described by an inelastic thermal spike phenomenon.

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Molecular Effect on Swelling and Surface Topography of GaN Irradiated by PF_n^+ Ions

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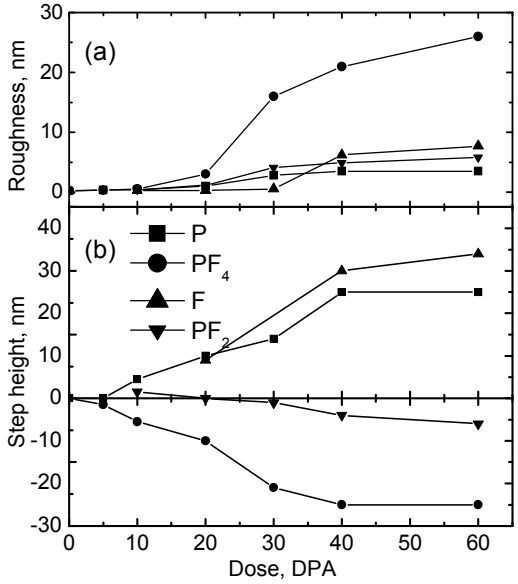
Ion-implantation-induced amorphization of GaN is accompanied by material decomposition with the formation of nanoscale N_2 bubbles and concomitant changes in the material density and surface topography [1]. As a result, swelling and increase in surface roughness takes place. Under molecular ion irradiation, collision cascades created by components of the cluster ion overlap in the near-surface region, creating combined individual collision cascades with larger volumetric densities of atomic displacements than in the case of irradiation with atomic ions of the same velocity. It results in a significant increase in the level of stable radiation damage in the near-surface region [2] and, accordingly, in change of surface roughness and swelling [3]. An additional effect during molecular ion bombardment is an increase of ion sputtering [4].



In the present report, results of room temperature irradiation of GaN by 1.3 keV/amu PF_n^+ (n = 0, 2, 4) and F^+ ions will be discussed. Roughness of the surface and height of the step between implanted and masked regions of the sample surface irradiated with different ions (see the legend) are shown in the figure as a function of dose in DPA. It is clearly seen that increase of ion mass (and hence the density of collision cascade) leads to roughness enhancement. Behavior of step height as a function of dose and mass of ions is a result of competition between swelling and sputtering. For F^+ irradiation, accumulation of implanted gas atoms has to be taken into account.

Work was supported by RFBR (grant 10-08-91751).

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A possible new mechanism for defect formation in irradiated UO_2

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In a previous study we observed the formation of irradiation induced defects in UO_2 by Raman spectroscopy [1]. 25 MeV He^{2+} ions were used and should have only induced ballistic defects around the implantation area at 120 µm depth. However Raman damage was observed from the surface to the implantation depth suggesting that the corresponding defects would be formed during electronic stopping of He^{2+} even though their dE/dx is less than the threshold for track formation.

In this paper we examine what could be the mechanism for the formation of these defects observed by Raman spectroscopy. For that purpose, we consider the UO_2 intrinsic defect named polaron. The polaron corresponds to an electron-hole pair formation associated to a lattice distortion. It was recently proposed that polaron could act as a supplementary channel for energy dissipation during electronic stopping of swift heavy ions [2]. For dE/dx lower than the track formation threshold, polarons can be formed because their formation energy is only 2eV. We then make the assumption that polaron formation would lead to positively and negatively charged domains. When the charged domains are large enough they could induce charged driven oxygen migration leading to the formation of hypo and hyper stoichiometric domains. This scenario is consistent with the three observed defect Raman modes (U_1, U_2 and U_3) interpretation given in [1]: U_2 is due to the activation of the Raman-forbidden LO mode, U_3 is due to an over-stoichiometric structural defect of cuboctahedral symmetry and U_1 may be the signature of sub-stoichiometric structural defect.

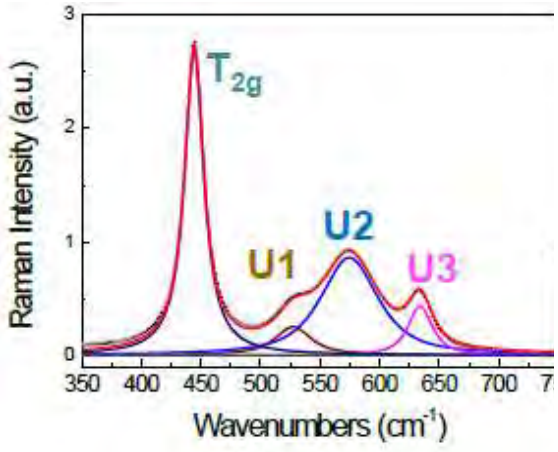

Figure 1. Raman spectra of He irradiated UO_2 evidencing UO2 Raman mode (T2g) and three defects modes U_1, U_2 and U_3

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SEM Analysis of Ion Implanted SiC

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SiC is a material used in two future energy production technologies: As a photovoltaic layer to harness the UV spectrum in high power solar cells, and as a diffusion barrier material for radioactive fission products in the fuel elements of the next generation of nuclear power plants. For both applications, there is interest in the implantation of reactive and non-reactive ions into SiC and their effects on the properties of the SiC.

In this study 360 keV Ag^+, I^+ and Xe^+ ions were separately implanted into 6H-SiC and in polycrystalline SiC at various substrate temperatures. The implanted samples were also annealed in vacuum at temperatures ranging from 900°C to 1500°C for various times.

In recent years there had been significant advances in scanning electron microscopy (SEM) with the introduction of an in-lens detector. This allows SEM images to be taken with very low voltages resulting in more surface sensitive images to be obtained. Examples will be shown of the effect of the accelerating voltage on the SEM image. Examples on cross-sectional samples will be shown of how radiation damage created by the implanted ions can be detected with SEM. The implanted depths and distributions of the ions can also be detected from such samples. Examples of void formation and of conglomeration of the implanted Ag into droplets will be shown. The different ions also led to differences in the recrystallization of the bombardment-induced amorphous SiC.

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Ultrashort electron dynamics in solids irradiated with a laser or swift heavy ion

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High-energy laser pulses of subpicosecond duration irradiating metals or dielectrics are primarily absorbed by electrons within the solid. Also swift heavy ions deposit energy mainly in the electronic system of the irradiated material. A common way to describe energy dissipation due to subsequent energy transport and electron-lattice heating is the two-temperature model [1], which was - before the advent of lasers - motivated to describe the interaction of charged particles with metals [2] and is known today in this context as the thermal spike model [3]. The application of the two-temperature model on ultrashort timescales is, however, questionable. For a nonequilibrium electron energy distribution, which does not resemble a Fermi- or Maxwell-distribution, respectively, the concept of a temperature looses its meaning [4].

In this talk I present how kinetic approaches as Boltzmann collision integrals or Monte Carlo simulations identify distinct effects of nonequilibrium energy distributions. Special attention is paid to the influence of the electronic energy distribution on the electron-phonon coupling parameter. Examples shown in the figure are under study [5,6].

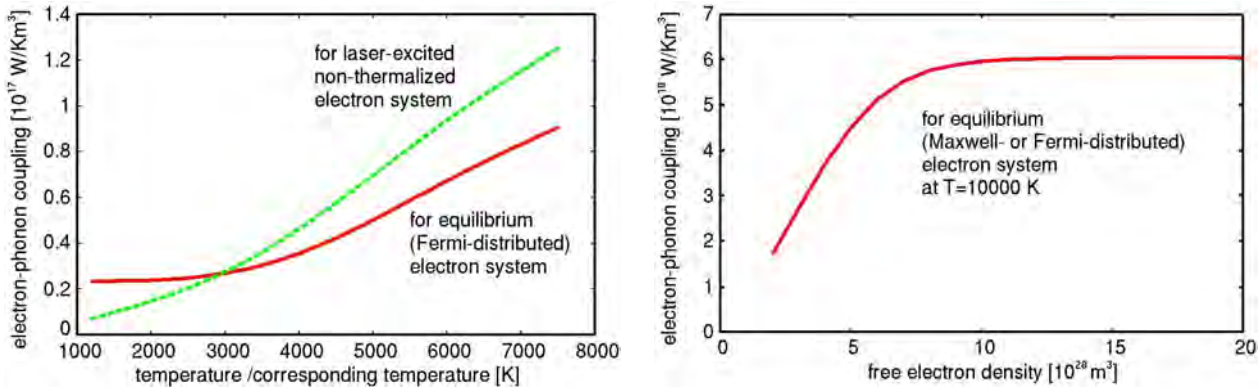

Figure 1. Electron-phonon coupling strength for laser-excited gold in dependence on excitation strength (left, [5]) and for fused silica in dependence on excited electron density (right, [6]).

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Ion tracks: new insights using small-angle x-ray scattering experiments

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Although discovered more than five decades ago, there are still many unanswered questions concerning ion track formation, structure and thermal stability. In recent years, we have demonstrated that synchrotron small angle x-ray scattering (SAXS) provides a powerful non-destructive tool for investigating the morphology of ion tracks. SAXS is sensitive to small density changes that often exist in the damaged regions and is well suited for studying tracks in amorphous materials, where most conventional techniques fail. Furthermore, due to the short acquisition times, time resolved measurements enable determination of the annealing kinetics and the stability of ion tracks in environments such as high temperature and high pressure using *in situ* experiments.

This presentation will give an overview of our recent results on ion tracks, including the morphology and annealing kinetics of ion tracks in natural apatite, which are important for geo- and thermochronology. According to our SAXS results, tracks are amorphous cylinders, which recover by a two-step process upon annealing through structural relaxation followed by recrystallization [1]. Tracks in amorphous SiO_2 (a-SiO_2) reveal a core-shell structure [2] and show an overlap behaviour consistent with a track-core annihilation process [3]. In α-quartz, *in situ* annealing of ion tracks below 600 °C reveals an interesting evolution of the ion track radius that can be well explained by an elastic model using the temperature dependent elastic behavior of quartz and a-SiO_2 for the matrix and track material, respectively. SAXS also provides evidence for ion track formation in amorphous silicon, germanium and several amorphous metallic alloys [4]. Results from the SAXS measurements are complemented by molecular dynamics simulations and calculations using an inelastic thermal spike model.

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Nanopores in 1 nm thick carbon-nanomembranes drilled by slow highly charged ions

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Nanostructures produced by slow highly charged ion (HCI) impact on surfaces have been a hot topic recently (see [1 - 4] and refs. therein). In this contribution we present first investigations on the effect of individual slow HCI bombardment of freestanding carbon nano-membranes (CNMs). The CNMs are produced by cross-linking of an aromatic self-assembled monolayer of biphenyl units with low-energy electrons [5]. The substrate is then subsequently removed and the resulting nanosheet (1 nm thickness) transferred onto a holey carbon TEM grid. CNMs produced in such a way are irradiated by slow Xe^{q+} ions of various charge states ($20 \leq q \leq 40$) and kinetic energies ($4\ keV \leq E \leq 180\ keV$). After irradiation the CNMs are inspected by high resolution imaging techniques, e.g. TEM, SEM and AFM. On the irradiated CNMs we find nanoscopic pores (3 - 30 nm in diameter, see fig. 1), whose number density corresponds well with the incident ion fluence, indicating that about every HCI produces a nano-hole in the CNM.

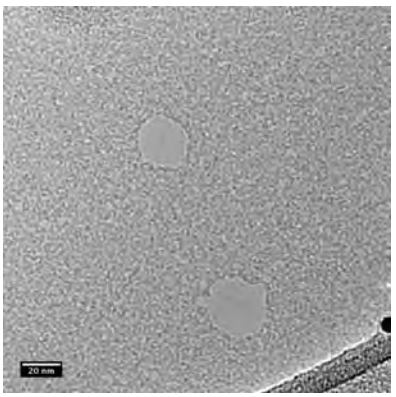

Figure 1: TEM image of 2 holes in a carbon nanomembrane induced by impact of two Xe^{40+} ions (E_{kin} = 40 keV, E_{pot} = 38.5 keV).

First evaluations of the size distribution of the created pores indicate that the average diameter of a hole induced by a given ion depends strongly on the potential energy of the projectile ion, but is also influenced by the kinetic energy.

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NanoscaleEngineering of Graphene with Heavy Ion Beams

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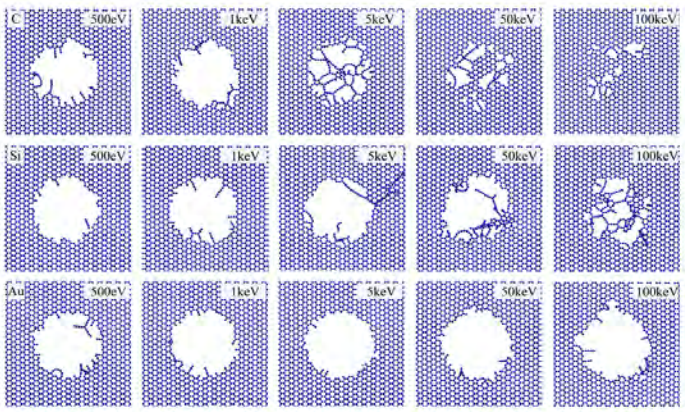
Graphene is a two-dimensional carbon nanostructure consisting of sp^2-hybridized carbon atoms arranged in a honeycomb-like lattice. Since techniques were developed to exfoliate it from graphite in the form of single layers or multilayers, it has been the focus of intense research due to its unique electronic properties. In view of its wide applications, controllable modification of the properties of graphene is crucial to achieve its optimum performance. In this context, ion beam technique as an effective way has been used to introduce various defects or dope foreign species in graphene in order to engineer its properties.



In this presentation, we have used various energetic ions including Au, C and Si to irradiate the graphene in order to fabricate nanopores in graphene, which holds promise for DNA sequencing, sea water desalination and biosensors, etc. Molecular dynamics simulations based on empirical potentials show that a nanopore with desired size and morphology could be created by carefully choosing the parameter of incident ions. The typical nanopores fabricated with this method are demonstrated in the above Figure, in which we give the shape of the nanopores as a result of different incident ions with various incident energies. We also performed experiments to irradiate the graphene supported by Cu substrate with various ions. It is found that nanopores with predetermined parameters was successfully created, in accordance with the simulation results.

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X-ray spectroscopy of the heavy ion interaction with matter

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Methods of X-ray spectroscopy were applied in investigations of the heavy ion stopping process in cold matter and the response of the stopping media on the deposited ion energy. The evolution of the ion charge and velocity was measured along 80% of the ion stopping path in gaseous and solid targets using the K-shell projectile radiation. The stopping dynamics of heavy ions (Mg, Ar, Ca, Ti, Ni) penetrating solid and gaseous targets with over-range thickness was measured using relativistic Doppler Effect. In order to resolve the ion stopping dynamics in solid targets, low density nanostructures (silicagels) have been used providing stretching of the ion stopping length in condense matter up to 100 times. The method was approved by comparing the ion charge state distribution defined from the X-ray spectra before emerging from the solid target with those measured by means of dipole magnets.

K-shell target radiation measured with a spatial resolution along the ion stopping path was used to investigate the early stage of the ion track formation – the excitation of the target electrons by the dynamical projectile Coulomb field. The application of the K-shell target radiation which occurs in the femtosecond time scale after the Coulomb excitation allowed for the first time investigations of the early stage of the material modification, which supplies the initial conditions for the next stages of the radiation damage process.

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Inner shell processes in the collisions of highly charged ions near Bohr velocity*

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Since the charge state equilibration time is typically in order of femto-second for a highly charged ions impacting into a solid, the initial charge state effect on inner shell processes (ionization and exchanging) between HCIs and target atoms will be significant in collision near Bohr velocity ($0.1\upsilon_{Bohr}<\upsilon<10\upsilon_{Bohr}$, υ_{Bohr}=2.19*10^6m/s), where the interaction length before charge equilibrium is around tens to hundreds atomic layers, which makes the initial charge effect possible to be observed, on the other hand, the HCIs will not only have enough kinetic energy to approach a target atom to a certain distance for inner shell ionization, but also have enough time to form a quasi-molecular and exchange the inner-shell electrons or vacancies. The initial charge state effect on inner shell processes will not be so significant, if the projectile velocity is too slow (much slower than υ_{Bohr}), the HCIs will be neutralized before a strong inner-shell process happens between projectiles and target atoms, while if the velocity is too fast (much faster than υ_{Bohr}, in order of MeV/u), only Coulomb ionization dominates the inner shell processes.

During this conference, we would like to report our preliminary results in measurements of X ray emission induced in the collisions of highly charge ions near Bohr velocity. The experiments were carried out recently at the 320 kV highly charged ion physics platform at IMP-Lanzhou, China. It was found that both the initial charge state and the initial kinetic energy strongly affect the cross-sections of the characteristic X-ray emission from the projectile or from the target atoms. Theories of quasi-molecular can give a reasonable description to those phenomena, while future experiments with very thin foil targets will probably confirm our deductions.

This works is supported by the “973” program (the National Program on Key Basic Research Project, No. 2010CB832902) and NSFC (the National Natural Science Foundation of China No. 11075192 and 11075125).

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X-ray Emission in Fast Collisions of Heavy Ions with Solids

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The x-rays excited by fast heavy ions in solids have a complex structure due to the multiple ionization of atoms leading to emission of x-ray satellites. Generally, such x-ray spectra carry information on the *dynamics* of the collision process as well as the *structure* and *relaxation* of multiply ionized atoms. In particular, the vacancy rearrangement processes taking place between the moments of collision and x-ray emission have to be accounted for in order to describe the measured x-ray spectra. For this reason the understanding of x-ray emission in fast collisions of heavy ions with solids needs adequate theoretical description of the multiple ionization process as well as the extensive calculations of the electronic structure and radiative/nonradiative decay rates for multiple ionized atoms.

In this report we summarize the results of systematic high-resolution studies of x-ray emission from metallic foils (Zr, Mo, Pd and Th) bombarded by energetic (10-25 MeV/amu) oxygen and neon ions. In particular, the x-ray satellites and hypersatellites for $L\alpha_{1,2}$ x-ray transitions in Zr, Mo and Pd [1] and $M\alpha_{1,2}$ x-ray transitions in Th excited by fast oxygen and neon ions were measured using a high-resolution diffraction von Hamos spectrometer [2] having an instrumental energy resolution below 1 eV. The x-ray hypersatellites for the L- and M-shells were observed for the first time. The measured x-ray spectra, including x-ray satellites and hypersatellites, were interpreted in terms of the relativistic Multi-Configuration Dirac-Fock (MCDF) calculations [3] which were performed for multi-vacancy configurations ($L^{-l,2}M^{-m}N^{-n}$ and $M^{-m}N^{-n}$) ($n,m \leq 4$) expected to contribute to the observed x-ray spectra. For higher number of vacancies the developed model of averaged <MCDF> calculations [4] was used. The performed MCDF calculations allowed to interpret the complex structure of x-ray satellites for $L\alpha_{1,2}$ and $M\alpha_{1,2}$ transitions taking into account the vacancy rearrangement processes. Finally, the ionization probabilities per electron for the moment of collision were extracted from the measured spectra of x-ray satellites. The ionization probabilities were compared with the predictions of the semiclassical approximation (SCA) using the relativistic hydrogenic (HYD) and selfconsistent Dirac-Hartre-Fock (DHF) [5] wave functions. Generally, it was found that realistic selfconsistent (DHF) description of the wave functions for the L- and M-shell electrons was necessary in order to interpret the measured ionization probabilities.

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The History of Swift Heavy Ions in Matter

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The first SHIM Symposium was held in 1989, promoted by J. C. Jousset from the CIMAP laboratory in Caen (France) and P. Armbruster from GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, (Germany). With this initiative, they pursued the aim of developing a better understanding of material transformations under dense and nanometric excitations induced by heavy ions in the electronic energy loss regime. Since the excitations are mainly reached with ions at high velocities, the attribute "swift" was chosen to characterize this field of research. We present an overview of the SHIM Conferences [1], considering their major contributions to topics such as fundamental processes, materials, nanosystems, and applications.

Part I: Interactions of swift heavy ions with matter

Swift heavy ions create in many solids straight, cylindrical, and nanometric damage trails, called ion tracks. These tracks result from a three-step process: (1) MeV to GeV projectiles generate excitations and ionizations in the electronic system of the atoms; (2) this energy is transferred from the electrons to the atoms; (3) the energy is dissipated in the material. The SHIM community has combined atomic physics, solid state physics, and materials science to study the track creation process and its final results. In this part, it will be shown how the understanding has improved over the last two decades and an attempt will be offered to clarify the present status of our knowledge.

Part II: Applications on the nanoscale

Ion tracks represent fascinating nanostructures that can be transformed via etching into open nanochannels. These channels can be modified specifically to control small species and act, e.g., as sensors and transmitters. Depositing a material in the channels provides nanowires that also exhibit various novel effects. In this part, microtechnological achievements with swift heavy ions will be briefly recollected that began already in the 1970ties, preparing the ground for gradual size decrease down to the nanoscopic objects now under study. Various examples illustrating recent results and emerging developments will be displayed, comprising material modifications on the nanoscale, plasmonic and thermoelectrical effects in nanostructures, and novel applications of nanochannel- and nanowire-based devices.

[1] The seven SHIM conferences: 1989 in Caen (France) [Rad. Eff. Def. Sol. **110** (1989) 1], 1992 in Bensheim (Germany) [Rad. Eff. Def. Sol. **126** (1993) 1], 1995 in Caen [Nucl. Instr. Meth. B **107** (1996) 1], 1998 in Berlin (Germany) [Nucl. Instr. Meth. B **146** (1998) 1], 2002 in Giardini Naxos (Italy) [Nucl. Instr. Meth. B **209** (2003) 1], 2005 in Aschaffenburg (Germany) [Nucl. Instr. Meth. B **245** (2006) 1], 2008 in Lyon (France) [Nucl. Instr. Meth. B **267** (2009) 859].

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Lindhard Lecture:
Short-time Processes Triggered by Fast Ions in Solids

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During the passage of solid or liquid matter, ions transfer their kinetic energy into different electronic and atomic excitation modes. Notwithstanding the complication that arises due to the large variety of ion-solid interaction processes, the primary interaction is extremely localized (typically on an atomic scale) and also very rapid (for fast ions). The time duration of individual energy-transfer processes is about 10^{-16} s or less, far below typical relaxation times. Since our current knowledge on energy-loss processes has reached a high level of sophistication [1], fast ions are ideal candidates for short-time investigations specifically of electronic relaxation processes in solids.

In this lecture, fast ions will be compared to pulsed photon sources in their ability as triggers and probes of short-time processes. Different detection schemes for short-time dynamics driven by fast ions in solids will be discussed. Special emphasis will be put on high-resolution Auger spectroscopy [2] (see also Fig. 1) for the investigation of rapid electronic and atomic [3] processes. Our current knowledge will be sketched and open questions will be high-lighted, specifically those regarding our understanding of atomic reactions triggered by dense electronic excitations.

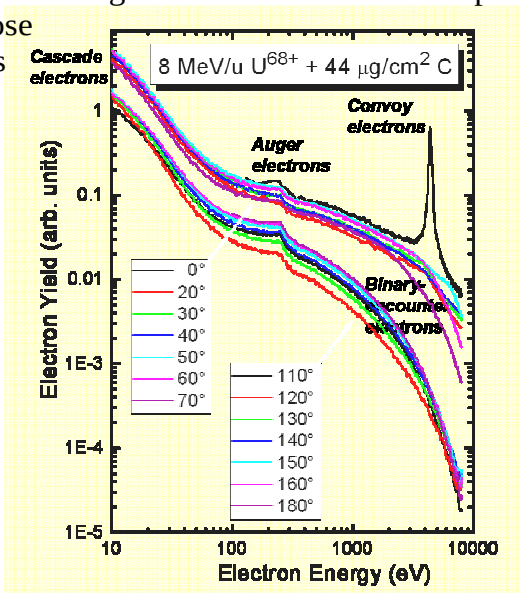

Figure 1.:
Electron-energy distribution for emission angles between 0 and 180 degrees with respect to the ion beam. Measured for highly charged uranium ions at normal incidence on a thin amorphous carbon foil [experimental data taken from D.Schneider, G.Schiwietz, and D.DeWitt, Phys. Rev. A 47, 3945 (1993)].

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Beyond the ion-beam shaping mechanism: toward plasmonic applications

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In the last years, ion-shaping technique has been proposed as an innovative and powerful tool to manipulate matter at the nanometer scale [1-3]. Deformation can be indirectly induced by embedding metallic NPs into an ion-deformable amorphous host matrix.

A model system composed of nearly monodisperse metallic nanoparticles (NPs) (8-100nm) confined between two silica layers is used to investigate the ion-shaping mechanism. We show that this phenomenon is not limited to the transformation into prolate nanorods and/or nanowires, but that depending on the initial size of the NPs, several new classes of ion-shaped NPs can also be obtained: i) facetted-like NPs, ii) nanowires growing from a facetted core or iii) chromosome-like NPs. In parallel, the evolution of the temperature profile within the nanoparticle is simulated by implementing the thermal-spike model for three-dimensional anisotropic and composite media [4]. In this way, a straight correlation is found between the fraction of the nanoparticle that is molten(vaporized) and the deformation path followed by the nanoparticles during the irradiation. This allows the construction of a size-vs-shape diagram relating the initial nanoparticle size to its final morphology. This diagram is used to give a rational description of the ion-beam shaping process for all the nanoparticle dimensions [5].

Besides the fundamental aspects related to the ion-matter interaction, ion-shaping can also be used to give new insights into the plasmonic properties of metallic nanorods and nanowires. Here, Electron Energy Loss Spectroscopy (EELS) is used to study Localized Surface Plasmon Resonances (LPSR) in ion-shaped metallic nanoparticles with a nanometer-scale spatial resolution, [6]. LSPR are generated through electron excitation is a Scanning Transmission Electron Microscope (STEM), equipped with a High Angle Annular Dark Field (HAADF) detector. As the NPs are continuously deformed under irradiation, we investigate the LPSRs dependence on both the geometry and aspect ratio of the nanostructure. Finally, the experimental results are simulated using a specifically developed Auxiliary Differential Equations-Finite Difference Time Domain (ADE-FTDT) code, [7].

This work demonstrates the possibility to use ion irradiation as tool for the controllable fabrication of a whole family of plasmonic nanostructures with topologically tunable optical properties. These ion-beam shaped composite media have potential applications spanning from plasmonic photovoltaics, to bio-sensing, SERS and SEIRA spectroscopies.

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Keywords: ion-beam shaping, metallic nanoparticles, plasmonics
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Synthesis of Semi-Embedded Au Nanostructures by Ion Irradiation: Combined Effect of Sputtering, Viscous Flow and Ion Recoil Implantation

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Ion beam synthesis is one of the techniques to synthesize the nanostructures [1-3]. Noble metal nanostructures are of great interest due to their high surface to volume ratio, surface plasmon resonance and applications in different fields. Formation of surface nanostructures by ion irradiation of thin films occurs mainly due to interplay between the surface instability and surface diffusion [2]. Semi embedded Au nanostructures were synthesized by 50 keV Si ion irradiation of 5 nm Au thin films on glass. High resolution Rutherford backscattering spectroscopy (HRBS) provided evidence of embedding of Au atoms into substrate irradiated sample at fluence of 3×10^{16} ions/cm^2. The formation of semi embedded nanoparticles having an average diameter of 16 nm was revealed from the cross sectional transmission electron microscopy (XTEM) characterization of irradiated sample at fluence of 3×10^{16} ions/cm^2. The mechanism of synthesis is explained by ion beam induced sputtering, thermodynamically dominated capillary forces [4] and recoil-implantation of Au [1].

Similar results were also obtained for 50 keV Ar ion irradiation of thin Au film from the fluence of 1×10^{15} ions/cm^2 to 3×10^{16} ions/cm^2. RBS spectra of pristine and irradiated samples reveals that Au peak shifts to the lower energy with decrease in the intensity of peak along with tailing in the lower energy edge with irradiation which indicates that sputtering and recoil-implantation occur during irradiation. The absorbance spectra of pristine and irradiated samples show that ion irradiation leads to the formation of plasmonic structures. Semi-embedded nanostructures have great potential for use as Surface Enhanced Raman spectroscopy (SERS) substrate. The test for SERS will be performed in near future.

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JO-I-07

Heavy Ion Sputtering of LiF, astrophysical ices and silicates

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Ion-surface collisions involving swift heavy ions (MeV/u), where the electronic energy loss S_e is dominant, lead to "electronic sputtering". The microscopic mechanisms are still under debate (coulomb explosion, thermal spike, excitonic mechanisms, etc.). The measurement of yields and of energy- and angular distributions of sputtered particles contribute to the understanding of the initial microscopic processes of defect creation in materials. We present recent results on heavy ion sputtering of different materials. A new UHV set-up allows measuring the velocity vector of secondary ions from controlled surfaces including thin layers [1] by means of the imaging technique XY-TOF-SIMS ("time of flight-secondary ion mass spectroscopy"). In addition to mass distributions of emitted particles, their energy- and angular distributions can be deduced. Results obtained with LiF crystals [1,2] and evaporated thin layers [3] show an important contribution of $Li^+(LiF)_n$ cluster emission. As first application to materials relevant for astrophysics (exposure of surfaces to cosmic rays or solar wind) we show sputtering yields and energy distributions for nepheline, a silicate being a model for mercury's surface [4]. We also present results obtained with astrophysical ices at 15K by FTIR infrared absorption spectroscopy. Although protons are orders of magnitude more abundant in the cosmic ray spectrum, the high electronic energy loss of heavy ions can compensate for the lower flux. This results in non-negligible contributions of heavy ion induced physico-chemistry. In particular, we observed a strong increase of sputtering yields Y with deposited energy $Y \sim S_e^2$ in CO and CO_2 ices bombarded with heavy ions [5,6]. Clearly, the contribution of cosmic ray heavy ion induced desorption from dust grains must be taken into account for understanding the presence of gas phase molecules in dense interstellar clouds [6].

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Microscopic analysis of particles sputtered with heavy ions in the electronic stopping regime

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For a variety of ionic crystals in particular LiF and CaF_2, sputtering processes with swift heavy ions have been studied in detail. In most cases, the total number of sputtered particles and their angular distribution were quantified by using the catcher technique in combination with elastic recoil detection analysis (ERDA) [1,2]. The most prominent phenomena are sputtering at rates much larger than values known from elastic sputtering and unexpected angular distributions characterized by a sharp jet-like component which is symmetric around the surface normal and superimposed on a cosine distribution.This contribution presents new transmission electron microscopy (TEM) investigations of fluorite particles sputtered onto TEM grids as catchers (Fig. 1). The analysis at different angular positions reveals that the jet-like component is correlated with the ejection of large nanocrystals of similar size (up to 10 nm), whereas outside the jet-like component, the size distribution of the particles is broad.

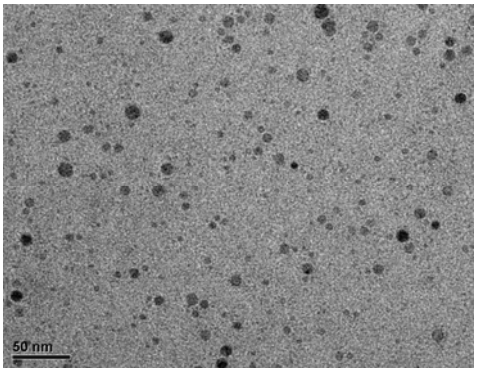

Figure 1. TEM image of catcher showing nanoparticles sputtered from a CaF_2 single crystal when irradiated with 180-MeV Au ions under 45º beam incidence. The sputtering experiments were performed at the Munich tandem.

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Ion Tracks in Non-amorphizable Non-radiolytic Materials – a Revision of the Thermal Spike Concept

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The basis for any thermal spike model is a combination of irreversible thermodynamics and continuum mechanics to fulfill conservation of mass, momentum, angular momentum, energy, and the second law of thermodynamics. Starting from this basis the rudimentary form of the presently used thermal spike models for swift heavy ions becomes obvious. By means of a fictive material with simplified material properties, quantitative differences between those models and a more advanced one will be outlined. It will be shown that a more complete model provides a natural basis to distinguish materials showing no tracks, amorphous tracks or more complicated track effects like hollow tracks or tracks with reduced mass density in the core. Particular emphasis will be put on the recently discovered phenomenon of ion hammering in originally single crystalline NiO. It will be argued that dislocation emission is inevitable if the thermal spike is sufficiently intense. Three electronic energy loss regimes can be distinguished. At low energy losses a non-radiolytic single crystal can remain essentially undamaged if transient melting is followed by epitaxial recrystallization. At intermediate energy losses essentially shear dislocation loops will be generated, and at very high energy losses prismatic loops will dominate. The latter are the starting point for the formation of dislocation networks, dislocation cells and, finally, to small-angle boundaries leading to an increase in crystal mosaicity or, depending on irradiation geometry, to the formation of nano-crystals and crystallite rotation.

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Computer Simulation of SHI Effects in Materials

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Interactions of swift heavy ions (SHI) with matter are of fundamental interests since they advance our understanding of high-energy accelerators, muon cooling, particle detectors by giving us an insight into the nature and properties of warm dense matter. In the present paper, the following phenomena are of interests such as (multiple-charged) plasma formation at SHI interaction with materials, charge screening and neutralization, shock wave generation, ion track and crater formation, and sputtering by SHI [1-14]. Sputtering of solids by SHI is interesting from both fundamental and potential application viewpoints. Experimental sputtering data obtained by SHIM were not explainable by a simple linear cascade theory [1]. Computer simulations of sputtering by SHI interaction with solids were capable of confirming at least some of the experimental observations [10,11]. Several new phenomena were discovered recently such as phase transitions by irradiation with SHI [2], atomic mixing in thin films by SHIs [3], crater formation on the surfaces [4], desorption from amorphous carbon [5], sputtering of large organic molecules from the surfaces by shock waves generated by SHIM [6] that are in the interests of our paper. We also discuss a recent development of computer simulation methods that were significant tools for understanding of the above fundamental and applied topics related to SHIM, including two-temperature molecular dynamics (TTM) [15,16] capable of studying the dynamics of hot electrons in the solids irradiated with SHI by introducing an electron-phonon coupling into classical molecular dynamics [9]; and coupling of TTM with the plasma model [8].

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Role of Ion Track Density Evolution in Void Formation in Amorphous Ge and in Metal Nanoparticle Shaping

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Combination of molecular dynamics (MD) simulations and experiments reveals nanoscale structure and time evolution in latent ion tracks. SHI irradiation induces porosity in amorphous Ge. As precursors, unusual bow-tie shaped voids are observed in transmission electron microscopy (TEM). MD and analytical models show how the density changes at phase transitions govern both the initial void formation in the molten ion track and its shape change out of the minimum surface energy spheroidal shape upon solidification.

In a comparison of small-angle x-ray scattering experiments and MD simulations, a previously unresolved fine structure with a low-density core and a high-density shell in ion tracks in amorphous silica was found [1]. The origin of the fine structure is a picosecond time scale pressure wave out of the track center that freezes in. We present large-scale MD simulations of SHI irradiation into Au nanoclusters in silica, compared to experiments where nanoparticles elongate into long nanorods. Simulations show how the track density evolution and thermal expansion of gold govern the shape transformation of nanoparticles [2].

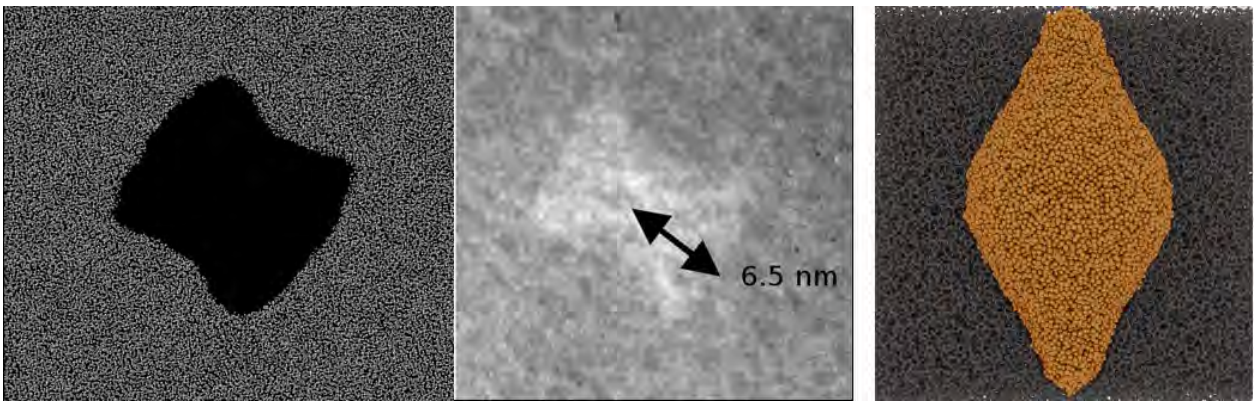

Figure 1. (left) Void in amorphous Ge ion track, MD simulation
(center) Bow-tie shaped void in aGe, TEM experiment
(right) Elongation of originally spherical gold nanoparticle in SiO_2 after multiple ion impacts in MD simulation

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SH-I-02

SWIFT HEAVY ION INDUCED THERMAL SPIKE ENGINEERING OF THIN FILMS: MODIFICATION AND EVOLUTION OF NANOSTRUCTURES

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High energy heavy ions popularly known as swift heavy ion (SHI) can be used as a unique tool to engineer the properties of materials down to nanoscale because of large energy deposition in the material. The energy deposited in the electronic subsystem eventually leads to a high temperature spike (in (subnanosecond time scale) within a narrow spatially confined (few nm in dimension) zone of the lattice. After a brief introduction to the basic mechanism of SHI-material interaction, the following three studies will be described: (i) elongation of nickel (Ni) and Au nanoparticles in thin SiO_2 film matrix and associated modification in optical and magnetic properties, (ii) evolution of Si nanostructures in Si rich silicon nitride films and (iii) evolution of nanodimensional structures and nanometallic lines on copper nitride thin films under SHI irradiation. The possible mechanism based on thermal spike mechanism and simulation explaining these effects will be discussed. Finally, future research direction and possible applications will be highlighted.

Key words: (i) Swift heavy ion, (ii) Thermal spike, (iii) Nanocomposite films, (iv) Silicon nitride, (v) Copper nitride.

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Effects of 2.6 GeV U Irradiation in Co-doped $BaFe_2As_2$

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The discovery of superconductivity in LaFeAs(O,F) has revived the research activity on superconductors [1]. Following this discovery, various iron-based superconductors (IBS) with layered structures have been found. For the applications of IBS, critical current density, J_c, is one of the most important parameters. Earlier studies on polycrystalline samples of IBS clarified that J_c of the order of 10^5-10^6 A/cm^2 flows within the grain, while intergranular J_c is orders of magnitude smaller [2]. This fact has been later confirmed by studies on single crystals [3]. Introduction of disorder in a controlled way offers an excellent opportunity for enhancing J_c. Such an improvement of J_c in IBS by defects created by swift ions has been demonstrated [4]. Depending on the energy and mass of particles, created defects are either point defects or continuous columnar defects [5].

In the present study, we explore the effect of 2.6 GeV U irradiation on J_c and vortex dynamics in $Ba(Fe_{0.925}Co_{0.075})_2As_2$ [5]. We focus on the origin of the novel low-field dip feature in *M-H* hysteresis loop as shown in Fig.1. This dip feature is wiped away by misaligning the field direction (θ_H) from the direction of columnar defects (θ_{CD}). Such a suppression of J_c near zero field can be caused by the curvature of vortices in flat superconductors close to zero field as shown in Fig. 2(a). When magnetic field is increased to the self-field (H_{sf}), vortices are straightens up as shown in Fig. 2(b) and the efficiency of columnar defects becomes higher, giving higher J_c.

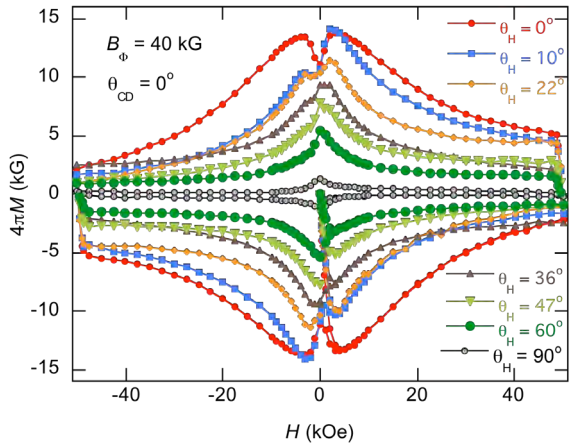

Figure 1. *M-H* hysteresis loops at 5 K in 2.6 GeV U irradiated $Ba(Fe_{0.925}Co_{0.075})_2As_2$ at several field angles.

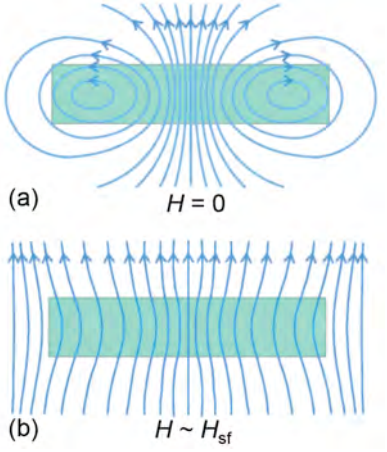

Figure 2. Schematic magnetic field lines in a flat superconductor at (a) zero field and (b) $H \sim H_{sf}$.

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Swift Heavy Ion Induced Sputtering in BaF_2 Thin Films

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The effect of swift heavy ion bombardment on thin films have a great variety of applications in understanding the theoretical modelling of the basic electronic sputtering phenomenon which includes the observation of change in sputter yield with the change in film parameters and of the sputtered species ejected from the film surface due to ion bombardment. This is what we have done in our present experiment with a series of barium fluoride thin films of different thicknesses and deposited by electron beam evaporation technique at room temperature on silicon substrates. The effect of film thickness on the electronic sputter yield of polycrystalline BaF_2 thin films has been reported in the present work. The thin films of BaF_2 have have been deposited with three different thicknesses 20 nm, 50 nm and 150 nm on Si substrates and sputtering has been performed by 100 MeV Au^{+25} ions. Glancing angle X-ray diffraction (GAXRD) measurements show that the pristine films are polycrystalline in nature and the grain size increases with increase in film thickness. Rutherford backscattering spectrometry (RBS) of pristine as well as irradiated films was done to determine the areal concentration of BaF_2. A reduction in the sputter yield of BaF_2 films with the increase in film thickness has been observed from the RBS spectra. The thickness dependence sputtering is explained on the basis of thermal spike and the energy confinement of the ions in the smaller grains.

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From Grain Fragmentation to Grain Rotation:

Swift Heavy Ion Bombardment of Single Crystalline NiO

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In insulators with complex crystal structures, e.g. silicates or garnets, ion tracks are often amorphous and can easily be identified by high resolution electron microscopy. At high ion fluences, track overlap leads to complete amorphization. In insulators with simpler crystal structures or composition, tracks can result in a change in crystal structure without amorphization at high fluences. Under ion bombardment, binary fcc insulators do neither amorphize nor change their crystal structure. Some of them, e.g. alkali halides or CaF_2, are destroyed because they are easily cleavable and decompose by radiolytic processes, while others, e.g. MgO and UO_2 are considered as very radiation resistant.

Single crystals of NiO at room temperature were bombarded with 600 and 940 MeV gold ions. Crystal modifications were monitored by means of on-line x-ray diffractometry with a four-circle diffractometer. We observed pronounced effects depending on the angle of incidence α between the impinging ions and the sample surface normal. During normal beam incidence, i.e. $\alpha = 0$, a (111)-oriented crystal remains an intact single crystal with an increase in mosaicity saturating at about 3×10^{13} Au/cm^2. At fluences $>10^{14}$ Au/cm^2 target destruction starts from the sample rims, a phenomenon which indicates large internal mechanical stresses. For $\alpha \geq 20°$, single crystals rapidly ($\sim10^{13}$ Au/cm^2) transform into well-aligned nanocrystals which change their orientation by crystallite rotation proportional to the ion fluence. In highly symmetric cases, i.e. when the projection of the ion beam onto the sample surface is parallel to one of the cubic crystal axis, the rotation axis coincides also with a crystal axis. In this case the rotation can reach more than 90° at sufficiently large fluences. The process is almost perfectly reversible, because changing the sign of α reverses the direction of rotation. In less symmetric cases there is an additional side motion which hampers the pursuit of the x-ray signal and destroys the reversibility.

Similar effects were also seen in MgO, UO2, TiN [1], and ω-Ti [2]. The occurrence of grain fragmentation and grain rotation seems to be a rather universal phenomenon but requires very high electronic stopping powers. On the other hand, a similar phenomenon was also reported for nanocrystalline gold bombarded with 7 MeV gold ions [3].

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PARAMAGNETIC TRIGONAL CENTER PRODUCTION IN YTTRIA-STABILIZED ZIRCONIA BY ELECTRONIC EXCITATIONS

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ABSTRACT

Electron paramagnetic resonance (EPR) spectroscopy is used to study the point defect production in yttria-stabilized zirconia (YSZ) (100) single crystals by swift heavy ion, electron and X-ray irradiations. A common color center known as the “T center” (for “trigonal” center) with an axial <111> symmetry is produced in all cases. We show that this defect is likely an intrinsic one with concentrations much larger than the major impurities. The growth curves of this point defect versus fluence for ion and electron irradiations can be on the whole rescaled as a function of the absorbed dose. This confirms that T centers are produced by the electronic excitations, either at low density with X-rays and electrons, or at high density with heavy ions. The production rate increases almost linearly versus the average volume density of electron-hole pairs that are generated by ions and electrons in the irradiated volume.

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High Energy Heavy Ion Therapy -Recent Activities at HIMAC NIRS-

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In 1994, carbon ion radiotherapy was begun at the NIRS (National Institute of Radiological Sciences)using HIMAC (Heavy-Ion Medical Accelerator in Chiba), which was the world's first heavy ion accelerator complex dedicated to medical use in a hospital environment. Among several types of ion species, carbon ions were selected for cancer therapy because they presumably had the most optimal properties in terms of biologically effective dose-localization. The purpose of the clinical study of carbon ion radiotherapy was to investigate the efficacy of carbon ions against a variety of tumors as well as to develop effective and safe techniques for delivering the efficient dose to the tumor. As of February 2012, a total of 6,512 patients were treated with carbon ion radiotherapy. The results have shown that carbon ion radiotherapy has the ability to provide a sufficient dose to the tumor without unacceptable morbidity in the surrounding normal tissues. Tumors that appear to respond favorably to carbon ions include locally advanced tumors and those with histologically non-squamous cell type of tumors such as adenocarcinoma, adenoid cystic carcinoma, malignant melanoma, hepatoma, and bone and soft tissue sarcomas. By using biological and physical properties of the high-LET carbon ion beams, the efficacy of treatment regimen with small fractions in shorter treatment course has been confirmed for almost all type of tumors in our carbon ion radiotherapy experience. Based on these experiences, we embarked on the research and development of a new generation beam delivery facilities such as a 3D-scanning method with a pencil beam and a compact rotating gantry. (Figure 1) A clinical research using the pencil beam scanning was in operation since May 2011.

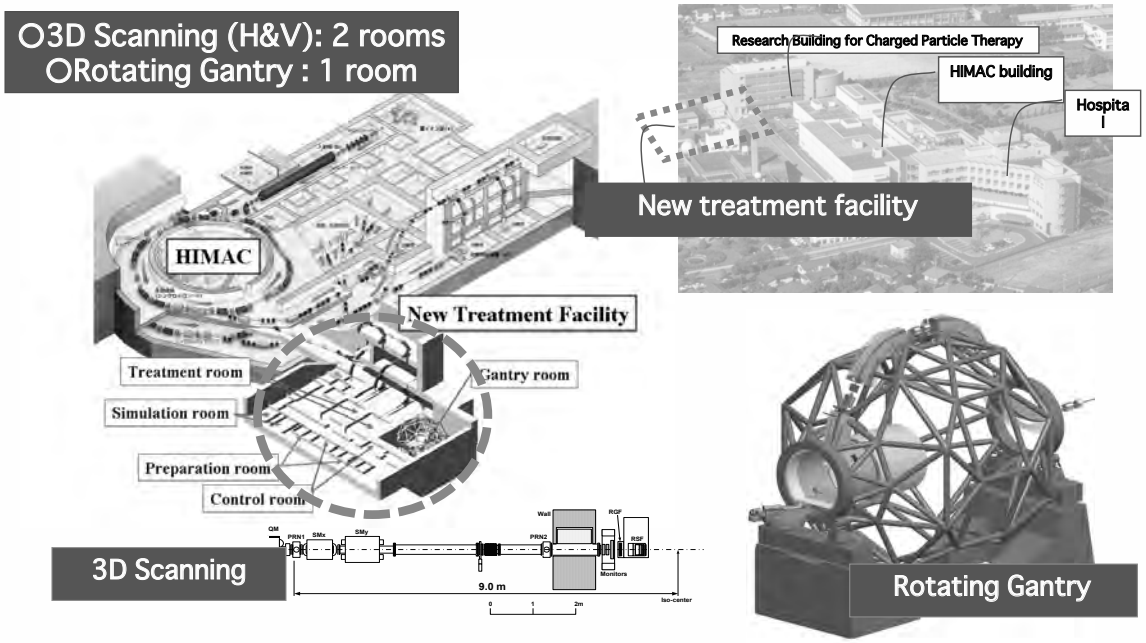

Figure 1. 3D-scanning and rotating gantry at the new facility.

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DNA Damage Due to Thermomechanical Effects Caused by Heavy Ions Propagating in Tissue

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Biological effects of ions incident on tissue are a subject of the intense discussion since carbon ion beams are successfully used for therapy and the assessment of radiation damage by heavier ions is important for radiation protection in space [1, 2]. While numerous suggested pathways of DNA damage are due to chemical actions of secondary particles such as secondary electrons, radicals, solvated electrons, etc. on covalent bonds of a DNA molecule, we are considering thermomechanical effects in the medium as a part of the phenomenon-based multiscale approach to the physics of radiation damage with ions [3].

The scenario of these effects starts from the ion's passage through the tissue. The largest fraction of the ion's energy is transferred to secondary electrons produced as a result of ionization of the medium. These electrons lose their energy to the molecules of the medium and it was shown that this energy transfer leads to a thermal spike in a liquid water environment [4]. Due to a transient rise of temperature in a limited volume, the pressure also increases and this leads to a cylindrical shock wave propagating away from the ion's path [5]. A high pressure on the front and its rapid decrease in the wake of the wave result in formidable forces acting on a DNA molecule surrounded with liquid water. Further analysis using Molecular Dynamic simulations allowed us to calculate the energies deposited to covalent bonds of DNA molecules located near the ion's path [6]. This investigation leads to the assessment of DNA damage due to thermomechanical effects. In addition, the shock wave serves as an alternative to diffusion effective mechanism of transport of chemically active species such as free radicals away from the place of their formation in the vicinity of the ion's path. This changes the chemical environment of DNA molecules and may add to the damage effects.

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Online monitoring of the ion range during ion therapy by means of prompt secondary radiations

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The determination in real time of the Bragg peak position during high energy ion irradiation is a challenging objective for the Quality Assurance of ion therapy. Indeed, such a control could allow therapists to stop a treatment in case any deviation from the treatment plan is observed. Since primary particles (carbon ion or proton) are stopped inside the patient, information on the ion range has to be extracted from prompt secondary radiations produced by nuclear reactions.

- Prompt-gamma imaging: during an irradiation, photons in the range 1-10 MeV are emitted almost isotropically within much less than a picosecond after nuclear reactions. Therefore, a dedicated collimated detection setup may provide real-time information on the location of fragmentation. This can be done with a collimated gamma camera or a Compton camera, provided time of flight is used to discriminate between direct photons and background scattered particles like neutrons [1];

- In carbon therapy, secondary protons are – more surprisingly – also helpful for real-time determination of the ion range, even for deep-seated tumors where the residual range for protons to escape the patient in forward direction reaches 10 cm. A tracking system is used to image the interaction vertices that are shown to be correlated to the carbon range [2].

- Simulations are performed with Geant4 to reproduce both the dose profile (including the non-localized dose by secondaries) and the emission of secondaries. A proper tuning of the hadronic models was necessary to reproduce satisfactorily the secondaries yields in order to optimize the detection setup in view of quality assurance instrumentation.

We will present a review of the ongoing activities for prompt radiation imaging, in terms of detector developments and physical issues concerning the correlation between the physical dose and hadronic processes.

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Water versus DNA: A theoretical description of the ionizing processes induced by proton impact

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Ion-induced collisions on DNA bases have been up to now rarely investigated on the experimental as well as the theoretical side. Among the existing theoretical approaches, we find the semi-classical study proposed by Bacchus-Montabonel *et al.* on C^{q+} (q = 2-4) induced collisions with uracil [1] and our recent classical-trajectory Monte Carlo (CTMC) description of single electron loss processes (capture and ionization) induced by H^+, He^{2+} and C^{6+} ions on DNA bases. To the best of our knowledge, quantum descriptions of such collisional systems remain scarce and only represented by two series of works, namely, that given by Dal Cappello *et al.* [3] where differential and total ionization cross sections have been reported for protons impinging on cytosine molecules and our recent first Born and CDW-EIS approaches [4-5] in which differential and total cross sections for protons impinging on DNA/RNA bases were reported and compared to experimental data [6-7]. Similarly, we have proposed two theoretical models based on the continuum distorted wave approach for describing the electronic capture induced by heavy charged particles in water and DNA/RNA and provided total cross sections in good agreement with the experiment [8].

In the present work, we describe the different quantum-mechanical approximations also developed to model the ionization and the capture processes for DNA/RNA components, namely, the bases and the sugar-phosphate backbone as well as for water molecule impacted by heavy charged particles. Comparisons with the existing measurements in terms of differential (in angle and in energy) and total cross sections show that the theoretical approaches give a very good description of the studied ionizing processes.

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Innovative technology in flower breeding using heavy-ion beams

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Induced mutations are highly effective in enhancing genetic variation in plants and have been successfully applied to the development of improved are new cultivars. Heavy-ion beam irradiation, which has been developed in Japan, is one of the most remarkable mutation technologies. At RIKEN, we have developed a unique technology for mutation induction by using heavy-ion beams from particle accelerators at the RI Beam Factory. This development was achieved through an efficient synergistic link between agricultural science and accelerator physics. The use of ion beams for mutagenesis has a number of advantages: the approach has low exposure levels and high survival rates with high mutation rates, and it creates a wide variety of different mutations. Because heavy-ion beams provide a very high amount of energy, even a single ion is enough to significantly damage a gene. The technique is also very useful in producing mutants that lack just a single gene; multiple propagation technology can be used to convert these mutants into new cultivars. We have put 20 new cultivars in the market in Japan, USA, Canada and EU since 2001. Flower color, long blooming period and a large number of flowers are the important characteristics of floricultural crops. Examples of such breeds include new flower color of 'Surfinia Rose' (petunia), longer blooming period of 'Temari Bright Pink' (vervena), 'Temari Sakura Pink' and 'Temari Momo' (Fig.1). The development period for producing new varieties is only 2 years.

Figure 1. A flower bed in front of the RIKEN cafeteria. These flowers were created by ion-beam irradiation. "Temari Momo", "Temari Bright Pink", "Temari Sakura Pink", and "Safinia Rose Veind" from the center.

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A large scale mutant panel of wheat developed by heavy-ion beam mutagenesis and its application for genetic research

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Mutation analysis is a powerful tool for investigation of gene function. Heavy-ion beam mutagenesis has been recognized to be an effective method of producing mutations because of its high linear energy transfer (LET). High-LET radiation effectively induces DNA double-strand breaks than other mutagenic methods. We have been constructing a large scale mutant panel of diploid einkorn wheat (*Triticum monococcum*) using heavy-ion beam mutagenesis for 12 years. Seeds of the einkorn wheat strain KU104-1, KU104-2 or DV92 were treated with 50-58 Gy of N or C ion beam with LET of 30 keVμm^{-1}, and then sown in the field. The spikes of M_1 plants were bagged and the harvested selfed seeds of each spike were used to produce the M_2 lines. Every year, we obtained about 1,000 M_2 lines, eventually developing a mutant panel with a sum of 10,000 M_2 lines (Fig. 1). We are using this mutant panel for screening mutation of reproductive growth, especially for flowering-time mutants. We have identified several flowering-time mutants of great interest; non-flowering mutants (*mvp*: *maintained vegetative phase*) [1], late-flowering mutants, and early-flowering mutants. The *mvp* mutant is powerful tool for investigation of genetic mechanism of flowering in wheat [2].

Figure 1. Experimental field for screening of M_2 lines in Fukui Prefectural University.

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The study of Energy transfers towards radiation-induced defects in polymers submitted to ionizing radiation

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The radiation chemical yields of hydrogen, $G(H_2)$, in polyethylene irradiated under vacuum tend to decrease with increasing dose. This is a known, although partially studied, phenomenon. Theoretical studies [1,2], as well as recent experimental results [3,4] on the evolution of $G(H_2)$ with the irradiation dose, suggest that this yield decrease is linked to the modification of energy transfers in the polymer due to defects created at lower doses and acting as energy sinks.

For a thorough study of this phenomenon, the action of each type of defect, among the major defects created under ionizing radiation, should be specified. But this is made difficult by the variety of defects created and the simultaneity of their creation. To overcome this obstacle, we adopted an innovative strategy based on the insertion, in a regioselective manner, of a given defect type at a given concentration, in a polyethylene backbone. Due to the specifications on the sink concentration and the regioselective introduction sough, these polymers were tailor-made. We focused here on unsaturations of the *trans*-vinylene type which are, with crosslinking, major defects created in the PE backbone.

After optimization, we have managed to synthesize long-chain 1,4-*trans*-polybutadiene whose hydrogenation leads to the regioselective insertion of *trans*-vinylene unsaturations, at molar contents ranged from 0.001% up to 25%, in polyethylene. These PEs were irradiated with ^{20}Ne ion beam at very low doses for $G_0(H_2)$ measurements. Evolution of $G_0(H_2)$ as a function of the chemically inserted C=C concentration was compared to the evolution of $G(H_2)$ as a function of radiation-induced C=C concentration in pure PE. Elsewhere, the *trans*-vinylene protection radius and protection factor were determined.

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SH-O-10

Response of Nuclear Ceramics to Heavy Ion impact

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Nuclear materials whether used as reactor fuel, inert matrix for transmutation or as a waste form are subjected to radiation damage. The more severe damaging sources are the high energy (~ 50 to 100 MeV) fission products generated during fission of uranium or plutonium in fuels or from other actinides in transmutation targets (providing the neutron spectrum is appropriate), and also in waste conditioning matrices or nuclear waste glasses from spontaneous fission of minor actinides.

Swift heavy ion irradiations have been performed in UO_2 [1, 2], $MgAl_2O_4$ [3-5], CeO_2 [6], $Nd_2Zr_2O_4$ [7] to study their behavior in the high electronic stopping power regime. Some materials have also been exposed to spontaneous fission from ^{244}Cm used as self-damaging source [8]. Energy loss thresholds have been determined for the formation of visible ion-tracks in several materials (see for example Fig. 1). A thermal spike model [9] has been applied to calculate the temperature along the ions trajectory. The microstructure evolution of some materials during reactor irradiation e.g. UO_2 [2]or $MgAl_2O_4$ [10] has been correlated to the damage from a single fission spike.

Transmission Electron Microscopy results from ion-irradiated samples (single effect study) or from ^{244}Cm doped samples will be presented together with some thermal spike calculations as well as the ultimate evolution of nuclear materials after cumulating high fission dose.

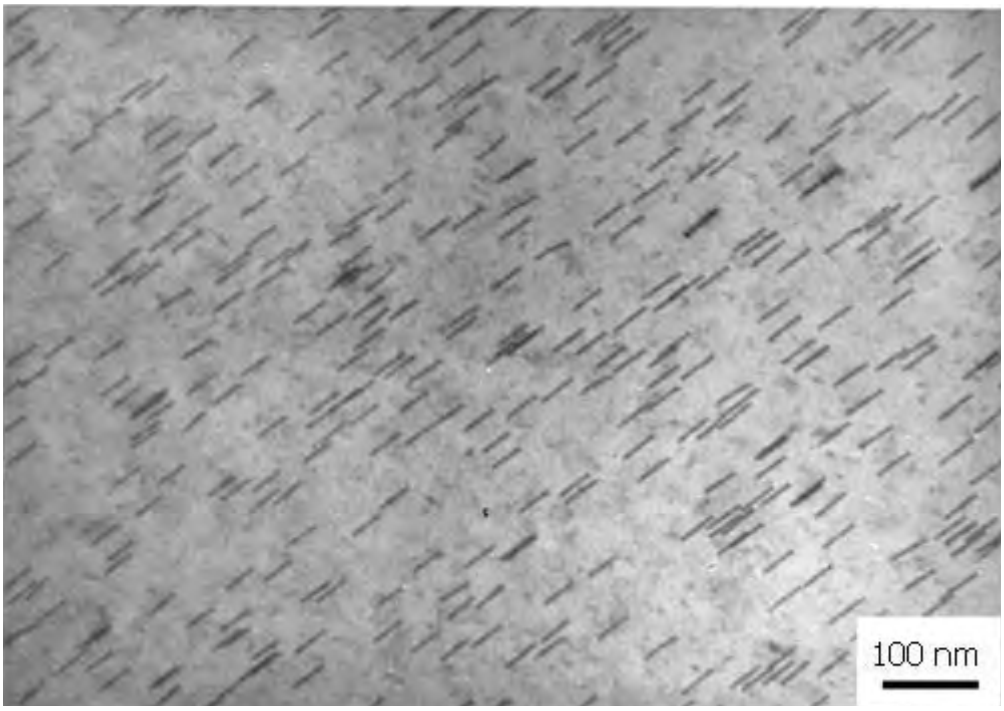

Figure 1: TEM bright field image showing 70 MeV Iodine ion-tracks in a <110> $MgAl_2O_4$ spinel single crystal.

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Thermoelectric and plasmonic nanowires fabricated by ion-track technology and electrodeposition

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We will present recent results on thermoelectric and plasmonic nanowires produced by electrodeposition in ion-track etched polymer templates.
Large efforts are being currently devoted to synthesize and design materials with higher thermoelectric efficiency, expressed via the figure of merit $ZT = S^2\sigma T/\kappa$, S being the Seebeck coefficient, and σ and κ the electrical and thermal conductivity, respectively. Nanomaterials are particularly interesting due to their reduced dimensions and controllable morphology. Finite- and quantum-size effects are expected to enable reductions in κ and increases in $S^2\sigma$ that are not possible in conventional bulk materials.
We show that Bi_2Te_3 and $Bi_{1-x}Sb_x$ nanowires with controlled composition between x = 0.05 and x = 0.40 are electrochemically synthesized in etched ion-track membranes over a wide range of diameters (20–100 nm) interesting for the investigation of the enhancement of thermoelectric efficiency via quantum size effects.[1,2] In the case of $Bi_{1-x}Sb_x$, the nanowire composition is controlled by the relative concentration of Bi and Sb ions in the electrolyte, together with the deposition potential. Two different templates were fabricated to enable the synthesis of thermoelectric nanowires with smooth and rough contour, which enables to influence the phonon scattering and thus the thermal conductivity of the nanowires.
In addition we will discuss the synthesis of AuAg nanowire dimers separated by nanogaps, which is undertaken in two-steps: (i) electrochemical deposition of segmented Au/Ag/Au nanowires from a single electrolyte containing $[Au(CN)_2]^-$ and $[Ag(CN)_2]^-$ ions, and (ii) etching of the silver segment.[3] We will discuss the localized surface plasmon resonances (LSPR) in these metallic nanostructures, which are relevant for applications such as surface-enhanced Raman spectroscopy (SERS), surface-enhanced infrared spectroscopy, and waveguiding below the diffraction limit of light.

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Non-Graphitizing Carbon Phase Induced by Swift Heavy Ion Irradiation of Graphite

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Information on radiation damage in graphite is mainly available from neutron irradiation in nuclear reactors. The present work assesses damage in the nuclear and electronic stopping regimes in graphite by means of Raman spectroscopy. Samples of HOPG (highly oriented pyrolitic graphite) and polycrystalline isotropic graphite (SGL-R 6650 grade) were irradiated at room temperature at the UNILAC accelerator at GSI using GeV heavy ions of ranges of a few tens of micrometers.. The depth evolution of the damage was monitored by performing micro-Raman spectroscopy with successive cleaving for HOPG. For polycrystalline graphite, a Raman depth profiling of damage was done on the cross-section of the sample starting from the surface down to the end of the irradiated layer. The Raman spectra within the irradiated graphite layer show that the graphitic structure evolves toward glassy carbon in the case of electronic stopping regime and towards nanocrystalline carbon in the elastic collisions regime. We have used two parameters deduced from Raman spectra to characterize the structure of the irradiated samples. One is the intensity of a broad peak at about 1460 cm-1, I_{am}, that can be fitted between the defect peak, D, and the graphitic peak, G. The other parameter takes into account the tortuosity of the basal planes. The intensity of the broad peak I_{am} in the Raman spectra scales with the electronic energy loss. Higher values at the surface of the sample indicate increased sensitivity of the surface to damage. The evolution of the second graphitic parameter shows a strong bending of the graphitic planes for the electronic stopping regime. The formation of a glassy carbon structure on the surface of the irradiated graphite is confirmed by the presence of the characteristic broad peak in the X-ray diffraction pattern and the strong hardening of the irradiated layer.

Detecting swift heavy ion modification with graphene

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It is very well known that swift heavy ion irradiation causes structural modification in many insulating materials [1]. These modifications can be brought to the surface by irradiating the material under glancing incidence conditions which results in a track of hillocks that has been termed “surface track” [2]. However, some insulators such as sodium chloride (NaCl) or silicon carbide (SiC) do not show protrusions. Instead, either no modification at all (NaCl) or trenches (SiC) are observed. In the first case, the modification may be only of transient nature, in the second case the material is obviously ejected from the track. The question arises, whether these effects can be investigated in more detail if the ejected particles or the transient modification could be somehow trapped. Here, we show that graphene, an atomically thin layer of carbon atoms, can indeed be used to trap the emitted material which renders further analysis possible.

For this, we have exfoliated graphene conditions on 6H-SiC samples under ambient conditions. The sample was heated under ultra high vacuum conditions to remove the intercalated water film between graphene and SiC. The irradiation took place at the IRRSUD beamline of the GANIL with a kinetic energy of about 100 MeV at a glancing incidence angle of about 1.5°. We show that the removal of the water film is crucial for this experiment because without it, the irradiation causes graphene to tear [3] and no surface tracks can be observed. A similar effect is observed on graphene on NaCl.

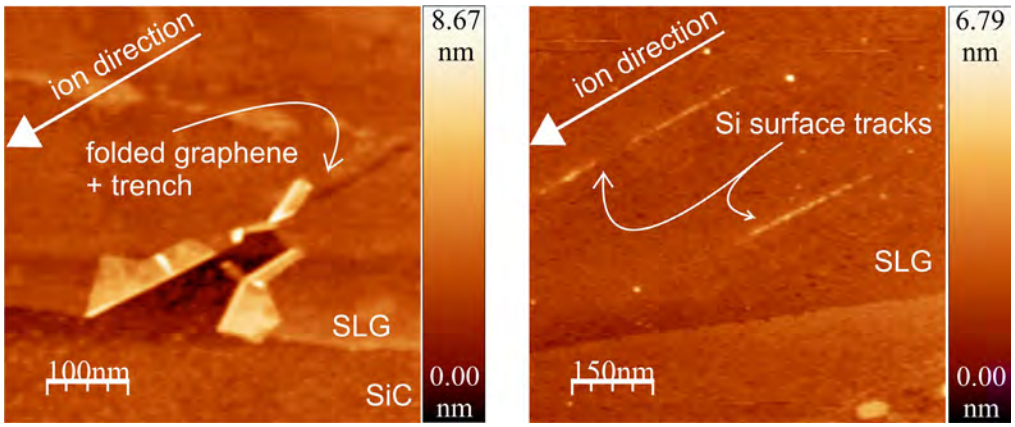

Fig. 1 – left: AFM image (non-contact) of SiC irradiated under a glancing angle of ~ 1.5°. White arrow indicates the direction of the incoming ion beam. A trench in the SiC substrate can be observed as well as the ion induced folded single layer graphene (SLG). Right: SLG flakes that are free of water do not fold and show surface tracks consisting of silicon (Si).

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Nanoscale Manipulation of the Properties of Solids at High Pressures and Irradiated by Swift Heavy Ions

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Relativistic heavy ions provide a unique opportunity to access a physical regime quite far from the conditions of thermodynamic equilibrium [1]. These projectiles deposit exceptional amounts of kinetic energy (GeV) within an exceedingly short interaction time (less than fs) into nanometer-sized volumes of the material, resulting in extremely high energy densities (up to tens of eV/atom). In this presentation, I will describe a new strategy of combining high-energy ion beams with high-pressure techniques by injecting relativistic ions from one of the world's largest accelerator facilities (GSI – Helmholtz Center for Heavy Ion Research – Darmstadt, Germany) through a mm-thick diamond anvil of a high-pressure cell into a target under pressure [2]. This experimental approach allows for the investigation of the behavior of materials at extreme conditions and opens up unprecedented possibilities for the synthesis of new materials.

We have investigated a number of different oxide compositions and structures at high pressures during irradiation experiments. Radiation-induced energy deposition into highly compressed materials (several tens of GPa) can dramatically modify phase-transformation pathways. The combined use of advanced *in situ* (synchrotron X-ray diffraction and Raman spectroscopy) and *ex situ* (transmission electron microscopy) characterization techniques in experiments up to 65 GPa have revealed: (*i*) the stabilization of a new metastable high-pressure phase of gadolinium-zirconate pyrochlore ($Gd_2Zr_2O_7$) [2] and (*ii*) the transformation into high-pressure and high-temperature phases of ceria (CeO_2) and zirconia (ZrO_2) at unexpectedly low pressures and/or radiation fluences [3].

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Annealing of radiation damage in graphite during swift heavy ion irradiation at high temperature

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For studying the feasibility of using graphite as a high-power target material for secondary nuclear beam production for the Facility for Rare Isotope Beams FRIB (USA) and the Facility for Antiproton and Ion Research FAIR (Germany) polycrystalline graphite thin foils were irradiated at GSI with a 8.6MeV/u 197Au beam with external electric ohmic heating up to 1600°C. The graphite radiation damage was monitored by in-situ electrical resistance measurements during and after irradiation until its stabilization and cooling to room temperature. The change of electrical resistance provided an assessment of electrical resistivity change and of the accumulation and recovery of irradiation-produced defects in graphite as a function of ion fluence and irradiation temperature. The results show that the saturation of defects occurs faster at low irradiation temperatures due to a less efficient recombination of the irradiation produced defects. The visual inspection of the irradiated graphite foils showed that the higher the irradiation temperature is, the less the observed swelling and dimensional change in the irradiated region. At irradiation temperatures higher than 1200°C no visible foil deformation was observed after irradiation. The annealing of radiation damage at high irradiation temperatures was also confirmed by measuring the crystallographic structure by small-angle X-ray diffraction and other mechanical properties at room temperature. All these measurements showed a nearly complete recovering of the pristine graphite properties at high irradiation temperatures.

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Heavy Ion Beam Factory for Material Science based on the KEK Digital Accelerator

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The KEK digital accelerator (DA) is an alternative of conventional cyclotron or synchrotron, which are much popular as swift heavy ion beam drivers. The KEK-DA has a capability of delivering a wider variety of ion species with various energy that results from an intrisic nature of this noble accelrator. It is going to serve as a heavy ion beam factory to material science society.

The DA, which is a small-scale induction synchrotron [1] requiring no high-energy injector accelerator and capable of providing ions from hydrogen ion to gold ion, has been constructed at KEK [2]. Since the last year beam commissioning has been carried out. The KEK-DA consists of a 200 kV high voltage terminal, in which a permanent magnet x-band ECRIS is embedded, 15 m long LEBT, electro-static injection kicker, and a 10 Hz rapid cycle synchrotron equipped with the induction acceleration system. An ion pulse chopped in 5 micro-sec by the newly developed Marx generator driven Einzel lens chopper [3] was guided through the LEBT and injected by the electrostatic kicker in one turn. The 3 micro-sec ion pulse was successfully captured with a pair of barrier voltage-pulses of 2 kV and accelerated up to 12-30 MeV with another flat induction-acceleration voltage-pulse through a full acceleration period of 50 msec. Beam commissioning has been started with a He1+ ion beam of 100 μA. Details of fully digital-controlled barrier bucket trapping and induction acceleration are described, although the acceleration/extraction is still at a preliminary stage. The irradiation beam-line has been completed and set-up for the irradiation is under way.

Unique application programs, such as laboratory space science using virtual cosmic rays [4], heavy ion mutation of microorganisms [5], deep ion implantation, modification of materials [6], that may be categorized in systematic studies of a spacial and temporal evolution of the locally and highly excited state of materials [7], are planned.

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Acoustic Wave Excited in Materials by Swift Heavy Ion Irradiation

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High energy density in matter is of fundamental interest for various fields of science, including plasma physics, astrophysics and applications. Intense heavy ion beams could produce high energy density in matter that resulting high pressure to generate acoustic waves and some of them can be detected with sensors [1]. The main subject of the present work is an experimental study of acoustic waves generated by heavy ions in materials.

The experiments were performed at the main electron-cooler storage ring of the Heavy Ion Research Facility in Lanzhou (HIRFL-CSRm). In experiments (Al or water) targets were bombarded using pulsed high energy carbon beams. The bunch width of the beam is 500 ns and the energy of the beam ranged from 650 MeV to 1.4 GeV for solid targets and 1.6 GeV to 2.19 GeV for water. Two acoustic emission sensors were used to detect the acoustic signals and the relative position of the sensors could be altered. For the solid targets, one sensor was fixed on the side of the sample, and the other was fixed on the back of the sample; for water, the sensors were directly soaked in water.

The waveforms of acoustic signals were analyzed and the results show that on the Al sample, for the sensors on both the back and side of sample, the amplitudes increased with the increase of the energy. However, in water, no regular results could be found.

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On-line Mössbauer Study of ^{57}Mn/^{57}Fe in Si Materials After Nuclear Projectile Fragmentation and Implantation at RIBF

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A set-up for on-line Mössbauer spectroscopy has been developed and applied for the studies of iron impurities in silicon materials at RIKEN-RIBF [1-4]. We implant GeV-nuclear probes of ^{57}Mn/^{57}Fe into silicon material immediately after a nuclear projectile fragmentation. Electron-hole pairs will be created along the nuclear track, and subsequently, the probe will come to rest on different lattice sites at the end of the track. We study the carrier trapping process on the ^{57}Fe probes in a p-type Si wafer and in a pn-junction, i.e., a solar cell. ^{57}Fe probes form deep levels in Si band gap, so that the excess carriers will be effectively trapped. Immediately after each implantation, it is, therefore, possible to observe directly the charge states of ^{57}Fe probes in terms of the isomer shifts of the Mössbauer spectral components.

^{57}Mn nuclei were produced by the nuclear projectile fragmentation of a $^{58}Fe^{21+}$ primary beam (E = 63 MeV/nucleon) with a Be target, and subsequently separated by an on-line isotope separator, RIPS. Mössbauer spectra of ^{57}Mn/^{57}Fe in different Si wafers and Si-solar cells were measured between 300 and 1200 K immediately after the implantation of the radioactive isotope of ^{57}Mn ($\tau_{1/2}$=1.45m). The implantation was performed through an aluminum foil with a thickness of 200 μm, so that the ^{57}Mn probes can be stopped at around 100 to 200 μm from the surface of samples. The total fluence of ^{57}Mn was 2×10^{12} ^{57}Mn/cm^2 typically for one spectrum. Immediately after the GeV-implantation of ^{57}Mn nuclei ^{57}Mn/^{57}Fe Mössbauer spectra in Si-solar cells are measured with/without light illumination. Comparing the spectrum of p-type multi-crystalline-Si with that of Si solar cell, the broad spectra of the solar cell can be analyzed as a superposition of interstitial and substitutional Fe components with different charge states. The charge states of Fe impurities are created by the directional carrier flow in the p-n junction. The present results provide us a possibility to clarify the carrier trapping process at the Fe impurities in Si-solar cells.

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TUESDAY POSTER PRESENTATIONS

ICACS-25

Experimental determinations of the energy straggling of slow ions in thin foils: the effects of foil roughness and projectile slowing down.

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Different theoretical models on the energy loss of ions in solids predict that the energy loss straggling Ω in metallic targets should be proportional to the ion velocity v in the limit $v<<v_F$, where v_F is the Fermi velocity of the target electrons. This is a common prediction of linear [1,2] and non-linear [3] theories (such as Lindhard´s dielectric model in the first case or the Density Functional Theory (DFT) in the second). Previous comparisons of the theoretical DFT predictions with experimental values [4] showed a fair general agreement. However, in a recent publication [5] an apparent deviation from the predictions of the theoretical models was reported.

The problem of determining the so-called intrinsic straggling from experiments in the low energy range is a complex problem, due to the combined effects of slowing down in a thin foil and roughness effects at the incident and emerging surfaces. The total straggling that can be measured after ion-beam transmission through a thin foil is a convolution of the intrinsic straggling (arising from the statistical nature of the energy loss phenomenon) and the surface roughness straggling which depends on the stopping power.

We report here the results of experimental and theoretical analysis of this problem. The theoretical analysis includes a study of the influence of foil roughness and energy decrease in a thin foil. The experimental analysis includes determinations of the energy loss straggling of proton beams in thin self-supported foils of C, Si, Ag, Cu, Au and Bi. We show that a quantitative analysis requires a careful evaluation of the intrinsic straggling and foil roughness, as well as consideration of the decrease of ion energy within the foil. We show that failure to consider all these effects in a precise way may lead to erroneous values of the intrinsic straggling.

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Computer-simulation study of the angular dependence of the energy loss of light ions in solids

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The interaction of ions with solids in the range of low energies is a subject of great current interest in relation with theoretical studies and experimental determinations of the energy loss and straggling coefficients for different ions and materials. Several recent publications have reported interesting effects that become particularly relevant at low energies, such as band structure effects (threshold effects), isotopic effects in the angular dependence of the energy loss, and non-linear effects in the screening and transport coefficients of ions in solids.

In this work we perform a computer simulation study of the energy loss of ions in solids and compare the results with experiments. The simulation code is based on the Monte Carlo method to represent the probability of ion collisions and deflections within the solid as well as fluctuations in the inelastic energy loss. The electronic energy loss is represented using the results of the density functional theory [1] as well as our own non-linear model, which includes band structure effects [2-4]. To represent realistic targets we also include in the simulations the effects of foil roughness. Using this approach we analyze the angular dependence of the energy loss and the associated energy straggling of protons, deuterons and helium ions transmitted through thin foils of different elements. Using different simulation options we are able to assess the contributions of elastic energy losses, path-length enlargement, foil roughness, and isotopic differences between protons and deuterons, as a function of the emergence angle. The results of these simulations are compared with those obtained from the SRIM code and with various experimental results.

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Evolution of Nanostructures in a Graded Multi-trilayer System upon Ion Irradiation

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Periodic multilayers are used as efficient reflectors of extreme ultraviolet radiation to hard x-rays. They are also used in x-ray telescopes for applications in x-ray astronomy. More recently graded (depth-graded, laterally-graded, and double graded) multilayers have found increasing applications [1]. Double-graded multilayers are used for broad band focusing. Stability of multilayers against heating and charged particle irradiation is an important aspect. Pt/C multilayers have been used for making x-ray telescopes. However, for detection of x-rays above 80 keV there is strong absorption of x-rays in the Pt layers (Pt K-absorption edge is at ~ 79 keV). Suitable alternatives, such as Ni/C or Pt/Ni/C multilayers are being explored. We have earlier investigated ion irradiation effects in Pt/C multilayers [2-4]. In these multilayers individual layer thickness is about a couple of nanometers. Ion irradiation was found to form nanoparticles with pseudo-ordering at new length scales. Here we present ion irradiation effects in a double-graded Pt/Ni/C multi-trilayer system with 15 tri-layers or repeat units with a total thickness of ~ 100 nm, grown on a float glass substrate by ion-beam sputtering technique. Irradiation was carried out with 2 MeV Au ions at five different fluences between $1x10^{14}$ and $2x10^{15}$ ions/cm^2. The samples were investigated by x-ray reflectivity (XRR), x-ray standing wave (XSW) and cross sectional transmission electron microscopy (XTEM) measurements. A 4-10% expansion of the multilayer thickness along with an increase of interface roughness has been observed. At the highest fluence complete mixing between Pt and Ni layers and nanoscale grain growth of Pt-Ni alloys have been observed. Additionally Pt-Ni alloy nanoclusters encapsulated within the C layers have been found. The results are understood in the light of positive heat of mixing between Pt and C, and Ni and C, and negative heat of mixing between Pt and Ni. The effect of heat of mixing is dominant at high fluences in irradiation

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Hydrogen negative ion formation on a graphite HOPG surface.

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In past years scattering of hydrogen ions on graphite surfaces has attracted considerable attention in relation with the development of plasma confinement devices, negative ion sources, the understanding of plasma/wall interactions and divertor physics [1-6]. Some experiments have shown that in scattering of atomic and molecular hydrogen ions on polycrystalline graphite and diamond surfaces at low energies (below a few keV) high negative ion fractions of have been observed. Because of the high workfunctions of these surfaces the observation of high negative ion yields were surprising. Some discrepancies amongst different experiments were noted. We therefore performed and report here a study of hydrogen negative ion formation on highly oriented pyrolitic graphite (HOPG), for grazing scattering conditions previously used for various metallic and dielectric surfaces [7-9]. Inspite of the large workfunction of the surface the negative ion fractions were found to be quite large: significantly larger than for metal surfaces such as Mg or Al. The dependence of the anion fraction on the exit angle with respect to the surface resembles that of metals as predicted by recent calculations of Goldberg et al [5,6]. However the magnitude is much larger.

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Secondary Electron Emission from a Thin Carbon Foil by H^+, He^{2+} and Li^{3+} of 1 MeV/u

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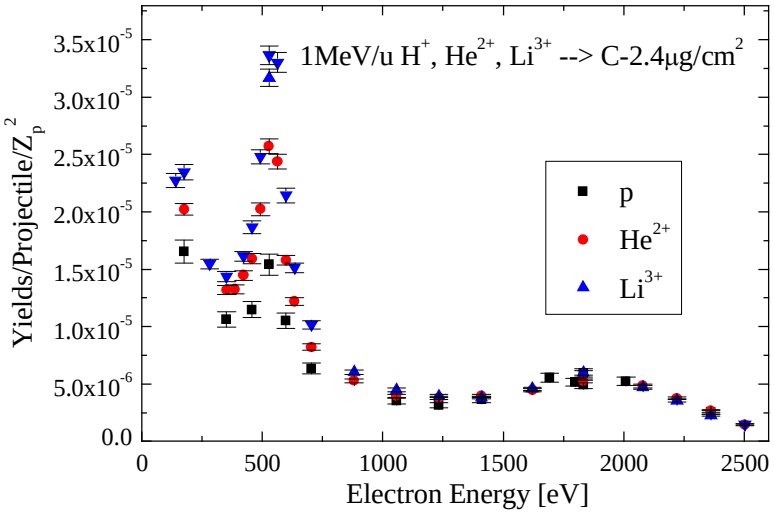
The statistical distributions of the number of simultaneously emitted secondary electrons (SEs) from a thin carbon foil have been measured with H^+, $^4He^{2+}$, and $^6Li^{3+}$ ions of 1 MeV/u. In this experiment, the forward- and backward-emitted SE's have been measured simultaneously in coincidence with foil-transmitted ions in order to investigate their correlation. As a result, it is found that the forward- or backward-emitted SE yields, that is, the mean numbers of the forward- or backward-emitted electrons per projectile decreases gradually with increasing the number of SEs in the opposite direction irrespective of projectile species. This trend is quite understandable assuming that the amount of the internal secondary electrons produced by the projectiles can be scaled with the square of the projectile atomic number, Z_p, over the entire electron velocity. On the other hand, the inclusive SE yields divided by Z_p^2 become smaller with increasing Z_p both in the forward and backward directions. To look into further details, we have measured the energy spectra of the emitted electrons from a carbon foil of a similar thickness to that employed in the number distribution measurement. Figure 1 shows the result. As is clear from the figure, the Z_p^2-scaling holds at the energy region of the binary electron. The observed reduction of SE yields from the Z_p^2-scaling seems to be due to the collective electric field along the projectiles path[1-3].



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Translational Energy induced Oxidation of Ni(111) Surface at Room Temperature by Supersonic O_2 Molecular Beam

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Although the Ni(111) surface reacts with O_2 molecules to form a thin oxide layer on the surface at 147 K showing a Langmuir-type oxygen uptake curve, a plateau appears in an intermediate region of the oxygen uptake curve at higher temperatures [1]. This behaviour was explained by a two-dimensional (2D) oxide island growth model [2, 3]. Generally speaking, the surface chemical reaction rate of incident molecules depends also on their translational kinetic energy. Indeed, the oxygen uptake curve for the Ni(111) oxidation by an O_2 beam with a hyperthermal energy of 0.6 eV at 300 K indicated a kinetics change from the 2D model to the Langmuir type [4]. Translational energy effects have been also shown for the initial sticking coefficients [5].

The incident energy of O_2 molecules was increased up to 2.3 eV by using our supersonic molecular beam (SSMB) technique. Using this technique, the effects of O_2 incident energy have been widely studied by soft x-ray photoemission spectroscopic surface analysis with high brilliance and high energy-resolution synchrotron radiation. Both an O_2 SSMB and the monochromatic synchrotron radiation were irradiated on a sample surface simultaneously. Real-time in-situ photoemission spectroscopy of chemical bonding states for the oxidized surface was conducted during SSMB irradiation.

Oxygen uptake on the surface has been observed at various O_2 incident energies higher than those of previous reports. The first plateau, which appears at an intermediate region of the oxygen uptake curve, was found to disappear with increasing O_2 incident energy. Furthermore, an oxygen content at saturation of 5.5 ML was observed for an incident energy of 2.3 eV. This is 1.8 times larger than that observed at a low energy region of 0.06 eV to 0.6 eV (3 ML). These observations can be attributed to the influence of activated adsorption mechanisms. The initial sticking rate continued to increase as incident energy increased up to 1.0 eV, and a remarkable re-increase was observed in the region around 2.3 eV. The first increase is due to the activated dissociative adsorption of O_2 molecules through a potential energy barrier of 1.0-eV height, and the second increase around 2.3 eV implies that another potential energy barrier exists with a height larger than 2.3 eV. Higher O_2 incident energy leads to higher formation rates and higher contents at saturation for the NiO component.

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The Positron Spur, Diffusion, and the Effective Interaction in the Liquid Phase

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Since fluctuation from the equilibrium medium is preferable in liquid phase, localization of charged particles like positrons is highly induced. Free energy density functional theories provide self-trapping as a solution of the charged particle in a given host liquid. Gramsch et al.[1,2] have observed very different behavior of the diffusion length L_+ of positrons in liquid and solid metals by means of a slow positron beam. That is, on melting L_+ decreases remarkably, and the liquid phase L_+ increases with temperature. Kanazawa and coworkers [3-6] proposed a qualitative explanation for the increase of the positron diffusion length with temperature in the liquid phase, by using the theoretical formula, which is based on the gauge-invariant effective Lagrangian with spontaneously broken density (the hedgehog-like fluctuation) and the massive internal gauge fields. In this study, extending the theoretical formula [3-6], we shall discuss the positron energy loss mechanism and the effective interactions in the liquid phase.

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Materials modifications using MeV ion beams obtained from small/medium sized accelerator facilities

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Materials modifications using swift heavy ion beams provided by large scale accelerators have been used for many years in a wide variety of ways, e.g. to produce ion tracks or to modify shape of nanoparticles. In all this applications the most relevant parameter for materials modification is electronic stopping power and not the ion total kinetic energy. For many materials, ions delivered from the medium and small size accelerators have sufficiently high values of electronic stopping power to modify materials in different ways. In the present contribution, we review recent experimental and theoretical achievements of the Zagreb group in this field. These include swift heavy ion tracks in $SrTiO_3$ [1], [2], development of single ion irradiation setup [3] and ion beam assisted formation of ordered QD arrays [4]. In all cases, ion beams delivered from the 6 MV Tandem Van de Graaff accelerator based at RBI, Zagreb have been used. Together with experimental work, we present thermal spike model, which was applied to describe obtained features. Recent description of highly charged ion tracks using an extension of the thermal spike model is also presented [5].

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Electronic stopping of slow light ions: Some experimental aspects

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Many experiments have shown that in contrast to common expectation, electronic stopping of slow light ions, S_e, may depend on the ion velocity in a quite complex way, due to band structure effects [1, 2]. There are various possibilities to determine S_e, but in any case it is a demanding task to measure S_e for ion energies below 1 keV. Let us consider this situation in detail. Obviously, any direct measurement of Se has to determine two types of information, typically sample thickness and energy loss of the ions.

In a transmission experiment a thin self-supporting foil is required; in backscattering a thin supported film may be used. In both cases, the request of the energy loss ΔE to be small compared to the ion energy, E, leads to a very low thickness of 10 nm or even less. Thus, quantitative thickness determination is demanding, with RBS being one of the most promising techniques, at a level of accuracy of better 5 %. What is also common to both experimental approaches is that due to the large scattering cross section at low ion energies the assumption of a straight trajectory is not justified anymore. Consequently, influences of multiple scattering and atomic collisions have to be taken into account when deducing Se from the measured energy loss. This requires non-trivial treatment, since not all impact parameters will contribute to the atomic collisions. In addition, surface contaminations may represent a major source of systematic error in a transmission experiment, as pointed out by Mertens, since surface impurities contribute to the energy loss of the ions [3]. In backscattering, surface impurities hardly lead to a systematic error [4]. Finally, also thickness inhomogeneity would lead to erroneous energy loss data, since thinner parts of a foil will lead to a narrower angular distribution than the thicker ones [5].

In backscattering, the use of thin layers can be avoided, by comparing the height of backscattering spectrum of the sample of interest to that of a material of known stopping. When the spectrum height ratio is also determined in a Monte-Carlo simulation which allows for multiple scattering and electronic energy loss, S_e for the material of interest may be deduced from the known S_e of the reference material. In this way, all possible systematic errors may be eliminated, the main source of uncertainty being the amount of primary ion charge impinging on the samples, which may introduce a possible error of 5 %. Thus, overall accuracy for S_e better 10% should be achievable even in this regime.

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The effect of conductivity on ion guiding through insulating capillaries

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First experiments on guiding of highly charged ions through straight insulator nano-capillaries showed a remarkable effect: after an initial charge up phase, the ion beam could be steered by tilting the capillary axis while remaining in the initial charge state indicating that the transmitted ions never touched the inner walls [1]. Subsequent experiments confirmed this guiding effect also for macroscopic glass capillaries, both straight [2, 3] and tapered ones [4]. Microscopic simulations revealed that a self-organized charge up of the capillary walls due to preceding HCI impacts leads to an electric guiding field, which steers the incoming projectile ions along the capillary axes [5]. Ion guiding ensues as soon as a dynamical equilibrium of charge-up by the ion beam and charge relaxation by bulk or surface conductivity is established. In this contribution we show that a key control parameter for guiding is the small residual electric conductivity of the highly insulating capillary material whose dependence of temperature $\sigma(T)$ is nearly exponential. We use a single straight macroscopic glass capillary (inner diameter: 160 μm; length: 11.4 mm) made of Borosilicate (Duran) for which the guiding effect has been previously established [2]. The current experimental set-up allows for a controlled and uniform temperature variation of the glass capillary between -30°C and +90°C [6]. Within such a moderate variation of the temperature the conductivity changes by almost five orders of magnitude. Our experiments [7] show that increasing the temperature of a glass capillary and therefore its conductivity leads to a reduction of guiding and, eventually, to a complete disappearance of the guiding effect. This strong temperature dependence can be employed to stabilize guiding against Coulomb blocking due to a high incident ion flux [8].

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Detection of Cu Vacancies During the Phase Transition of the 0.5 ML Sn/Cu(001) Surface Alloy by Direct Recoil Spectroscopy

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Atoms deposited on metal surfaces may form islands siting above the top substrate layer or they may substitute some atoms to form a surface alloy. Formation of a surface alloy implies the movement of many atoms, often leading to surface reconstruction and or vacancy creation. Direct detection of vacancies is important to understand the surface behavior but usually it represents a difficult task for most surface techniques. This is not the case in ion scattering at surfaces since a missing atom implies an extension of the interatomic distances and therefore a reduction in either the shadowing or the blocking critical angle, so by tuning the azimuthal and incidence angles appropriately one can obtain a backscattering signal or a recoiling signal that appears only if a vacancy has been created (Figure 1). In this work we use these effects to characterize the line of vacancies formed by the adsorption of Sn on the Cu(100) surface. In addition, we follow the evolution of these vacancies during the reversible crystallographic phase transition of the 0.5 ML Sn/Cu(100) taking place around 360 K ($(3\sqrt{2}x\sqrt{2})R45° \rightarrow (\sqrt{2}x\sqrt{2})R45°$). Combining this technique with MC simulations, we conclude that the high-temperature phase is disordered. The phase transition can therefore be characterized as an order-disorder transition driven by the Cu vacancies entropy.

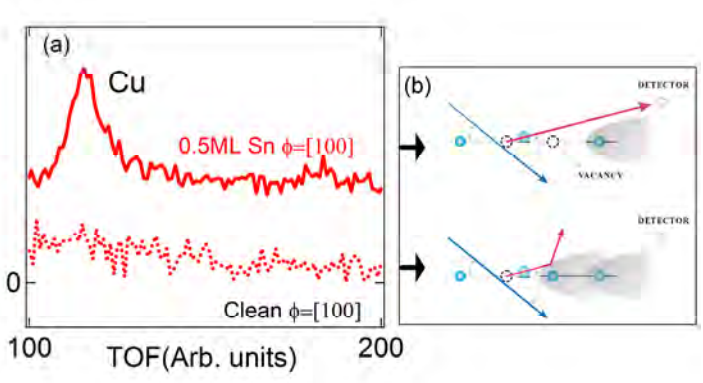

Figure 1 (a)TOF spectra for the clean surface and for Sn/Cu. The appearance of the Cu direct recoil peak is related to the formation of a vacancy line upon adsorption of Sn. (b) Schematics of the blocking effect.

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Monitor for Detection and Analysis of Electrons and Ions in Geostationary Orbit Satellites

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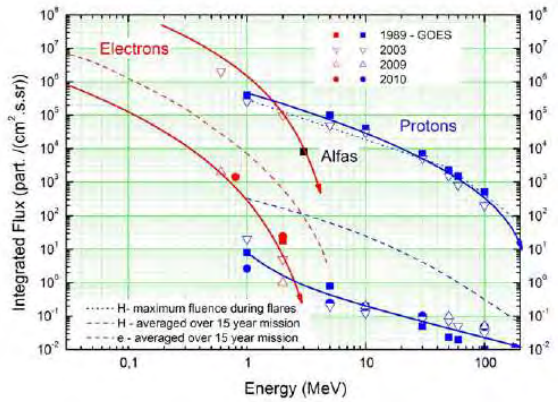
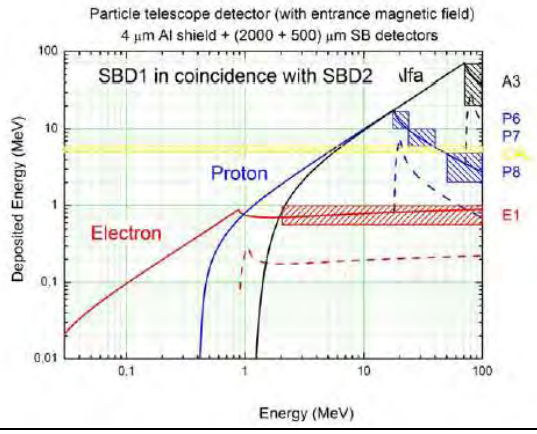
Commercial satellites in geostationary orbits are exposed to a strong environment (mainly electrons and protons) that generates a degradation of the satellite surfaces, materials, and electronic components, thus limiting the life of the satellite. In this context, monitoring the space weather to provide signals of warnings and to characterize the spectrum of both electrons and ions becomes a critical issue for the satellite itself, and can also be used to study the solar activity, particularly during solar flares. The requirements for such a monitor include 1) more than ten orders of magnitude in the variation of the fluence, 2) more than 5 orders of magnitude in the energy range of the particles to be detected, 3) expected life of more than 15 years unattended. In this report we present a design and preliminary tests of a simple instrument for monitoring the electrons and ions hitting the surface of an Argentinean commercial GEO satellite. First we present estimations of the space weather to be encountered by the monitor and of the expected effects (deep and surface charging, SEUs,) on its components. The detector design based on a combination of collimators, filters and surface barrier detectors is then discussed. Calculations of stopping and ion ranges in solids are used to choose the best materials for shielding the detectors according to the energy thresholds of operation. Some considerations about the analog and digital electronics, and about the thermal behavior of the detectors are finally provided.



Expected space environment during low and high solar activity.



Example of the estimation of the energy deposition of the particles on two surface barrier detectors after transmission through the entrance foil.

Reactive MD Study of Hyperthermal Si-Oxidation Mechanisms in Ultrathin *a*-SiO_2 Films

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Recently, interest in hyperthermal oxidation of the Si-surface as an alternative to thermal oxidation has been rapidly increasing, especially for semiconductor applications and spacecraft investigations, especially since hyperthermal oxidation can be carried out at room temperature [1]. Although numerous studies have elucidated the overall oxidation behavior, various aspects are still poorly understood [e.g., 2, 3]. There are still open questions regarding the growth mechanism in hyperthermal oxidation. This contribution therefore focuses on the study of the oxidation of ultrathin amorphous silica (*a*-SiO_2) surfaces by both atomic and molecular oxygen with initial energies of 1 eV and 5 eV. These atomic-scale investigations were carried out using reactive molecular dynamics simulations employing the ReaxFF potential.

Hyperthermal oxygen adsorption on and penetration depth in an *a*-SiO_2 film with an initial oxide thickness of about 10 Å is analyzed and compared with impacts on a pure Si(100){2x1} (*c*-Si) surface at room temperature. Our results demonstrate that the oxygen mostly resides in the silica region rather than in the *a*-SiO_2|*c*-Si interface at low temperature. However, at higher temperatures, starting at about 700 K [4], oxygen atoms can diffuse through the oxide layer and react with the *c*-Si region. The new oxide layer formation by diffusing oxygen atoms at high temperature is discussed as well. The oxidation mechanism is similar to the oxide formation mechanism in the thermal oxidation case, which can be explained by well-known Deal-Grove mechanism [5].

This study is useful for the fabrication of silica-based devices in the micro and nanoelectronics industry, and more specifically for the fabrication of metal-oxide-semiconductor devices.

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Characterisation of nanostructures induced by slow highly charged ion bombardment of HOPG

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Earlier studies, which have identified highly charged ion - induced defects on HOPG surfaces as regions of enhanced friction [1] have been extended by measuring the microscopic friction coefficient at the impact sites and the surrounding matrix by means of lateral force microsopy. Additional investigations have been performed on samples irradiated with ions in very high charge states (Xe^{40+} and Bi^{62+}), and, for the first time, defects have also been found employing the intermittent contact AFM mode (Figure 1), where friction forces are basically eliminated from the measuring process (no pseudo-topographic contributions arising from friction). This is a strong indication that there is indeed a true topographic modification (as found for other target surfaces; see [2] and refs therein) if the impinging ions exceed a certain potential energy threshold. Furthermore, defects have been imaged in the conductive AFM mode, where strong local changes (imaging at atomic resolution) in the conductivity are apparent.

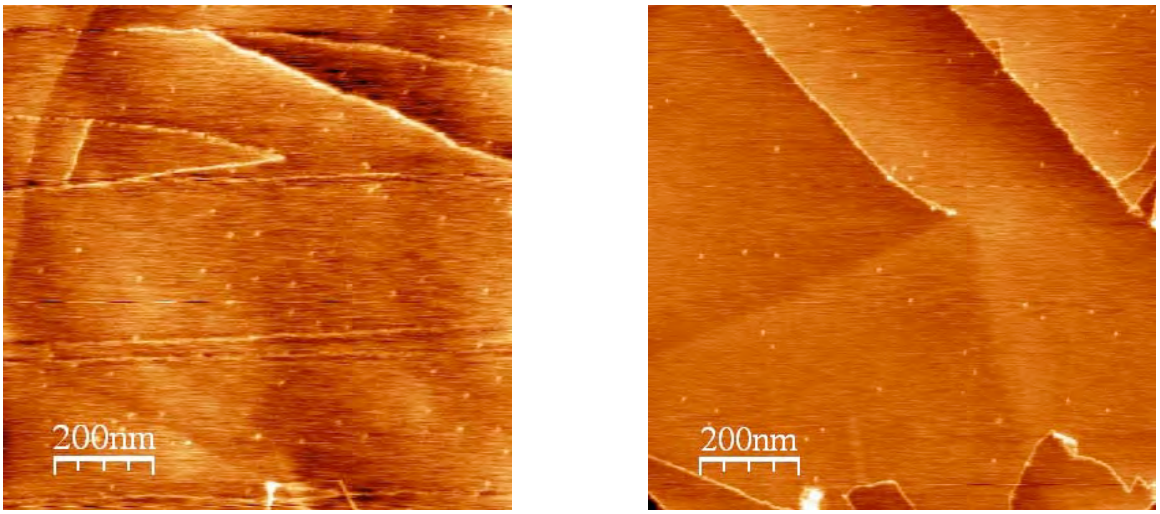

Figure 1: Intermittent contact mode AFM images showing defects induced by Xe^{40+} (E_{kin} = 40 keV) ions (left) and Bi^{62+} (E_{kin} = 37 keV) ions (right) on HOPG.

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Energy Loss and Electron transfer processes in fluorine scattering on oxygen covered Ag (110) – crystal azimuthal dependence

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We present measurements of energy-losses and electron transfer processes in fluorine ions and atoms scattering on clean and oxygen covered Ag(110) surface. In this system chemisorption of oxygen results in an added row (nx1) reconstruction and in an increase of surface work function. Our oxygen covered Ag(110) measurements correspond to various added row reconstructions (e.g. 8x1, 4x1 and ultimately 2x1). Measurements were performed for 1 to 4 keV ion energies under surface channelling conditions for different surface azimuths. Energy losses for the clean and oxygen covered surface are measured for various azimuthal orientations and are observed to change strongly after oxygen adsorption. In general, adsorption of oxygen results in a fairly strong decrease in the negative ion fraction. Some variations on crystal azimuth were observed. The decrease in F^- production can be associated with changes in electronic structure as a function of oxygen coverage and trajectory dependent changes. Energy loss results are discussed in the light of trajectory calculations of ions scattered under grazing incidence conditions on the surface. Using non-linear models for stopping power, *ab initio* crystal structure calculations of the electronic density and semi-classical simulations [1, 2], we obtain data that is in good agreement with experimental results. These simulations in particular allow us to properly take into account the variations of the surface electronic density and hence obtain an accurate description of the energy loss processes for ion scattering along various azimuthal orientations of the target. We are thus able to describe the multi peaked structures observed in the energy losses for certain azimuthal orientations and assign them to specific types of trajectories.

* The authors regret the untimely death of Ana Rita Canario-Bettencourt.

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Surface Nanostructuring of $LiNbO_3$ by High-Density Electronic Excitations

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Lithium niobate ($LiNbO_3$) single crystals were irradiated with high energy gold ions (0.5-2.2 GeV) at the UNILAC (GSI) and with 150-keV highly charged Xenon ions from an EBIT (Electron Beam Ion Trap, HZDR). The surfaces of the irradiated crystals were analyzed by scanning force microscopy showing very similar topographic changes. Swift heavy ions and slow highly charged ions produce hillock-like surface nanostructures on this surface. In both cases, the energy deposition of the ions is characterized by dense localized electronic excitations and efficient transfer to the lattice. Furthermore, the irradiation results in a shift in the band gap as evidenced by UV-Vis absorption spectroscopy. Specific modifications (e.g. hillock size, energy loss threshold) induced by slow highly charged ions are discussed in comparison with effects due to the electronic energy loss by swift heavy ions.

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Modeling Secondary Electron Emission from Nanostructured Materials in Helium Ion Microscope

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The scanning ion microscope (SIM) using a helium ion beam [1] has been a new tool that gives us for nanometer-scale resolution and effective contrast schemes for structural and compositional analysis. Although the image formation in SIM by detecting secondary electrons (SE) is similar to that in conventional scanning electron microscopes (SEM), there are some differences in the properties [2]. We present here a Monte Carlo study on imaging for nanostructures and charging for analyzing insulating SiO_2 layers.

Irrespective of whether a material is conducting or insulating, SE emission can be modeled by a three-stage process [3]. The first stage involves generation of internal SEs by ions penetrating the material and target atoms recoiled by them. The second stage is transport of these SEs to the surface. In the third stage, the SEs escape over the surface barrier. For SiO_2, the model is combined with charge accumulation, inducing electric field formation in the material and in the vacuum, and analysis of equation of motion for SEs emitted in the vacuum [4]. The sample nanostructures consist of SiO_2 layers with trapezoidal lines and trenches formed on a Si substrate, the surface of which are scanned by a zero-sized He ion beam for calculation of the SE profile. There appears large and sharp peak of the SE yield at the edge of the structures. The height of the peak is much more than that for an electron beam, whereas the width is less. This indicates that the structures are more clearly observed by SIM than by SEM.

The SiO_2 layer is charged positively due to ejection of SEs and injection of positive ions, which draw the ejected SEs back to the surface. The charging voltage progressively increases and the net SE yield decreases more strongly than for the electron beam, eventually vanishing. However, it increases when the ion incidence occurs at the position near the edge of the structure in a similar way to that observed for the electron incidence. The increase in the yield is more localized than for electron incidence. Furthermore, when the trench is irradiated with the ion beam, the side wall of the trench becomes negatively charged from re-entrance of SEs emitted from the bottom of the trench. The negative charging increases the SE yield at the bottom, because it assists SEs, which may be reabsorbed by the side wall if they are not charged, to exit the narrow trench. This enhancement in the SE yield is stronger for the ion beam than for the electron beam.

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THE EROSION COEFFICIENT OF A METAL SURFACE UNDER ION BEAM IRRADIATION

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The charged particle beams and plasma flows are successfully used for modifying material properties. The action result is determined by a great number of physical processes. One of them is the erosion of an irradiated surface due to sputtering, radiation heating up, and subsequent evaporation. The developing plasma-beam technologies demand to control the erosion properties and to choose the optimal processing mode and parameters. The numerical investigation results of evaporation kinetics for a metal target under high-power pulsed ion beams have been presented in [1]. But, contribution of collision sputtering has not been considered due to high ion energy (hundreds of keV) and high power density of a beam ($10^6 \ldots 10^9$ W/cm^2). However, for adequate calculation of erosion coefficient, in particular at low ion energy (less than 100 keV), the energy losses on collision sputtering should be taken into account.

The present work is devoted to the investigation of erosion processes on a metal surface under pulsed irradiation with 1 keV…1 MeV ions. The erosion coefficient is determined by the expression:

$$Y = \frac{\left(\frac{S}{e}\int_0^\tau j(t)dt + n\int_0^t V_f(t)dt\right)}{\frac{1}{e}\int_0^\tau j(t)dt}, \qquad (1)$$

where S – sputtering coefficient, calculated according to the statistical model [2, 3], τ – impulse duration, $j(t)$ – current density varying during an impulse, n – atomic density of a target material, V_f – evaporation rate, calculated according to the heat erosion model [1], e– the electron's charge. The calculations have been implemented for copper and silver targets irradiated by argon ions with 10^{-7} s impulses. The obtained values of erosion coefficient vary in the range of $0.1 \ldots 10^4$ atoms per ion depending on the current density of a beam. The developed program code can be successfully used to predict the amount of removed substance and the velocities of atom emission in ion-beam technologies.

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Structural changes of water ice analyzed by infrared spectroscopy

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H_2O is the most abundant component of astrophysical ices. The aim of the present work is to contribute for the understanding of the structural changes that occur in the amorphous component when water ice is warmed up. For this, the dependence of infrared band absorption (FTIR) on ice temperature has been analyzed from 15 to 180 K. Results are compared to the chemical and physical effects induced by ion irradiation on frozen pure water (H_2O) over the same temperature range, obtained from the secondary ion yield measurements performed with 1.5 MeV N^{2+} ion beam bombardment at Van de Graff Accelerator at PUC-Rio [1]. In both experiments, a thin ice film was prepared by vapor deposited into a substrate at about 10 K. The goal is to investigate if phase transitions in the ice could influence the desorption yield of $(H_2O)_nH_3O^+$cluster ions and also the FTIR water band areas. In Fig.1 the FTIR and the mass spectrometry (MS) results are compared. The left side axis represents the ratio between the $(H_2O)_1H_3O^+$and the hydronium H_3O^+ desorption yields. For water, three predominant IR bands are observed: 3250 cm^{-1}, 1651 cm^{-1} and 760 cm^{-1}. The right side axis represents the area correspondent to the vibration mode of water, ν_1 (3250 cm^{-1}) IR band. The agreement in the evolution of both curves during annealing (warming up in a very slow process) suggests that both techniques are sensitive to the high-density amorphous ice (I_{ah}) and the low-density amorphous ice (I_{al}) structures.

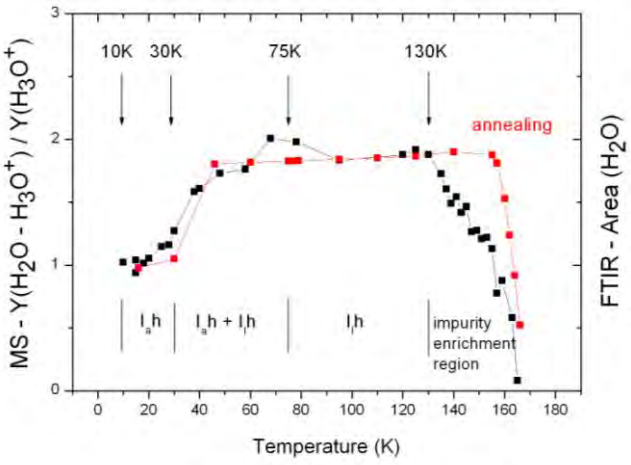

Figure 1. MS and FTIR analyses of phase change of water ice: during annealing, the high density I_{ah} ice changes gradually into the low amorphous I_{al} ice.

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Channeling and Parametric X-ray Studies at the SAGA Light Source

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We present experimental results on channeling and parametric X-ray radiation (PXR) which have been obtained at the SAGA Light Source (SAGA-LS). The SAGA-LS is a synchrotron radiation facility newly constructed in Japan. The SAGA-LS accelerator complex consists of a 255-MeV injector linac and a 1.4-GeV storage ring, and an electron beam from the linac was used in the experiments.

Figure 1 shows the schematic of the experimental setup [1]. (i) We have observed both channeling phenomena and doughnut scattering through measurements of profiles of the electron beam transmitted through a 20-μm-thick Si crystal using a screen monitor [2]. (ii) We have measured PXR angular distributions from channeled electrons using an imaging plate as a two-dimensional X-ray detector [3]. These experimental results were compared with new [3] theory which takes into account combined effect of channeling and PXR, and good agreement is obtained.

Combining the experimental methods described above, we plan to search diffracted channeling radiation (DCR). Although the existence of DCR is predicted theoretically [4,5], the DCR has not yet been observed. The strategy for detecting DCR is also discussed.

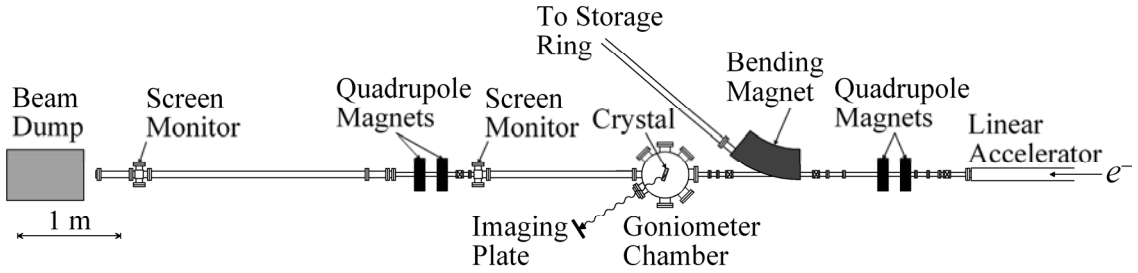

Figure 1. Schematic of the experimental setup.

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Change of Diameters of Multi-walled Carbon Nanotubes by Multiply Charged Ar Ion Irradiation

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Nanostructured carbon materials such as carbon nanotubes (CNTs)[1] and graphenes[2] have been extensively studied toward realization of potential nanodevice applications. On the other hand, irradiating nanostructured carbon materials with energetic particles is thought to be capable of tailoring their structure and properties, and can be applied to process of nanodevice fabrication[3,4]. Multiply charged ions (MCIs) are recognized as having unique properties. The approach / collision of MCIs to solid surfaces results in multiple electron emission, since the MCIs have relatively high potential energy. This electron emission process strongly modifies the local electronic states of the materials. It was reported that the transformation from sp^2 to sp^3 hybridization by modification of the local electronic states of HOPG was demonstrated using the MCI irradiation[5]. However, the effect of MCI irradiation on the structural proeprties of nanostructured carbon materials has not been fully understood.

In this study, singly and multiply charged Ar ions (Ar^+, Ar^{2+}, Ar^{4+}) were irradiated to multi-walled CNT (MWCNT) films. The structural properties of irradiated MWCNT films were characterized by scanning electron microscopy (SEM), Raman spectroscopy, and transmission electron microscopy (TEM). In addition, soft X-ray photoelectron spectroscopy (XPS) and soft X-ray absorption spectroscopy (XAS) measurements were performed to characterize electronic states of the irradiated MWCNT films at BL17SU of SPring-8 and BL09 of NewSUBARU, respectively. It was found that the diameter of the MWCNTs was changed after the ion irradiation. Moreover, the change of the diameter was dependent on the charge state of multiply charged Ar ions. The increase of the diameter of the MWCNTs can be explained by bending and randomizing the orientation of broken graphene sheets, which is the origin for the large volume expansion of the irradiated graphite[6].

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Analysis of the C 1s X-ray Photoelectron Spectrum and the C Kα X-ray Emission Spectrum of Multi-walled Carbon Nanotubes Irradiated by Multiply Charged Ar Ions

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Nanostructured carbon materials, such as carbon nanotubes (CNTs)[1] and graphenes[2], have been promising nanomaterials for various nanodevice applications because of their superior properties. Modification of the electronic states of nanostructure carbon materials has been essential to improve the nanodevice performance. For example, singly charged Ar ion irradiation enhanced the field emission properties of CNTs. Singly charged H ion irradiation improve the response time of the electrochemical sensors using CNTs. Thus, singly charged ion irradiation has been commonly used technique to modify the electronic states of nanostructured carbon materials. On the other hand, multiply charged ion (MCI) irradiation induced unique modification with solid surface, not observed with singly charged ions[3,4]. However, the effect of MCI irradiation on the electronic states of nanostructured carbon materials has not been fully understood.

In this study, singly and multiply charged Ar ions (Ar^{+}, Ar^{2+}, Ar^{4+}) were irradiated to multi-walled CNT (MWCNT) films. The electronic states of irradiated MWCNT films were characterized by soft X-ray photoelectron spectroscopy (XPS) and soft X-ray emission spectroscopy (XES) at BL17SU of SPring-8. The C 1s photoelectron spectra of the as-grown and irradiated MWCNT films were analyzed by means of a least-squares fitting procedure using Doniach-Šunjić functions convoluted with a Gaussian function[5]. The spectra were basically decomposed into five components (bulk sp^2 C, surface sp^2 C, surface sp^3 C, C-O bonds, and C=O bonds). It was found that intensity ratio of sp^2 C to sp^3 C was decreased after Ar^{+} ion irradiation, and Γ_G (FWHMs of the Gaussian function) was increased. Moreover, the spectra for Ar^{4+} ion irradiation showed different shapes from Ar^{+} ion irradiation. The C Kα X-ray emission spectra were also changed after the ion irradiation. These results were attributed to decrease of sp^2 C region, and increase of disordered region in the irradiated MWCNT films. Differences of XPS spectra between charge states of Ar ions will be discussed, and detailed results of analysis of XES spectra will be also presented.

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Measurements of an Ion Beam Diameter Extracted into Air through the Various Capillaries

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A beam optics with a capillary has proposed a unique way to obtain PIXE spectra from any type of samples: solids, liquids and gases. The result of the PIXE measurement for the seabed sludge has demonstrated the ability of this method[1]. Since this technique is simple and effective to obtain micro beams in an atmospheric pressure, various laboratories have begun to use it. We have also performed in-Air-PIXE with glass capillary(GC) and a metal capillary(MC) and developed a 2D-mapping technique with a copper wire of 25 μm in diameter on an aluminum basement[2]. In order to estimate the position resolution, the diameter of the ion beam extracted through the capillaries into air should be estimated of this system. Here, we measured using a PIXE technique.

In this experiment, we have employed a conventional injection needle with a 200 μm inner diameter as the MC and a tapered GC with a 50 μm inner diameter. In order to extract the ion beam through the GC and MC, the capillary was fixed on a stage which are movable along three directions perpendicular to each other and the angle of which with respect to the incident beam axis was also adjustable. The wire was fixed another stage which is movable two dimensionally, that is, directions perpendicular and parallel to the ion beam axis. Induced characteristic X-rays by the beam irradiation were detected by a High-Purity Germanium photon detector. We measured the intensity of the characteristic X-rays as a function of the wire positions. The details of the beam diameter in air will be presented at the conference.

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Tu-024

Ion beam irradiation effects on Ge nanocrystals synthesized by using RF sputtering followed by RTA

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Ge nanocrystals embedded in Silicon oxide matrix have been synthesized on Si substrate by using RF magnetron sputtering technique. The pristine samples were annealed at various temperatures using rapid thermal annealing (RTA). Eventually, these Ge nanocrystals are irradiated with heavy ions of various fluences at room temperature. Rutherford backscattering spectrometry (RBS) has been used to estimate the thickness and Ge composition of the composite films. The structural characterization was performed by using X-ray diffraction which confirms the formation of Ge nanocrystals. Raman scattering spectra showed a peak of Ge-Ge vibrational mode shifted with respect to its bulk value which is due to quantum confinement of phonons in the nanocrystals. Size and shape of irradiated Ge nanocrystals embedded in silicon oxide matrix are studied using transmission electron microscopy (TEM). Surface morphology of the samples is studied by Atomic Force Microscopy (AFM). Variation of the nanocrystal size and shape due to ion beam irradiation will be discussed in detail. The basic mechanism of interaction of ions with Ge nanocrystals at various ion fluences is being investigated and will be presented during the conference.

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Structural characterization of CdSe/ZnS quantum dots using Medium Energy Ion Scattering

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Compound quantum dots QDs are promising materials that can be used in many fields of the technological development, but the accurate knowledge of compositional depth profiling inside of them is still a technological challenge. Medium energy ion scattering (MEIS) is an ion beam analysis technique, capable of elemental depth profiling with subnanometric depth resolution. Recently, the MEIS technique was optimized for nanostructured materials analysis [1] and became a promising tool for structural characterization inside of QDs [2,3]. In this work, we use the MEIS technique to characterize a core-shell nanostructure of CdSe/ZnS. The crystal size of 5.2 nm, determined by MEIS, is in good agreement with optical measurements and TEM images. The core-shell structure is resolved by the present configuration of MEIS in contrast to the present TEM measurements. The commercial CdSe/ZnS QDs has non-stoichiometric Cd and Se concentrations. The sample selected for this work have a Cd:Se ratio of 0.69:0.31. Our investigation shows that there is Cd present on the shell and the CdSe core tends to be a stoichiometric crystal. That indicates that, despite the unbalance of material, the CdSe crystal is preserved during the industrial process which allows the control of the QDs diameters.
This study shows that the MEIS technique, combined with other analytical techniques, is a powerful method to determine elemental distribution profiles, inside nanoparticles with diameter about 5 nanometers. This allows for studies of the formation and stability of the internal structure of the QDs when exposed to several kind of processes, like heating and ion irradiation. We also observed that for the present analysis the line-shape asymmetry of the energy-loss distribution is of minor importance. This is due to the use of a helium beam combined to a large number of isotopes of cadmium, selenium and zinc whose energy variation overshadows the asymmetrical effects from the backscattering collision.

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A study on hydrogen performance in high-*k* stacks by high-resolution ERDA

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With continuously decreasing in the thickness of high-*k* stacks along the advances of semiconductor process technology, negative bias temperature instability (NBTI) has shown its increasing influences on the lifetime of electronic devices. NBTI occurs in *p*-channel MOS devices stressed with negative gate voltage at elevated temperature. It manifests as absolute drain current I_{Dsat} decrease and threshold voltage V_T increase. [1]

Currently, two major models have been proposed to explain NBTI. One explanation is referred as a "diffusion-limited" model in which H^+ diffuses to SiO_2/Si interface and reacts with Si-H traps to produce the silicon dandling bond and H_2. The other major explanation can be regarded as a "reaction-limited" model in which holes diffuse to SiO_2/Si interface and reacts with Si-H trap and neutral water-related species to produce H^+. In addition, some of the H^+ ions diffuse from the interface to the oxide layer. However, no explanation of NBTI is firmly accepted because there still lacks an observation of the diffusion of elements in the devices under the NBTI stress.

In this work, we have measured the hydrogen performance in high-*k* stacks by high-resolution elastic recoil detection analysis (ERDA) [2]. The influence of the different kind of metal layer on the hydrogen distribution in metal/HfO_2/SiO_2/Si was examined. Because 260 ºC is the typical stress temperature for NBTI, we also observed the H distribution at 260 ºC.

The results indicate that large amount of hydrogen has been introduced into the n-type Si substrate by the deposition of palladium layer. This result supports the "diffusion-limited" model which is consistent if H^+ can exist in the silicon. Hydrogen density in the high-k stacks has a small accumulation at the interface between high-k film and the SiO_2. Due to the 260 ºC vacuum annealing, the H density in the HfO_2 film and Si substrate can be significantly reduced.

We acknowledge the support of Kyoto-Advanced Nanotechnology Network, supported by "Nanotechnology Network" of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. The authors are thankful to the Advance Research Center of Metallic Glasses of Tohoku University. The presenters sincerely appreciate the financial help of the Tohoku Leading Women's Jump Up Project.

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Electronic energy loss of slow Ne ions in ultrathin Au-films deduced by TOF-MEIS

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The electronic stopping power S_e for slow Ne ions in Au with energies between 80 and 180 keV was deduced experimentally. Time-of-Flight spectra for Ne ions backscattered from a 159 Å Au-film deposited on a Si substrate were recorded. The obtained energy-converted spectra were simulated by a TRIM based Monte-Carlo simulation [1] which employs a screened scattering potential applicable at these low energies. The electronic energy loss in the simulations can be tuned, until a best fit between experiment and simulation is obtained. Furthermore, the use of Monte-Carlo simulations permits to handle contributions from multiple scattering and the corresponding nuclear energy losses. Fig. 1 shows an energy-converted experimental spectrum obtained for 180 keV Ne primary ions and TRBS-simulations for three different magnitudes of S_e.

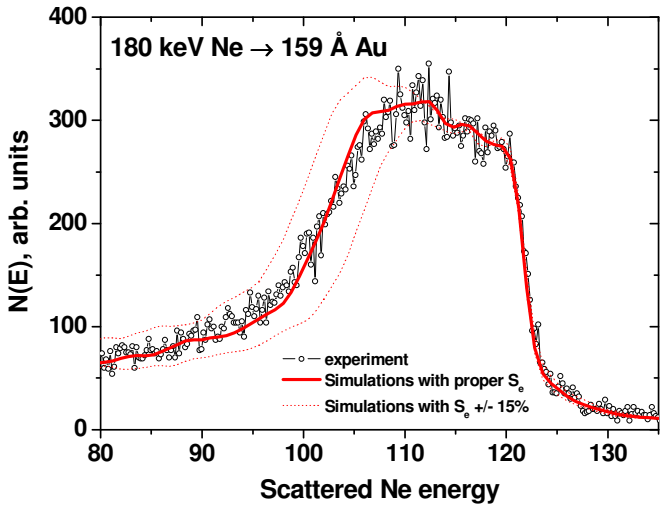

Fig.1: Energy converted Time-of-Flight spectrum for Ne ions backscattered from a thin Au film on Si. Also shown are Monte-Carlo simulations using different electronic stopping powers.

In this contribution the deduced stopping powers are also compared to earlier investigations, which were performed in transmission geometry (e.g. [2] and references therein).

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Molecular Effect on Damage Accumulation in Si under PF_4^+ Ion Irradiation: Effect of Ion Energy

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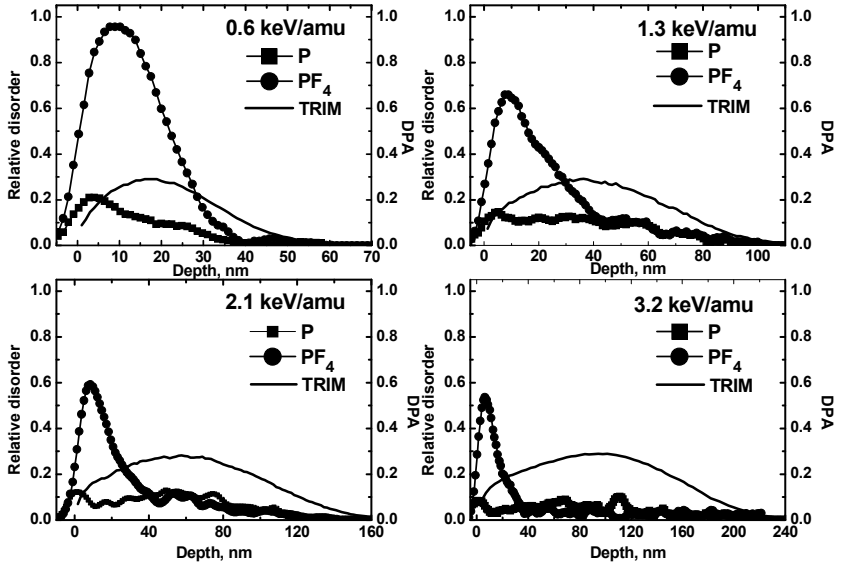
The efficiency of radiation damage accumulation differs for atomic and cluster (molecular) ion bombardment regimes under correct irradiation conditions. This is the so-called molecular effect (ME). The ME in damage accumulation has been attributed (i) to increased disordering in nonlinear energy spikes (such as thermal and displacement spikes) [1], which form due to spatial overlap of collision cascades produced by the atoms comprising a molecular ion or (ii) to nonlinear dynamic annealing processes (i.e. processes of annihilation and clustering of point defects during ion irradiation) [2].

In this contribution, we study the ME in (001) Si irradiated at room temperature in a wide ion energy range of (0.6 – 3.2 keV/amu) with cluster PF_4 ions comprising different atomic species. Implantation was carried out at 7° off the (001) direction in order to minimize channeling. Damage concentration was measured by RBS/C technique (0.7 MeV He ions) with low glancing angle of detecting (13°) to improve depth resolution. For correct estimation of the ME the following parameters were kept constant: ion energy normalized to amu, ion dose normalized to the number of displacements per atom (DPA) in maximum of elastic energy loss, and ion beam flux normalized to DPA s^{-1} [3]. As an example, shown in the figure are depth distributions of relative disorder formed after implantation of P^+ and PF_4^+ ions to doses resulting in a DPA of 0.29 at the maximum of the nuclear energy loss profile. Also shown by lines are DPA depth distributions calculated by TRIM code. The molecular effect is clearly seen in this figure which results from both mechanisms mentioned above.



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The Distribution of Induced Charge in Ion-Metal Surface Collisions

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In ion-metal collisions, an induced charge is produced inside the metal; this drastically affects formation of electronic states of the system under consideration. Spatial distribution of the induced charge within the metal was analyzed using the classical electrostatic model [1], and the following formula for electron density distribution ρ was obtained: $\rho(R) = 1/(2\pi)\, R_0 / \{R^3(R-R_0)\}$. Here R is the distance between the incoming ion and electron, R_0 is the ion-surface distance.

Quantum-mechanically, electron cloud is expanded into vacuum via tunneling mechanisms. Therefore, dependence $\rho(R) = A \exp\{-?(R-R_0)\}$ can be expected, while inside the metal the $\rho(R)$ dependence is almost classical. To satisfy both asymptotics, we choose the following form of $\rho(R)$: $\rho(R) = A/\{(R+d)^3 [(R-R_0)^2 + b^2)]^{1/2} [1+\exp(\gamma(R-R_0)]\}$.

Parameters can be found from the minimum of the energy functional that depends on electron density distribution [2, 3]:

$E[\rho] = \int U(R^{\rightarrow})\, \rho(R^{\rightarrow}) dR^{\rightarrow} + \iint \rho(R^{\rightarrow})\rho(R'^{\rightarrow}) / (?R^{\rightarrow} - R'^{\rightarrow}?) dR^{\rightarrow}\, dR'^{\rightarrow} + 2{,}87 \int \rho(R^{\rightarrow})^{5/3}\, dR^{\rightarrow}$ $+ \int E_{exc}[\rho]\, \rho(R^{\rightarrow}) d\, R^{\rightarrow} + 1/72 \int [\nabla\rho(R^{\rightarrow})]^2 / \rho(R^{\rightarrow}) d\, R^{\rightarrow}$. Here $U(R^{\rightarrow})$ describes the interaction between the induced electron and incoming ion, the second is for the electron-electron interaction, the third is the electron kinetic energy, the fourth is the electron subsystem correlation-exchange energy, and the last is the gradient correction of the second order [4]. Calculations for the C^{6+} - Cu case are shown in Fig.1. R_0 = 10 at.u. The arrow indicates the position of the first row of metal ions. Obtained density distribution is shifted towards vacuum (left side). The electron wall radius in Cu is 1.6 at.u. The incoming ions field shifts slightly the potential wall position towards vacuum.

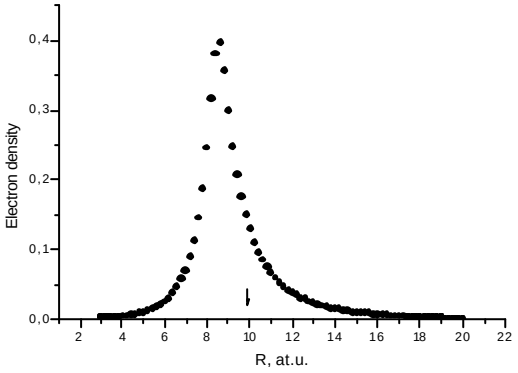

Fig.1. Obtained induced electron density distribution for C^{6+} - Cu case, R_0 = 10 at.u.

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Fragmentation of ^{56}Fe on C, Al and CH_2 targets at 471 A MeV

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The total charge-changing cross sections, the partial cross sections of fragment productions, the emission angles and transverse momentum distributions of fragments of the fragmentation of ^{56}Fe on Al, C, CH_2 and H targets at 471 A MeV are measured using CR-39 plastic nuclear track detector and compared with other experimental results and the predictions of the theoretical models. The total charge-changing cross sections agree will with other experimental results at different energies and the predictions of Bradt-Peters semi-empirical formula, which are approximately independent of the beam energy but increase with the increase of target mass. The partial cross sections are consistent with other ones at close energies and show a significant enhancement for the fragments with even-Z, especially for the fragments with charge $10 \leq Z_F \leq 20$. The improved quantum molecular model (ImQMD) combined with the GEMINI model can well represent the production of charged projectile fragments. The emission angles and transverse momentum distributions of fragments are compared with the predictions of ImQMD model, it is found that the model agree well with our results. The transverse momentum distributions of fragments can be explained by a single Gaussian distribution and the average transverse momentum decreases with the increase of the charge of fragment. Finally, the temperature parameter of emission source of fragment is discussed and it decreases with the increase of the size of fragment.

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Microscopic Model of Material Excitation in Swift Heavy Ion Tracks

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Swift heavy ions (SHI, M>20 amu., E>1 MeV/nucl) lose the largest part of their energy for excitation of the electron subsystem of a target (up to 95%, 10-70 keV/nm). Subsequent transfer of even small parts of the deposited energy and momentum into the lattice can cause unusual nanometric structure transformations which kinetics crucially depends on the parameters of the initial excitation. This transfer occurs at femto-pico timescales after the projectile passage and can not be properly described in terms of the macroscopic models.

The molecular-dynamics model (MD) combined with the formalism of the dynamic structure factor (DSF) [1-3] is employed to calculate the cross sections of electron-lattice interaction at such short timescales. DSF takes into account the complete spectra of lattice excitations originated from spatial and temporal correlations in positions and dynamics of target atoms. It can be applied when (a) no thermal equilibrium of the lattice can be assumed [2], and (b) at times much shorter than the time of atomic vibrations when electron-to-lattice coupling differs from the electron-phonon mode appearing in the DSF as the low energy/long timescale limit [1,3]. The short timescale and high excitation results in the plasma-like electron-lattice energy exchange [3]. All the intermediate Warm Dense Matter states are also covered by the DSF formalism [4].

The obtained cross sections are introduced into the Monte-Carlo (MC) model of event-by-event simulations describing the kinetics of the electron subsystem in a SHI track. Based on the Complex Dielectric Function (CDF) formalism for inelastic scattering [5,6], this MC model takes also into account the dynamics of all collective modes appearing in the electronic subsystem.

Application of the combined MC-MD-DSF model supplies us with the spatial and temporal distributions of fast electrons, valence and core holes as well as the rates of the energy and momentum exchange between electrons and atoms in SHI tracks in different materials (SiO_2, Y_2O_3, LiF, Al, Si).

This approach can be used in *ab-initio* models and for obtaining the initial conditions for kinetic MC or MD models describing the structure transformations and defect formations in relaxing SHI tracks at longer timescales.

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Dynamic Structure Factor Based Approach for Electron-Lattice Coupling in Swift Heavy Ion Tracks

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The spatial and dynamic couplings of atoms affect considerably the kinetics of energy and momentum transfer from the excited electronic subsystem to the lattice in nanometric tracks of swift heavy ions (SHI, E>1MeV/amu) decelerated in the electronic stopping regime. The Dynamic Structure Factor formalism (DSF) [1] is applied in the developed Molecular Dynamic (MD) model to describe the cross sections governing these transfers. DSF takes into account the complete spectra of the lattice excitations and can be applied when (a) no thermal equilibrium of the lattice can be assumed [2], and (b) at times much shorter than the time of atomic vibrations when the modes of electron-lattice coupling are similar to those in plasma and differ from the electron-phonon mode appearing in the DSF formalism as the low energy/long timescale limit [1,3]. All the intermediate Warm Dense Matter states are also covered by the DSF formalism [4].

LiF and Al are chosen as system for application of the developed MD model. Aluminum is chosen as a typical metal with a simple free-electron-like band structure. Alkali-halides find wide applications in investigation of the kinetics of damage formation in SHI tracks. The widest band gap supplies with the direct mechanism of point defects creation based on formation and decay of self-trapped excitons during relaxation of the excited electronic subsystem. To keep the electoneutrality, point defects catch electrons and holes forming the color center electron energy levels inside the gap. Transitions between these levels result in photon emissions providing with the quantitative information for the analysis of the electron and damage kinetics in SHI tracks.

Application of the MD-DSF model provides us with the frequency and wave vector dependencies of DSF, which are then used to construct realistic cross sections of electron-lattice interaction in SHI tracks in Al and LiF. This gives a possibility to investigate the effect of the different modes of dynamical coupling of lattice atoms, which can be realized in SHI tracks (e.g. the electron-phonon mode vs the “instantaneous” plasma-like approximation), as well as the effect of thermalization of the electronic subsystem on the kinetics of lattice excitation.

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Fabrication of Planar Waveguide in KNSBN Crystal by Swift Heavy Ion Beam Irradiation

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We demonstrate the application of swift heavy ion implantation to generate optical waveguides in photorefractive materials. Potassium sodium strontium barium niobate (KNSBN) crystal is irradiated with 17 MeV C^{5+} ions at a dose of 2×10^{14} ions/cm^2. A nearly 10μm thick planar waveguide is fabricated after implantation. The properties of waveguide have been characterized using prism-coupling, microscope, and end-fire coupling. A refractive index increasing is formed in waveguide region based on the electronic energy deposition. The two-dimensional modal profiles of the planar waveguides, measured by using the end-coupling arrangement, are in good agreement to the simulated modal distributions.

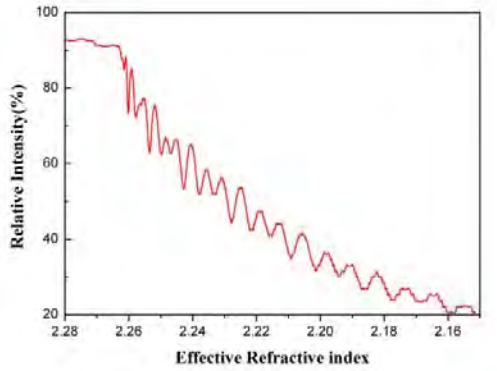

Figure 1. (Color online) Dark-mode spectra of TE modes of the KNSBN planar waveguides irradiated by 17 MeV C^{5+} at a fluence of 2×10^{14} ions/cm^2.

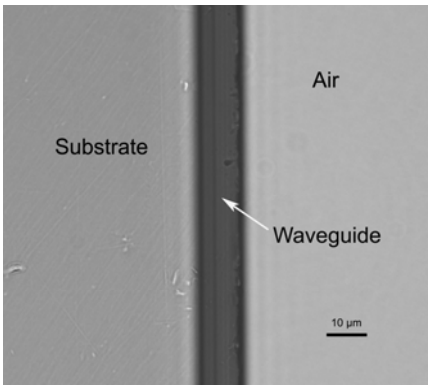

Figure 2. Optical microphotograph of cross section of the KNSBN waveguide sample irradiated by 17 MeV C^{5+} at a fluence of 2×10^{14} ions/cm^2.

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Stopping Power in Magnetized Plasma

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In many-electron systems of the ionosphere around the earth, there appears the frequency of precession of electron in a magnetic field, ω_0, in addition with the plasma frequency, ω_p. Such a kind of magnetic effect is mainly expressed by ω^{-3} term of the dielectric function $\varepsilon(\omega)$ at the high-frequency approximation. The dielectric function $\varepsilon(\omega)$, in which up to ω^{-3} term is taken into account, is given as the following expression in a uniform magnetized plasma by Jackson[1].

$$\varepsilon(\omega) \cong 1 - \frac{\omega_p^2}{\omega^2} \pm \frac{\omega_0 \omega_p^2}{\omega^3} \boldsymbol{bn}. \tag{1}$$

In the above, $\boldsymbol{b}$ and $\boldsymbol{n}$ indicate unit vectors of the uniform magnetic field $\boldsymbol{B}_0$ and the wave number $\boldsymbol{k}$ of electro-magnetic field involved in interaction with an incident projectile. We note that the stopping power discussed here has the direction dependence toward to $\boldsymbol{B}_0$ through $\boldsymbol{bn}$ in Eq.(1). The stopping power S is derived from the following general formula.

$$S = \frac{(Z_1 e)^2}{\pi^2 V} \int \frac{d^3k}{k^2} \int_0^\infty d\omega \omega Im\left[\frac{-1}{\varepsilon(\boldsymbol{k}, \omega)}\right] \delta(\omega - \boldsymbol{kV}), \tag{2}$$

where $Z_1 e$ and $\boldsymbol{V}$ are the charge and the velocity of the projectile, respectively. The integrand in Eq.(2) has φ-dependence in spherical coordinate (r, θ, φ) generally, because of the direction dependence toward to $\boldsymbol{B}_0$ mentioned above. In this presentation, we mainly report theoretical results of the cases that the incident direction of projectile are parallel or anti-parallel to the uniform magnetic field.

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Single-mode Waveguides Generated in Nd^{3+}-doped Silicate Glass by Nickel Ion Irradiation

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In this paper we describe the fabrication of single mode waveguides in Nd^{3+}-doped silicate glass substrates by ion implantation technique. Nd^{3+}-doped silicate glass is irradiated with 3MeV Ni ions at a dose of 5×10^{14} ions/cm^2. The prism-coupling method is used to measure the effective refractive indices of the waveguide dark modes. Only one mode is found, its effective index(n_{eff}=1.5207) is higher than the substrate index (n_{sub}=1.5202). The near-field intensity distribution and propagation loss of the light in the waveguides were measured by the end-fire coupling method. It is found that after annealing the propagation loss of waveguide is effectively reduced.

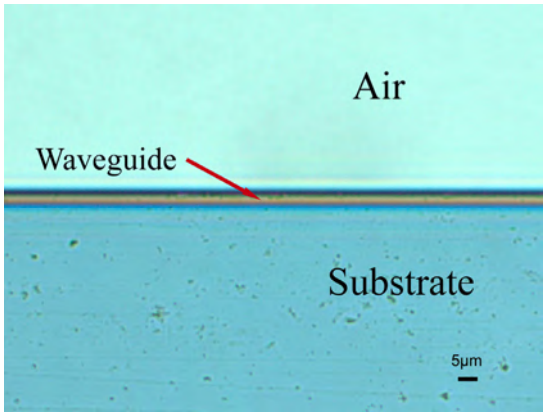

Figure 1. Optical microphotograph(500×) of cross section of the Nd^{3+}-doped silicate glass waveguide sample irradiated by 3MeV Ni ions at a fluence of 5×10^{14}ions/cm^2.

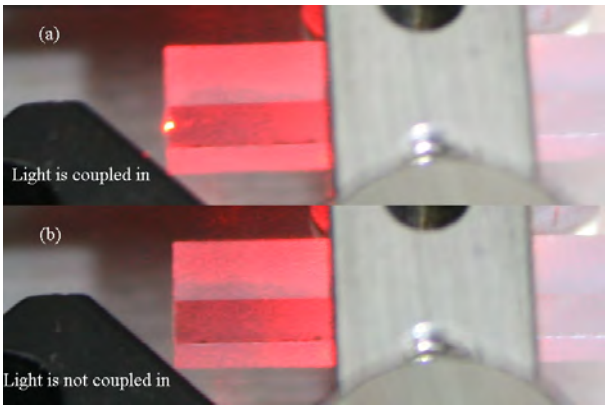

Figure2. (a)Light propagates out from the left ending of the waveguide, when light is coupled in by prism at the right angle for single-mode propagation. (b) Light is not coupled into the waveguide.

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Bridge-Like Radiation Defects in Few-Layer Graphene

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Few-layer graphene structures as well as graphene itself become objects of great interest for the nearest future applications. It can be predicted, that in some cases few-layer graphene-based devices will be subjected to irradiation, which will result in changes of their properties. Therefore, study of possible radiation defects in these structures attracts attention of researchers and technologists. In the work presented few layer graphene fragments were produced by mechanical exfoliation and placed on a copper grid for TEM. Specimens were preliminary characterized by optical microscopy and Raman spectroscopy and after that exposed to electron beam irradiation (100 keV) with a mean exposure dose $3 \cdot 10^{19}$ el /cm^2. Raman spectra of the irradiated specimens showed the essential changes in intensities and positions of G and 2D peaks and apparent contribution of the D peak, indicating radiation damage of the structures. Computer simulation of the possible process of damaging in few layer graphene was performed by molecular dynamics and density functional theory. Results of modeling displayed that under the energetic conditions of irradiation the stable and strong-coupling bridge-like radiation defects [1,2], linking graphene sheets together can be produced as predominanting. Results of simulation allow making the interpretation of Raman spectroscopy data of the irradiated structures.

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SiC Surface Damage Originating from Synergy Effect of Ar Plasma Ion and Plasma-Induced Ultraviolet Light Irradiations

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SiC has been attracting much attention for applications to high power electronic devices [1], which originates from the fact that SiC has a high breakdown field and a high thermal conductivity. These characteristics result from a wide band gap energy and a high sound velocity. A large number of issues still exist in fabricating SiC-based devices because SiC is a binary compound [2]. In particular, plasma-induced damage to SiC in the etch process is a crucial issue; namely, surface roughening and/or spatial disordering lowers SiC-based device performances [3].

In the present paper, on the basis both of an experiment and of a simulation, we discuss Ar plasma etch damage to SiC at the different gas pressures from the viewpoint of synergy effect of Ar plasma ion and plasma-induced ultraviolet (UV) light irradiations: at the low gas pressure (10 mTorr), no UV light is emitted from the plasma, whereas at the high gas pressure (50~100 mTorr), the UV light corresponding to ArII is emitted from the plasma [4]. We focus on changes in the morphology, roughness, etch depth, and Si/C ratio at the SiC surface under the different gas pressures.

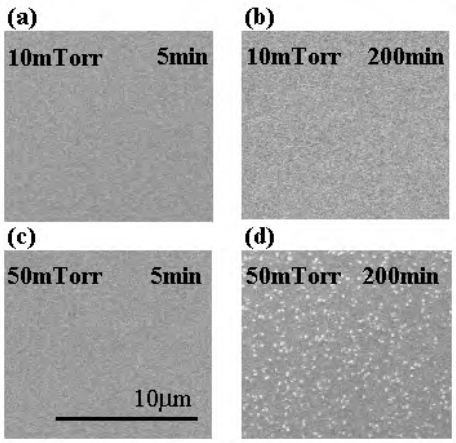

Fig. 1. SEM images of SiC surfaces etched by Ar plasmas at different gas pressures.

In the absence of UV light emission at the low gas pressure of 10 mTorr, the etched SiC surface morphology is quite similar to that of the as-grown sample, regardless of the etch time, as shown in Figs. 1(a) and 1(b). Si/C ratio at the etched surface, however, decreases with an increase in the etch time, which agrees with the simulation: Si is preferentially removed by Ar^+ plasma ions impinging on the surface. This agreement indicates that the physical etch effect, which originates from the impact of Ar^+ plasma ions, contributes to the surface damage. In the presence of the UV light emission resulting from ArII, the surface morphology at the high gas pressure (50~100 mTorr) depends on the etch time: the change in the surface morphology occurs in the case where the etch time increases to 200 min, as shown Figs. 1(c) and 1(d). The experimental etch depth at the etch time of 200 min does not agree with that of the simulation: the experimental etch depth is much higher. The difference connecting with the gas pressures can be related to the factor whether the UV light is emitted: the result at the high gas pressure suggests the contribution of the synergy effect caused by the following possible phenomenon: Si-C bonding is much weakened.

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Evaluation of Electronic Stopping Cross Section for Well-Channeled Ions Using New Formula

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In previous work, we have determined the screening length with shell effect of an isolated atom adopting the average radius of the Thomas-Fermi electron distribution instead of that of Hartree-Fock electron distribution [1]. Based on the Firsov theory, we have also derived a formula of the electronic energy loss, which has a simple form $\Delta E_e(b) \propto S_e(E)\exp(\gamma b)/(1+\beta b)^6$, where $b = p/a$ (β and γ are the fitting parameters, p and a are the impact parameter and the screening length, respectively), and $S_e(E)$ is the electronic stopping cross section.

In present study, we suggest a new formula of the electronic energy loss taking account of the interaction effect between the incident ion and the conductive electron in the Firsov model. For low ion velocity, the ion is moving slowly compared with the electrons at the Fermi surface. Electrons at the Fermi surface are viewed as being scattered by the screened potential of the ion [2]. The stopping power for a slow ion can be written by the phase shifts at the Fermi energy [3]. The energy spectra of channeled B ions impinging along the <110> axes of a silicon crystal were calculated by the ACOCT simulation code included the screening lengths with shell effect and the new formula for 400 keV B incident on a sample thickness of 0.55 μm [4]. It was manifested that the energy loss of well-channeled ions consists mostly of the electronic energy loss.

In addition, we calculated the electronic stopping cross sections for well-channeled ions by the present ACOCT code employing treatment on the maximum energy of transmitted ions as a function of energy of the incident ions for channeling along the <110> direction of silicon in the Eisen's experiments [4]. We obtained that the electronic stopping cross sections against the atomic number of incident ions at a constant velocity show an oscillatory dependence owing to the shell effect of electron.

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Planar Waveguide Formed in $LiNbO_3$ by Proton Exchange Combined with Cu Ion Implantation

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We report on the fabrication of planar waveguide in lithium niobate by proton exchange combined with copper ion implantation. A z-cut $LiNbO_3$ crystal was immersed in a molten benzoic acid for 20 min and then was implanted with 1.5 MeV copper ions at a fluence of 3×10^{14}ions/cm^2. The guiding modes of the planar waveguides before and after copper ion implantation were measured by the prism-coupling method at 633nm. The modes in proton exchanged waveguide can be modulated by copper ion implantation. The reflectivity calculation method (RCM) was used for reconstructing refractive index profiles. The near-field intensity distribution and propagation loss of the light in the waveguides were measured by the end-face coupling method. We used the finite-difference beam propagation method (FD-BPM) to simulate the light propagation. Absorption spectra of the bulk $LiNbO_3$ before and after copper ion implantation were measured. Absorption bands of the bulk LiNbO3 crystal have been preserved after copper ion implantation. The Rutherford backscattering/channeling technique was used to investigate the damage of the waveguides.

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Electronic Stopping for Swift Carbon Cluster Ions connected with Average Charge Reduction

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Interaction of cluster ion with solids has attracted intensive attention in that the so-called cluster effect will be expected in the electric excitation phenomena, e.g., the energy-loss[1-3] and secondary electron emission[4]. These processes induced inside a material are related to the charges of constituent ions in a bulk, whose average charges are known to be less than that of a single ion in a bulk with an equivalent speed. The reduction of the average charge is also characteristic in cluster-solid interaction[5], and its structure dependent feature was measured [6]. To our knowledge, however, basic data on the above phenomena were not ample till now. The aim of this study is to provide as an elemental quantity the electronic stopping cross section, S(n), for swift carbon cluster (Cn) ions in linear-chained structure, and C60 fullerene as a function of ion speed in connection with reduction of cluster average charge in a bulk. The average charges of constituent ions for a Cn incidence are estimated in self-consistent manner, where the average charge per ion Q(n) for a C60 reduces at most about sixty percent of that of a single carbon ion Q(1) with an equivalent speed, though Q(n) and Q(1) increases monotonically with increasing speed. By inclusion of the average charge reduction, the electronic stopping cross section is estimated in the dielectric function formalism as a function of speed and inter-ionic separation. At high speed, the positive cluster effect appears. In particular, the electronic stopping for a C60 represents the giant increase which is due to contribution of the collective resonance excitation.

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Effects of energetic ions on the structural and vibrational properties of bonded hydrogen in silicon

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It is well known that hydrogen is an important impurity in semiconductors. Hydrogen plays a key role in crystal growth and can change electrical, optical and mechanical properties of many materials. Most importantly, the hydrogen passivation of defects in silicon has been an essential processing step in modern integrated circuit technology. Hence it is important to study the factors that can influence the stability, structural and vibrational properties of defect associated hydrogen in silicon. Here we present a study on the influence of swift heavy ion irradiation on the structural and vibrational properties of Si-H complexes associated to various defects in silicon. These defect associated Si-H complexes were obtained by low temperature (80 K) implantation of protons into silicon followed by room temperature annealing. Energetic protons (250 KeV, 190 KeV and 95 KeV at doses of $1x10^{13}$ to $1x10^{17}$ H^+/cm^2) were implanted into high resistivity, double side polished Si samples at 80 K using the low energy ion beam facility at IUAC, New Delhi. Presence of various defect associated Si-H complexes was confirmed by Fourier Transform Infrared spectroscopy (FTIR). It is shown that the concentrations of these Si-H complexes initially increase monotonically with increase in dose and saturate at higher doses. The influence of swift heavy ion irradiation on the stability of these Si-H complexes will be studied as a function of silicon resistivity, local structure, irradiation temperature and electronic energy loss of incident ions. These results will be discussed in detail during the conference.

Keywords: Hydrogen passivation, Si-H complexes, FTIR, SHI.

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Effects of swift heavy ion irradiation on the structural and electrical properties of HfO_2 and HfO_2/SiO_2 films deposited on silicon

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Hafnium based high dielectric constant materials are critical for the *state-of-the-art* integrated circuit technology. As the size of the transistor decreases, the thickness of the gate dielectric (SiO_2) should be reduced to maintain device capacitance at a desired level. This thickness reduction results in high OFF-state leakage current due to quantum tunneling (~ 100 A/cm^2 for 1 nm SiO_2 on Si). Eventually high-k materials, like HfO_2, have recently been introduced as gate dielectrics. However deposition of these high-k materials on Si wafers results in high concentration of interface defects due to their thermodynamic instability on Si. Introduction of thin inter layer of Silicon oxide / nitrides between Si and HfO_2 is expected to improve interface quality. Hence it is important to study the composition, thickness and intermixing effects to optimize the fabrication of Hafnium based MOS devices. Here, we have performed High Resolution Rutherford Backscattering Spectrometry (HRBS) and X-Ray Reflectivity (XRR) studies of Atomic Layer Deposition (ALD) grown $HfO_2/SiO_2/Si$ samples obtained from SEMATECH, USA. HRBS measurements and Synchrotron based XRR measurements were performed at National University of Singapore (NUS). These results will be discussed in view of possible inter diffusion and straggling effects. In addition, the influence of swift heavy ion irradiation on the structural and electrical properties of HfO_2 films deposited by e-beam evaporation on Si and SiO2/Si will also be discussed in detail

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Effect of Atomic and Cluster Ion Irradiation on Mechanical Properties of DLC Films

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The dependence of internal residual stress and film thickness of thin diamond-like carbon (DLC) films on ion irradiation conditions is described. These films (0.01 – 1μm) were grown on Si substrate by PECVD technique and had significant residual compressive stress about few GPa. Grown samples were irradiated to atomic P^+ and molecular PF_4^+ ions. Post-growth ion irradiation causes decrease of compressive stress followed by its inversion to tensile one. For all ion energy combinations used residual stress changes linearly with normalized fluence up to 0.2 DPA with slope (8.7 ± 1.3) GPa/DPA. In all cases anomalous swelling (up to 50% of initial film thickness) was observed after irradiation. The step on the film between irradiated and virgin regions depends on ion dose and cascade density similarly to internal stress. We propose a model which explains the swelling by appearance of the energy spikes in film during ion stopping. According to this model the superheated regions around a spike near the surface of the film are extruded above the surface, where they cool down. Thus, the density of the film decreases, and its thickness increases. This process is saturated when the loosened film can no longer squeeze the material to the surface due to the presence of internal pores and accumulated tensile stress in the film. Dose measurements of internal stress and XPS measurements confirm the conclusions of our theory. Also we observed some increasing of the roughness on irradiated regions of film.

The change of internal stresses as well as the film thickness is similar in nature and to a dose of ~ 2 DPA is linear and then saturates. Moreover, irradiation of molecular ions (with high cascade density) leads to a rapid change in properties when compared with the case of atomic radiation (at the same amount of totally generated knock-ons), i.e., the molecular effect takes place.

This work was supported by RFBR grant № 12-08-01197.

Molecular dynamics simulations of subsurface Ar bubble rupture in copper after the impact of Ar atoms

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Noble gas bubbles in solids can be created by a high-dose ion implantation of noble gases into solids and it is of practical interest for the local modification of material properties. Franzreb & Williams [1] observed the formation of noble-gas cluster ions ejected from bursting subsurface bubbles during noble-gas ion sputtering. We present a molecular dynamics simulation of the rupture of a subsurface Ar bubble in Cu(100) and the ejection of small Ar clusters initiated by the impact of sub-keV Ar atoms. In addition we calculated local temperature and pressure maps inside the Ar bubble as a function of time elapsed from the impact and discussed mechanisms of the bubble burst.

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Radiation damage and annealing effects in diamond implanted with high-dose, high-energy carbon ions

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Diamond is one of candidate materials for fabrication of high power, high frequency devices, because of its excellent characteristics such as a wide band gap (~5.5 eV), extremely high thermal conductivity, high breakdown voltage, high radiation hardness, etc. However, to realize such semiconducting diamond devices, we need high-quality and large-size single crystal (SC) diamond wafers, similar to conventional semiconductor materials. To date, we have developed a chemical vapor deposition (CVD) SC diamond growth method, which will allow one to produce large SC diamond wafers in the future, and attempted to fabricate freestanding thick SC films (plate). Among them, separation of a thick diamond film from the seed substrate is one of central issues because of high hardness and chemical inertness of diamond. To remove the substrate at ease, we have developed a "lift-off method"[1]. The procedure of this process is as follows: prior to the film growth, a highly defective layer is formed in the subsurface of the substrate using high-dose, high-energy ion implantation. After the implantation, a thick SC diamond film is grown on the substrate. After the film growth, the above highly defective layer is etched away, finally resulting in the fabrication of a freestanding thick diamond film (CVD SC wafer). In this paper, we will present investigations of crystallinity of the diamond substrate damaged by high-dose, high-energy ion implantation, mainly by means of measurements of optical properties. It is important to estimate crystallinity of the substrate, because CVD films are grown on such ion-implanted substrate surfaces.

As samples, high-temperature, high-pressure synthetic type-Ib SC diamond plates were used. The diamond plate was implanted with 3 MeV carbon ions to a fluence of 2×10^{16} cm^{-2} (post-implantation annealing was 1200 °C/5min). The TRIM simulation showed that the depth profile of radiation damage has a sharp peak of 2.5×10^{23} cm^{-3} with 0.1 μm (FWHM) at a depth of 1.6 μm. On the other hand, the radiation damage is not much in the depth region from the surface to 1.6 μm (3×10^{21} cm^{-3} at the surface).

The optical transmission spectrum less than ~700 nm of as-implanted sample is almost zero, while more than ~700 nm it steeply increases with the wavelength and finally reaches 60 % at 3.2 μm. In that of the post-implantation annealed sample, the optical transmission less than ~1 μm is zero, and it gradually increases with the wavelength above ~1 μm, but remains at most ~4 % at 3.2 μm, unlike the as-implanted sample. On the ion implanted diamond, accumulation of radiation damage over $\sim 1 \times 10^{22}$ cm^{-3} followed by annealing over ~1000 °C results in the structural transition to a graphitic phase. Thus, the lowering of the optical transmission observed after annealing reflects graphitization of the depth region over $\sim 1 \times 10^{22}$ cm^{-3} as indicated in TRIM. On the other hand, in the depth region from the surface to the depth below radiation damage of $\sim 1 \times 10^{22}$ cm^{-3}, the diamond structure should be preserved. In fact, an interference pattern is seen in the optical transmission spectrum of the post-implantation sample. From this interference pattern, it is calculated that a thickness of the above preserved thin diamond layer is ~1.7 μm, consistent with the result of TRIM simulation. In addition, an optical luminescence from this layer was observed, also indicating that the diamond layer was preserved, while the observed luminescence spectrum was a broad band, most likely related to radiation damage, which stretches in the wavelength 600–900 nm and consists of several peaks, unlike the pristine substrate.

Acknowledgment: They are also grateful to members of DRL at AIST for various technical support.

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An Electrostatic Quadrupole Lens for Focusing Swift Heavy Ions in MeV-SIMS

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The importance of imaging mass spectrometry (MS) for visualizing the spatial distribution of molecular species in biological tissues and cells is growing. SIMS imaging has been used to visualize elemental distribution at the cellular level because of its low molecular ion yield. In conventional SIMS with keV-energy ion beams, elastic collisions occur between projectiles and atoms in constituent molecules. The collisions break the molecules and produce fragments, which makes acquisition of molecular information difficult. In contrast, MeV-energy ion beams excite electrons and enhance the ionization of high-mass molecules, and a SIMS spectrum of ionized molecules can be obtained. In a previous study, we have developed a new system for imaging mass spectrometry using MeV-energy heavy ion beams, termed MeV-secondary ion mass spectrometry (MeV-SIMS), and demonstrated more than 1000-fold increase in molecular ion yield from a peptide sample (1154 Da), compared to keV ion irradiation. In addition, we successfully obtained mass spectrometric imaging of the deprotonated peptides (m/z 1153) without any matrix enhancement [1]. However, obtaining molecular imaging data at present, takes a long time, because the current density of the primary beam is not high enough. We have developed an electrostatic quadrupole lens to focus the swift heavy ion beam and reduce measurement time. MeV-SIMS imaging using the Q lens was performed with the instrument depicted schematically in Fig.1. The primary beam of 6 MeV Cu^{4+} was focused with the Q lens and introduced onto the sample surface through an aperture with a hole of 100 μm diameter. Secondary ions were analyzed with an orthogonal acceleration (oa) time of flight (TOF) mass spectrometer [2]. Using the quadrupole lens, the current density increased by a factor of ~60 and we obtained an MeV-SIMS image of 100 × 100 pixels of protonated distearoyl phosphatidylcholine (DSPC) (m/z = 790.6) over a 4 mm × 4 mm field of view with a pixel size of 40 μm within 5 min, showing that the Q lens reduces measurement time of current imaging by a factor of ~30.

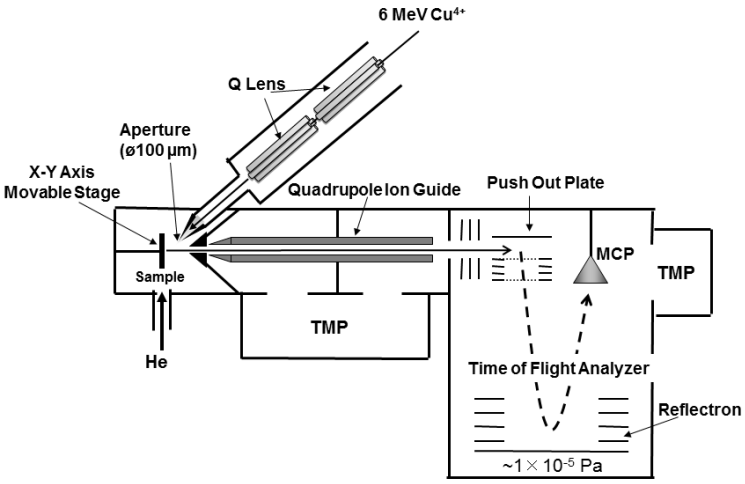

Figure 1. Schematic diagram of the MeV-SIMS instrument with Q lens.

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The near-infrared waveguide properties of LGS crystal formed by swift Kr^{8+} ion irradiation

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In this work, we report on the optical properties in the near-infrared region of $La_3Ga_5SiO_{14}$ (LGS) planar waveguide formed by swift-heavy-ion (SHI) irradiation. The planar optical waveguide in LGS crystal was fabricated by 330-MeV Kr^{8+}-ion implantation at a fluence of 1×10^{12} ions/cm^2. The SHI irradiation was carried out at the Heavy Ion Research Facility in Lanzhou (HIRFL). The initial beam had an energy of 2.1-GeV and was slowed down by passing through a 259-um-thick Al foil which is determined by the Stopping and Range of Ions in Matter (SRIM) simulation [1]. The guided mode was measured by using a model 2010 prism coupler at the wavelength of 1539 nm. The refractive index profile was reconstructed using the reflectivity calculation method (RCM). The near-field intensity distribution of the mode was recorded by a CCD camera using the end-face coupling method. The finite-difference beam propagation method (FD-BPM) was used to simulate the guided mode profile. There is a good agreement between the recorded and the simulated mode profiles. The lattice damage induced by SHI irradiation in LGS crystal was studied by the micro-Raman spectroscopy. The Raman spectra are consistent with the energy loss distributions of Ar ions simulated by SRIM and the micro-photograph of the waveguide taken by a microscope using a polarized light.

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Coulomb explosion in swift-heavy-ion-irradiated tracks: a hybrid PIC/MD simulation

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We study the coupled electron and ion dynamics in swift-heavy-ion-irradiated dielectric materials. As a prototypical case we investigate a LiF crystal irradiated in perpendicular direction at a deposited energy of around 400 eV/nm.

Our hybrid code is based on a molecular-dynamics study of the ionic Li+/F- system. The electron dynamics in the track is described by a microscopic particle-in-cell (PIC) scheme. As an empirical fit parameter we use the lifetime of excited electrons, before they recombine with ions.

We evaluate the sputter yield as well as the energy and angular distributions of the ejected ions. We find:

- the sputter yield decreases with the lifetime of excited electrons,
- the angular distribution is peaked along the surface normal (jet-like emission),
- the energy distribution of emitted ions has a bimodal structure, in which a low-energy component (~ 1 eV) is accompanied by a high-energy (> 5 eV) contribution characteristic of a Coulomb explosion.

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Experimental investigations of synchrotron radiation at the onset of the quantum regime

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The classical description of synchrotron radiation fails at large Lorentz factors for relativistic electrons crossing strong transverse magnetic fields. In the rest frame of the electron this field is comparable to the so-called critical field of $4.414*10^9$ T. When the Lorentz factor times the magnetic field is comparable to the critical field, quantum corrections are essential for the description of synchrotron radiation to conserve energy. With electrons of energies 10-150 GeV penetrating a germanium single crystal along the <110> axis, we have experimentally investigated the transition from the regime where classical synchrotron radiation is an adequate description, to the regime where the emission drastically changes character; not only in magnitude, but also in spectral shape. The spectrum can only be described by quantum synchrotron radiation formulas. Apart from being a test of strong-field quantum electrodynamics, the experimental results are also relevant for the design of future linear colliders where beamstrahlung - a closely related process - may limit the achievable luminosity.

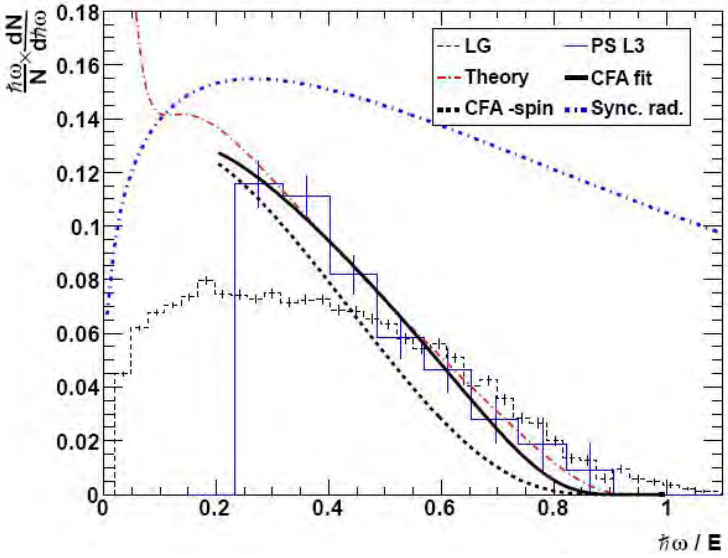

Figure 1. The radiation spectrum from a 100 GeV electron traversing a Ge crystal along the <110> axis.

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Formation of Noble Metal Nanoparticles on Damaged and Undamaged Graphite Studied by Photoelectron and Auger Electron Spectroscopies

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A metal nanoparticle (MNP) depoisited on a substrate exhibits unusual physical properties, such as optical, electrical, and magnetic properties. The properties greatly depend on the size and shape of MNPs.It is, therefore, necessary to establish the method to control morphology of MNPs. The particle-substrate interaction is a key factor to effect the morphology. Ion-irradiation damage produced on a substrate can modify the interaction between MNP and a substrate through defects, e.g., vacancies and dangling bonds.

Highly oriented pyrolytic graphite (HOPG) was used as a substrate. The HOPG was irradiated with 1 keV-Ar ions at several irradiation times ranging from 0.1 to 30 s. Au, Pt or Ag NPs were deposited by sputtering of respective bulk sheets by using 0.8 keV-Ar ions. The areal densities of the noble metal atoms deposited on the substrate were determined by Rutherford backscattering spectrometry. X-ray photoelectron spectroscopy (XPS) and x-ray induced Auger electron spectroscopy (XAES) have been applied to examine the effect of ion irradiation to a substrate on size of the noble MNPs. The $4f_{7/2}$ binding energy (BE) can be used to size estimation for the Au and Pt NPs. In the case of Ag NPs, on the other hand, the kinetic energy of $M_{4,5}VV$ Auger electrons is a measure for sizing.

Fig.1 shows Ag $M_{4,5}VV$ Auger electron kinetic energy (KE) shifts from a bulk value at various areal densities of deposited Ag atoms. For deposited Ag NPs at areal density of 7.0×10^{14} atoms/cm^2, for example, the KE shift is −0.80 eV for the Ar^+-irradiated HOPG, much larger than that for the pristine HOPG (−0.40 eV), indicating that the smaller NPs form on the damaged HOPG. A material dependence as well as defect density dependence of particle size will be discussed.

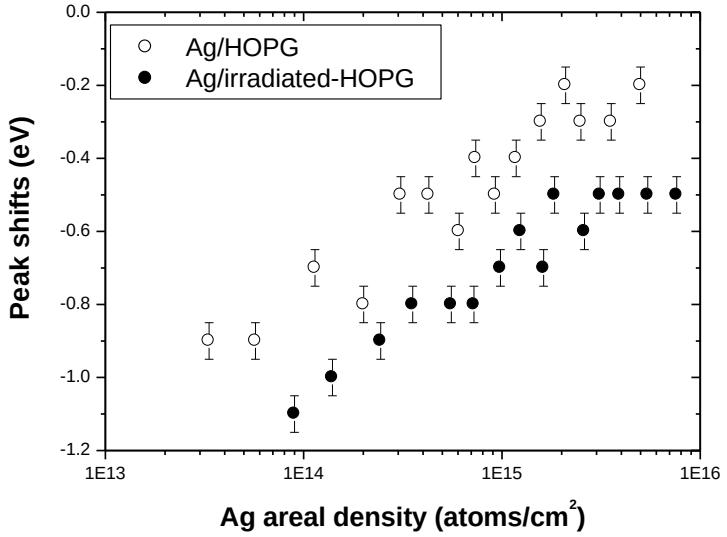

Fig. 1 :XAES Ag $M_{4,5}VV$ kinetic energy shifts as a function of coverage (number of deposited Ag atoms) for Ag/HOPG (○) and Ag/irradiated-HOPG (●).

Kinetic electron emission from monocrystalline Ru and Cu induced by impact of slow Cs^+ ions

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We have studied the energy distributions of electrons emitted from the surfaces of Ru(0001) and Cu(100) bombarded by slow Cs^+ ions below the classical threshold. The electron yields at Cs^+ impact energies between 100 eV and 5000 eV are presented as a function of the inverse Cs^+ impact velocities 1/v. We have analyzed the data in terms of Sroubek's phenomenological model for a sub-threshold ion-induced kinetic electron emission [1].

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Characterization of Epitaxial Transformation Phenomena Induced by the Interaction of Implanted N-Ions with Ti Thin Films

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Non-stoichiometric titanium nitrides, TiN_y, have covalent properties as well as metallic and ionic properties, which make them fascinating for both fundamental research and technological applications. Recently, it has been revealed that the interesting physical properties are related to the crystallographic (preferred oriented) and electronic structures [1]. In the present study, the formation mechanisms of preferred orientation of epitaxial TiN_y films, especially epitaxial formation phenomena induced by the interaction of implanted N-ions with Ti thin films, will be clarified.

The as-deposited Ti films on thermally cleaned NaCl substrates consisted of both TiH_x and hcp-Ti with some preferred orientations at RT. Nitrogen ions (N_2^+) with 62keV were implanted into the deposited Ti films held at RT in the 400kV analytical TEM connected to an ion accelerator at JAEA-Takasaki [2]. The hydrogen component measurement by ERDA was performed to elucidate the H depth profile change, by heating and nitriding Ti films. Furthermore, EELS measurement and DV-Xα MO calculations were used to clarify the electronic structure changes in as-deposited Ti films during N-implantation.

By careful analysis of these results, the following has been clarified. Nitriding of TiH_x in the deposited Ti with N-occupations of octahedral sites of H-released fcc-Ti sublattice leads to the formation of TiN_y without transformation of the Ti sublattice. However, the shift of the atoms on the closed-packed (00・1) plane of hcp-Ti induced by the bonding interaction of Ti sublattices with implanted N atoms plays an important role in the epitaxial transformation of hcp-Ti sublattices to fcc-Ti sublattices due to the occupation by N atoms, partially inheriting the specific atomic arrangements of hcp-Ti. Moreover, it has been found from the analyses of EELS measurements that the hcp-fcc transformation would occur preferentially above a critical concentration ratio N/Ti≈0.25 during N-implantation. This means that above the N/Ti≈0.25, the invasion of implanted N atom to the N-unoccupied octahedral site in the neighboring unit cell next to the N-occupied one occurs preferentially and induces the growth of nucleus of the hcp-fcc transformation.

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Effects of low energy electrons and thermal annealing on the formation of color centers in nitrogen implanted diamond

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Color centers in diamond, e. g. the nitrogen-vacancy center (NV) are promising quantum bit candidates and they enable advanced magnetometry schemes [1]. Implantation of nitrogen ions into single crystal diamonds followed by thermal annealing is a straightforward approach that leads to the formation of some NV-centers. But the reliable formation of NV-centers with long spin coherence times and high spatial resolution is challenging. The established mechanism for NV-formation following nitrogen ion implantation is a two step process that takes place at annealing temperatures above ~600° C. Nitrogen is first incorporated onto a lattice site, followed by the capture of a vacancy by the substitutional nitrogen. We report an unexpected effect of exposure to low energy electrons on the formation of NV-centers in nitrogen implanted diamonds. Exposure to electrons (2–30 keV) in a scanning electron microscope induces formation of NV-centers without any thermal annealing [2]. We find that non-thermal, electron-beam-induced NV-formation is about four times less efficient than thermal annealing. But NV-center formation in a consecutive thermal annealing step (800º C) following exposure to low-energy electrons increases by a factor of up to 1.8 compared to thermal annealing alone. These observations point to the reconstruction of a precursor defect complex (which possibly includes interstitial nitrogen and two vacancies) that is induced by electronic excitations from low-energy electrons as an NV-center formation mechanism. The finding of enhanced NV-formation when exposure to low energy electrons is followed by thermal annealing indicates the importance of microscopic charging effects on the formation of NV-centers. In our presentation we will discuss strategies for the enhancement of NV-formation efficiencies.

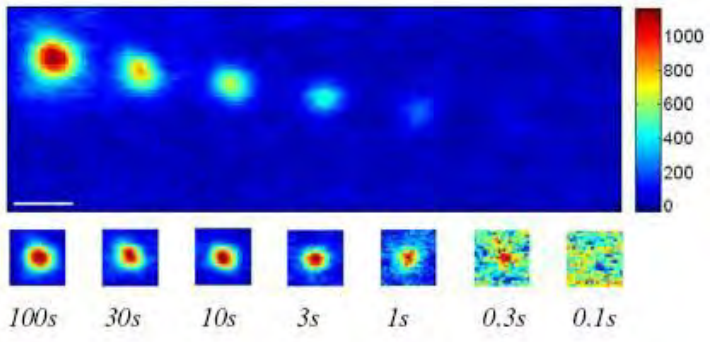

Figure 1. Confocal photoluminescence image of NV− centers (integrated spectral intensity 635–642 nm). The image was recorded following exposure of 1μm squares with a 2 keV, 9 pA electron beam. Insets show locally auto-scaled spot details. The scale bar is 3μm.

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This work was supported by the Office of Science of the US Department of Energy under contract no. DE-AC02–05CH11231 and by Darpa.

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Acetone Cluster Ion Beam Irradiation on Solid Surfaces

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The efficiency of polyatomic cluster ion beam irradiation in the surface processing and modification of solid materials has been demonstrated [1]. The characteristic features of the polyatomic cluster ion irradiation may be attributable to the chemical properties of polyatomic molecules as well as the common characteristic properties of the cluster ion beam irradiation such as high sputtering yields and surface smoothing effect. According to molecular dynamics calculations, the local temperature of the area bombarded by a cluster increase within approximately 1 ps [2], which may result in the enhancement of the chemical reactions between the surface and molecules that comprise the cluster. In this study, the irradiation effects of acetone cluster ion beam on solid surfaces were investigated to enlarge the applicability of the polyatomic cluster ion beam technique. Acetone is a common material in the industry, and has different chemical properties from ethanol or water molecules that have been used as the source material of clusters [1].

Acetone clusters were produced by the adiabatic cooling effect during the adiabatic expansion of a supersonic nozzle flow. The production of acetone clusters were performed without helium support gas. The acetone clusters were ionized by electron impact ionization. The acetone monomer and small cluster ions were removed by the retarding voltage method. The typical acceleration voltage was from 3 to 9 kV. The cluster size distributions were measured by the time-of-flight (TOF) method, where singly charged clusters were assumed.

Figure 1 shows the cluster size distributions of the acetone cluster ion beam measured by the TOF method. The mode of the cluster size distribution was approximately at 2000, and gradually increased with source pressure. The typical source pressure used for the production of acetone clusters for the irradiation on the solid surfaces was 0.3 MPa.

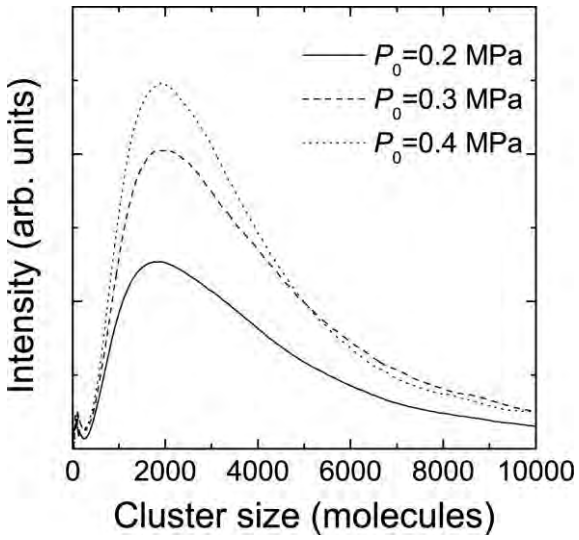

Figure 1. Cluster size distributions of acetone cluster ion beam.

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Development of TOF-MEIS and the limitation of existing ion-interaction models

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We have developed, for the first time, a time-of-flight (TOF)-MEIS system with a collection efficiency 4 orders of magnitude higher than that of conventional MEIS to minimize the ion beam damage while maintaining a similar energy resolution. Furthermore, it can detect neutrals and ions which removes the ion neutralization problems in absolute quantitative analysis. A TOF-MEIS system was designed and constructed to minimize the ion beam damage effect by utilizing a pulsed ion beam with a pulse width < 1 ns and a TOF delay-line-detector with an 8 inch diameter and a time resolution of 300 ps. TOF-MEIS spectra were obtained using 70 keV He^+ ions that can rastered over 500 x 500 μm^2 and with an ion beam diameter of 10 μm. The TOF-MEIS system was applied for ~ μm small spot analysis of gate oxides and ultrashallow junctions and profiling of nanoparticles that are susceptible to ion beam damage. We report the quantitative compositional profiling with single atomic layer resolution for 0.5~3 nm CdSe/ZnS QDs with a conjugated layer. A large non-stoichiometry in sub nm CdSe cores with the Cd/Se ratio of 2.3 and its diameter dependence in the initial growth stage were clearly observed.

In spite of practical and exciting applications of TOF-MEIS for nanostructured materials analysis, a few questions regarding to physics on ion-surface interactions remain not clearly answered such as the effect of multiple scattering, electronic stopping power, the electronic straggling, and ion beam damage in the abnormal MEIS ion energy range. Discussions how to overcome these physics issues and extend applications to various nanotechnology and biotechnology shall be be invited. *email; dwmoon@kriss.re.kr

Study of the Stopping Power of H^+ and H_2^+ in Silicon in E<90keV Energy Region

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The experimental measurement of ions' stopping power in low energy region is always a challenge work. The uncertainty of existed experimental stopping power data is rather large in keV energy region and can only be used for modifying the extrapolated curve based on higher energy data. In this work, the stopping power of H^+ (proton) and H_2^+ (hydrogen molecular ion) have been obtained from the depth profile of H^+ and H_2^+ in silicon. The H^+ and H_2^+ ions with energies of 10, 25, 35, 80 and 90 keV/amu were implanted into silicon with a fluence of 1×10^{17} p/cm^2, the hydrogen depth profiles in implanted samples were then measured by H(^{15}N,α)^{12}C resonance Nuclear Reaction Analysis (NRA). The projected ranges of implanted ions are therefore obtained from the depth profiles. Then, a code based on the Projected Range Algorithm given by Biersack, Andersen and Ziegler has been developed to extract the stopping power data. In this code, the nuclear stopping power is the same as that from SRIM, but $^2He^+$ is used to instead H_2^+. The best coefficients have been obtained by fitting the experimental range data. As a result, the stopping power of proton in silicon is larger than the data used in SRIM, a maximum difference reaches to 15% at 30 keV/amu. The stopping power of H^+ and H_2^+ molecular ion is also different. The difference of the stopping power of H^+ and H_2^+ are velocity dependent. A critical velocity is found at the energy of 40 keV/amu. Below the velocity, the difference is positive, and it is changed to negative above the velocity. An interpretation related to the vicinage effect of H_2^+ is given.

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The Restoration Spikes of Local Phonon During the Post Annealing in Diamond

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A long time is required for the thermal annealing after ion implantation to restore the once damaged crystal, e.g., it requires a few millisecond at shortest. For the target crystal, the whole process from ion-implantation to the end of post-annealing is the phase change of "crystal-amorphous transition (order → disorder)" and "amorphous-crystal transition (disorder → order)" in the atomic distribution in the same crystal. We have evaluated this order in terms of the long-range-order (LRO) parameter rather than the short-range one [1] based on the analysis of crystalline defects called the Pixel mapping method [1]. The degree of the order is simply indicated by the LRO parameter, that spans from *LRO* = 1 (order) to *LRO* = 0 (disorder). The atomic distribution is obtained by an atomistic simulation of molecular dynamics (MD) simulation. Therefore, we have used the MD and the PM to study the effect of post-annealing. Here, the projectile is the N_2 molecule with energy (E_0) of sub-keV per atom, which is implanted into a pure diamond at room temperature. After a period of thermal stabilization, until the bulk temperature became equilibrated by interacting with heat-bath, we started the post-annealing. Before the start of heating, the CA transition has already identified through the change in the *LRO*. The temperature of the heat-bath was raised up to the annealing temperature (T_A), which should enhance the lattice vibrations in a crystal simulated in MD. Just after the start of heating up to the order of tens ps, no appreciable change appeared in the *LRO* parameter. Then, we observed temporal *restoration spikes* [2] in the *LRO* parameter, where each spike changes "0 → 1 → 0" quickly. The time-interval between restoration-spikes was almost same for each case defined by a set of (E_0 and T_A). For example, in the case of 200 eV/atom and T_A = 1000 K, 9 regular spikes were identified between 60 ps and 670 ps, i.e., spikes appeared every 70 - 80 ps. We suppose such a regular profile of the restoration spikes signifies the trigger toward a final state of nearly ordered. The critical conditions for achieving the post-annealing will be presented at the conference.

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Quantitative evaluation of charge-reduction effect in cluster constituent ions passing through a foil

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It is known that an average charge of the constituent ions resulting from the foil-induced dissociation of cluster ions is smaller than that of monatomic ions at the same atomic number and speed. Such a charge-reduction effect would decrease with increasing of the internuclear distance of the constituent ions moving in the solid. The internuclear distance is thus one of the most important parameters for understanding the mechanism of the charge-reduction effect. However, it is difficult to measure accurately and directly the internuclear distance increasing gradually by the screened Coulomb force between constituent ions, because of an interference correlation between the internuclear distance and the charge state. Therefore, we developed a method for estimating the internuclear distance distribution through the divergence angle distributions in each combination of charge states of the constituent ions after foil penetration [1], and then succeeded in quantitatively evaluating the empirical relationship between the internuclear distance and the charge state. As shown in Fig. 1, it was demonstrated regarding 6-MeV C_2^+ ions that the charge-reduction effect can be described as a function of the internuclear distance. Furthermore, a theoretical value indicated in a solid curve in this figure, calculated by the model considering the cluster effect on average charge [2], was well consistent with our experimental value.

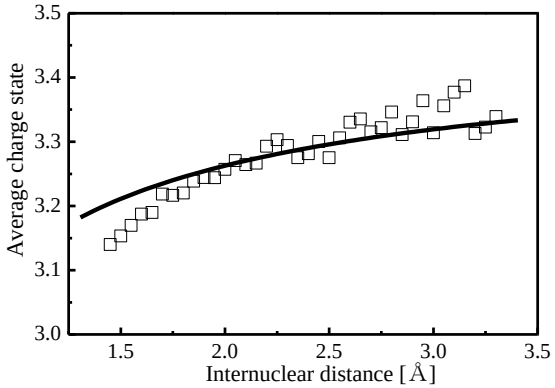

Figure 1. Average charge state of the constituent ions dissociated from 3-MeV/atom C_2^+ ions moving in a carbon foil, as a function of internuclear distance. The solid curve indicates a calculated result using the cluster average charge theory reviewed in Ref. [2].

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A Positron Beam Analysis on Defect Formation in Iron by MeV Ion Beam

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Defect formation by energetic particles such as neutron and ion in metals has been studied for many years, and recent computational simulation in atomic scale has contributed to further understanding of cascade damage processes. However, experimental validation of these computational works is not sufficient mainly because of experimental difficulties in investigating such a fast (~ps) and fine scaled (~nm or less) process. This study is an experimental challenge to investigate defect production involving cascade damage processes produced by MeV ion irradiation.

Defect configuration after cascade damage is expected to be preserved at low temperature below stage I where interstitial atoms begin to migrate. MeV ion beam irradiation to pure-iron was carried out at 12 K, and then positron beam is implanted at the same temperature to the irradiated surface as a vacancy probe to evaluate vacancy concentration remained in the irradiated specimens. By this method, defect production efficiency which is defined as a ratio of residual defects to defect formation predicted by NRT model [1] was evaluated for iron irradiated with proton and carbon ions. Most of generated vacancy-type defects were likely to monovacancies, independent of PKA energy spectrum. Defect production efficiency values qualitatively represent the difference in PKA energy spectrum of H^+ and C^+, but the values were lower than simulation-based ones, possibly due to inhomogeneous distribution of vacancies caused by cascades and enhanced mutual annihilation of Frenkel pairs. Post irradiation annealing results and electric resistivity experiment results will be also discussed.

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"The mechanism of emerging catalytic activity of Gold nano-clusters studied by ion scattering coupled with photoelectron spectroscopy"

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This paper reveals the fact that the O adatoms (O_{ad}) adsorbed on the 5-fold Ti rows of rutile TiO_2(110) react with CO to form CO_2 at room temperature and the oxidation reaction is pronouncedly enhanced by Au nano-clusters deposited on the above O-rich TiO_2(110) surfaces. The optimum activity is obtained for 2D clusters with a lateral size of ~1.5 nm and two-atomic layer height corresponding to ~50 Au atoms/cluster. This strong activity emerging is attributed to an electronic charge transfer from Au clusters to O-rich TiO_2(110) supports observed clearly by work function measurement, which results in an interface dipole. The interface dipoles lower the potential barrier for dissociative O_2 adsorption on the surface and also enhance the reaction of CO with the O_{ad} atoms to form CO_2 owing to the electric field of the interface dipoles which generate an attractive force upon polar CO molecules and thus prolong the duration time on the Au nano-clusters. This electric field is screened by the valence electrons of Au clusters except near the perimeter interfaces, thereby the activity is diminished for three-dimensional clusters with a larger size.

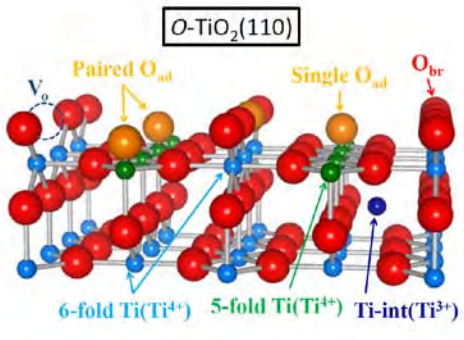

Fig. 1 Ball and stick model of *O*-TiO_2(110)

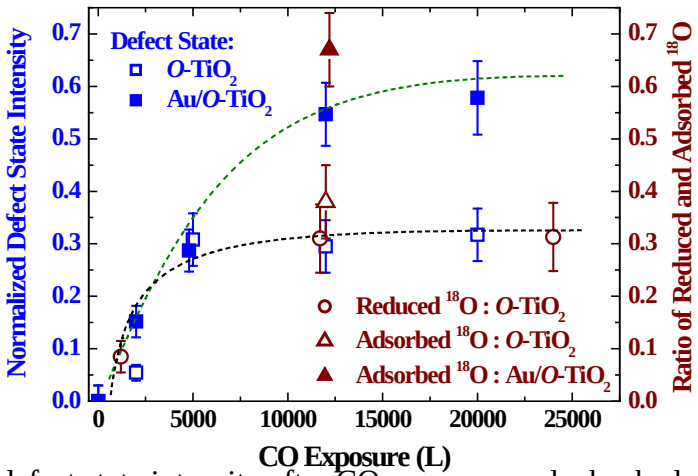

Fig. 2. Normalized defect state intensity after CO exposure and adsorbed ^{18}O after CO exposure followed by $^{18}O_2$ dose for *O*-TiO_2 and Au/*O*-TiO_2.

Irradiation Effects on Hexagonal Boron Nitride Coated Titanium Diboride Reinforced Boron Carbide-Silicon Carbide Composites

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Boron carbide has wide application areas including nuclear technology [1]. Boron carbide has high hardness, wear resistance, chemical stability and thermal neutron cross section value [1]. However it has some disadvantages such as high sintering temperature, low mechanical strength and fracture toughness. So some additives such as silicon carbide and titanium diboride are used to reach high densities of boron carbide [2]. In this study hexagonal boron nitride (h-BN) coated titanium diboride reinforced boron carbide- silicon carbide composites were studied. In the sintering process of the materials hexagonal boron nitride was used for coating. Average thickness is 1 μm for hexagonal boron nitride. The materials were sintered by hot pressing method which has 2250 °C temperature, 130 MPa pressure and 2 hours sintering time properties. The titanium diboride ratio in the composites varies up to 4% by volume [2,3]. The wide using area of boron compounds in nuclear technology has generated interest to irradiation damage mechanism in boron compounds [4,5]. The composite materials were irradiated by 4 MeV electrons to fluence ranging from 10^{15} to 10^{17}cm^{-2} at room temperature.For the initial and irradiated samples XRD, SEM and EDX analyses were performed. The parameters of crystalline lattices and stresses were investigated for bulk (substrate) materials (boron carbide, silicon carbide and titanium diboride) and coated material (h-BN) at each dose value and titanium diboride ratio. The structure features of boron carbide, silicon carbide, titanium diboride and hexagonal boron nitride were carried out. The effects of dose and titanium diboride ratio on the crystalline lattice parameters and stresses (micro and macro) were discussed. We also discussed possible mechanism of accumulation and evaluation radiation defects by high energy electron irradiation.

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Ion Scattering on Polarity-controlled ZnO Surfaces by MeV ions

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An almost complete reflection of a 2.5-MeV proton beam on an evaporated Au layer was found at a grazing-incidence angle [1]. Focusing of 2-MeV He^+ ions by means of tapered glass capillary optics was achieved by Nebiki et al. [2]. It has generally been considered that small-angle scattering on the surfaces play important roles in the reflections. However, the details of the mechanism have not been clarified yet. On the other side, the polarity-controlled ZnO crystals have been available, recently. They have two different surfaces, or "faces", terminated with Zn and O atoms. We studied the mechanism of collisions between MeV ions and polarity-controlled ZnO surfaces aligned to the *c*-axis in order to investigate the efficient reflection of swift ions on solid surfaces.

The experiment was performed at the the JAEA Takasaki laboratory. C^+ (1–2 MeV) ions of a continuous beam (~50 pA) was modulated to a 10-kHz pulsed beam after attenuating the fluence rate to 1/300 or 1/30. Free-standing ZnO single crystals with two opposite surfaces, so-called "Zn and O faces," were set on a manipulator in the chamber. The two crystals were of the same dimensions 10 mm × 10 mm × 0.5 mm. The energy of the ions scattered at 3° with respect to the beam axis was measured by a conventional Si surface barrier detector. The energy distribution was recorded by a multichannel analyzer. Figure 1 shows the energy distribution of the scattered ions in collisions of 2-MeV C^+ ions on the ZnO surfaces at an incidence angle of 2°. The distributions on the two opposite surfaces are significantly different. A larger energy loss and a higher yield of scattered ions on the Zn face compared to the O face suggest that elastic collisions with surface atoms play key roles.

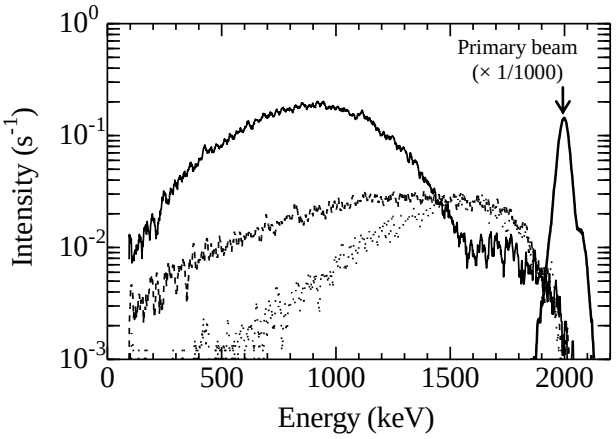

Figure 1. Energy distributions of scattered ions on Zn face (————) and O face (– · – · –) of ZnO crystals, and Au (- - - - -) surfaces in grazing-incidence collisions of C^+ (2 MeV) ions.

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Stopping power for 5.2 – 6.8 MeV C ions into Si [110] direction

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Stopping powers for channeled H and He ions in single crystal silicon have been investigated for long time. There are also needed for surface, interface or impurity structure analysis by ion scattering. In contrast to H and He ions, there are few experimental studies of stopping powers for channeled heavy ions. Jiang et al [1] measured the energies of various heavy ions though the silicon foil in [100] axis and {110} plane channeling incidence.

We investigated stopping powers for C ions along the [110] direction in silicon single crystals with the energy regime from 5.2 to 6.8 MeV. Backscattering spectra for [110] direction incident C ions were measured from SIMOX (Si(100)/SiO_2/Si(100)) as target sample. Ion trajectories and energy loss were calculated by Monte Carlo simulation.

We assumed that the impact parameter dependent stopping powers were expressed by simple exponential formula. Stopping power S (E,r) is expressed by next equation.

$$S(E,r) = a \cdot \exp(-b \cdot r)$$

Hence, r is the closest approach, b is fitting parameter and a is appropriate normalizing coefficient.

Figure 1 shows the observed and simulated RBS spectra for 6.0 MeV. We determine parameter b to reproduce the RBS spectra for the channeling incidence. The best fitted parameter b values are 1.8, 1.8, and 1.95 for the incident energies of 5.2-MeV, 6.0-MeV, and 6.8MeV respectively. Figure 2 shows averaged stopping powers for axial channeling and random (SRIM2008). The ratio of [110] channeling to random stopping powers for 5.2, 6.0, 6.8 MeV are 0.67, 0.68, and 0.64, respectively.

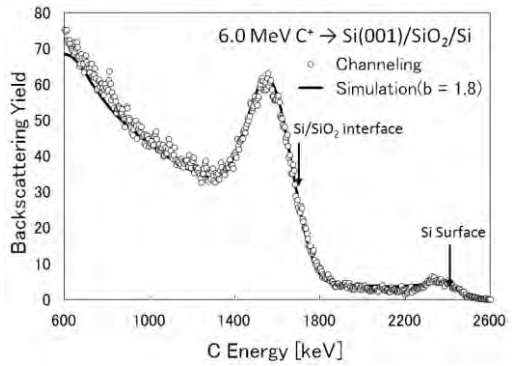

Figure 1. Observed and simulated RBS spectra for 6.0 MeV.

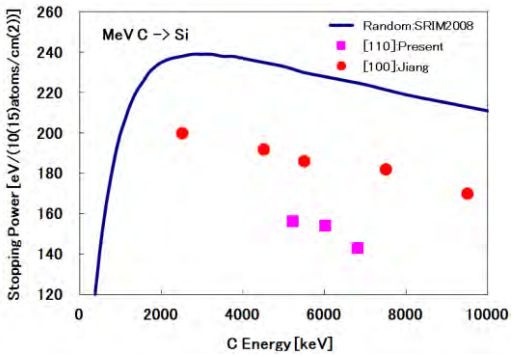

Figure 2. Averaged stopping powers for axial channeling and random (SRIM2008).

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Trajectory dependent energy loss in grazing collisions of keV He atoms from a LiF(001)-surface

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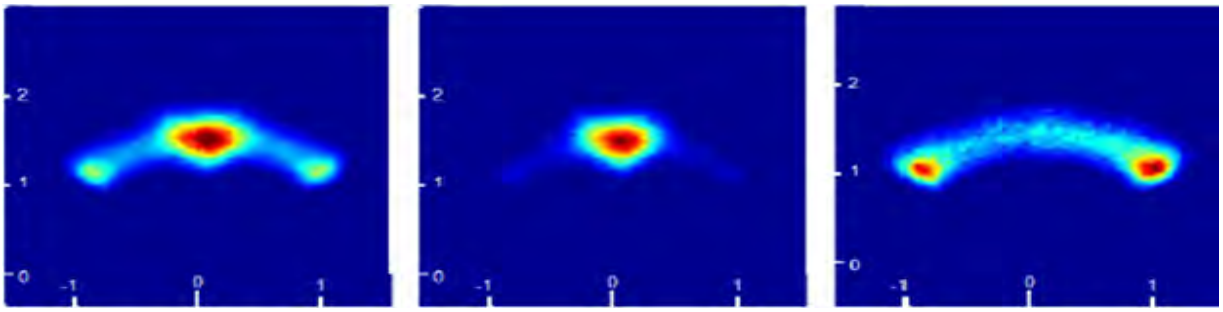
Scattering of fast atoms from insulator surfaces under grazing angles of incidence is accompanied by electronic excitation and emission processes based on the formation of transient negative ions. This implies that the capture process of well localized valence band electrons from so-called “active” sites dominates charge transfer and projectile energy loss giving rise to discrete peaks in the energy loss spectra for scattered ions [1]. In experiments on the coincident detection of energy loss and number of emitted electrons the basic mechanisms of the interaction scenario could be cleared up in some detail [2].

In the work presented here, we have extended these studies by recording the angular distribution of scattered projectiles in coincidence with the projectile energy loss in the regime of axial surface channeling. For scattering along strings of atoms in the surface plane the projectiles are deflected out of the incident scattering plane and at the extreme of the azimuthal angle an intensity enhancement is observed (“collisional rainbow”) [3]. In our experiments, the scattered atoms were recorded by means of a position sensitive micro-channelplate-detector and the projectile energy loss is obtained making use of a time-of-flight setup. As an example, we show in Figure 1 the angular distributions for 12 keV He atoms scattered from a LiF(001) surface under an angle of incidence of 1.4°. For scattering along <110>, i.e. along channels formed by alternate strings of Li^+ and F^- ions, the coincident distributions reveal that rainbow scattering is accompanied with a discrete energy loss and proceeds primarily from F^- strings, whereas scattering from Li^+ ions is fully elastic. This finding fully agrees with the concepts of charge transfer between atoms and insulator surfaces.



intensity of all scattered atoms intensity of elastically scattered atoms intensity of atoms with 15 eV energy loss

Figure 1. Angular distributions as recorded by means of position sensitive micro-channelplate-detector for scattering of 12 keV He atoms from LiF(001) along <110> direction with incidence angle of 1.4°.

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Gas Cluster Ion Beam Accelerator: First Results

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Gas cluster ion beams and their interaction with solid surface is a rapidly developing area during the last years. In this work gas cluster ion beam accelerator is described. Clusters are formed by supersonic expansion of gas through Laval nozzle. The gas passes through a valve operating in pulsed regime to reduce gas load on the pumping system and to support pressure below 10^{-2} Torr in the expansion chamber. Neutral clusters are ionized by an originally designed ionizer; electrostatic field accelerating cluster ions can be set up to 20 kV. Magnetic field is used to remove monomers, and then focused beam is directed onto a sample.

In the experiments, argon was employed as the working gas. Using variable homogeneous magnetic field it was shown that Ar_N^+ clusters with N>500 are there in the beam when the stagnation pressure is above 2,5 bar. Time of flight technique was applied to measure argon cluster size distribution; the spectra obtained are in good agreement with literature [1]. Cluster sizes are in a range from 200 to a few thousands of atoms in a cluster.

Surface relief and structure of different materials after cluster irradiation was investigated.

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Sputter Induced Cesium Luminescence: In Situ Optical Information During ToF-SIMS Depth Profiling With Cesium

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Low energy (<500 eV) Cs^+ sputtering allows molecular depth-profiling of organic materials, from amino acids to polymers [1,2]. Depending on the sample, molecular ions or characteristic molecular fragments can be monitored. Like in inorganic materials, anionic signals are much improved upon Cs irradiation, mostly due to reduction reactions with implanted cesium atoms. Those atoms also react with free radicals, therefore inhibiting cross-linking reactions.

We have used Optical Emission Spectroscopy (OES) in order to observe light emission induced during the sputtering mechanism [3]. The $6P_{1/2}$ and $6P_{3/2}$ to $6S_{1/2}$ neutral cesium transitions are intense. Peak intensities can be easily monitored during a depth profile simultaneously to ToF-SIMS measurements and can be attributed to neutral cesium atoms, excited by atomic collisions.

In this communication we will discuss typical differences between light emission from organic/inorganic depth profiles with cesium. We also have the ability to simultaneously use cesium and xenon as primary ions for sputtering (Cs/Xe co-sputtering). We will show that, on polystyrene, collisional excitation with cesium or xenon can be discriminated thanks to a Stark effect on those transitions. Sputtering yield differences have also an implication on the IR yields at the interface by OES. Through this communication we will show that Sputter Induced Optical Emission Spectroscopy can give access to fundamental processes occurring during depth profiling.

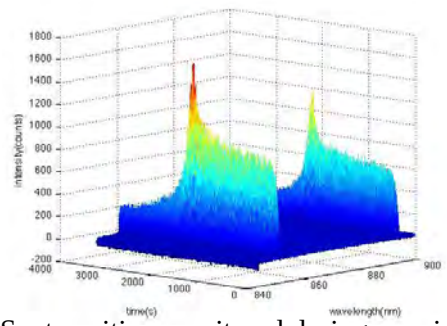

Figure 1. $6P_{3/2}$ and $6P_{1/2}$ to $6S_{1/2}$ transition monitored during a cesium depth profile of polystyrene on silicon

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Highly charged Xe ions inducing nanostructure on CaF_2 surface at low energy and characterized by SFM in tapping mode

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Nature and intensity of ion-surface interactions are intimately connected to projectile energy deposition in the target and therefore depend both on the kinetic and the potential energies [1]. A coherent synergy of nuclear and electronic energy losses is suggested in ion-irradiation processes from the nuclear to the electronic energy regime [2]. In comparison with swift heavy ions (SHI), highly charged ions (HCI) carry several tens of keV of potential energy which is delivered into only a few atomic layers of the surface, resulting in many different phenomena that are significantly dependent on the potential energy deposition. Defects on dielectric surfaces irradiated by the energetic ions are usually tested by scanning force microscope (SFM). SFM has three modes: tapping, contact and non-contact. It is noted that a contact-SFM observation is often not very reliable in discussing topological structures while the tapping mode SFM was successfully applied to observe protrusions [3].

Experiments on nanostructure formation on CaF_2 single crystals irradiated by highly charged Xe^{30+} ions with kinetic energies of 0.54 and 3 MeV have been carried out on the 320 kV ECR highly charged ions experimental platform at the Institute of Modern Physics (IMP), Lanzhou. In the tapping mode SFM image, the nano-sized hillocks protruding from the surfaces are probed. Results show that the height is equal to 3.1 ±1.1 nm and radius is equal to 13 ± 7 nm by irradiation of 0.54MeV Xe^{30+}. Such results are compared to hillocks created also by Xe^{30+} at an energy of 0.3 MeV studied by El-Said et al. [4]. Using SFM in contact mode, the measured height is equal to 0.4 ± 0.1 nm and radius to 20 ± 4 nm. The height is lower and the radius is larger in contact mode than in tapping mode as already observed for hillocks on CaF_2 surface irradiated by swift heavy ions and measured by contact mode [5] or tapping mode [6].

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High resolution depth profile analysis of ultra-thin STO/TiN layers on Si by LEIS

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Low-energy ion scattering (LEIS) can selectively analyze the atomic composition of the outermost atoms of a surface. Just like in higher energy RBS techniques (High and Medium Energy Ion Scattering) the incident projectiles may also scatter back from atoms in deeper layers. The effective neutralization of ions like He^+ strongly reduces the LEIS signal from subsurface layers and is thus responsible for its extreme surface sensitivity. However, above a particular threshold energy, a small fraction P^+ of the He^o projectiles is reionized again upon leaving the surface. Details of this LEIS process and values of the energy threshold are given in [1]. From the analysis of ions, including reionized projectiles, information can thus be obtained on both outer surface and sub-surface layers. By use of the sensitive Qtac LEIS analyzer, which combines a very large acceptance angle with parallel energy detection, this is done with high-resolution and high efficiency. Since at low energy E the energy loss along the ion trajectory scales with $\sqrt{E}$, the depth resolution improves when using lower primary energies. Thus with1.2 keV He^+ scattering one can detect, for instance, the increase of a layer thickness by 1 carbon atom [2].

For a quantitative analysis of the depth profile it is crucial to know the (energy dependent) ion fraction P^+ or perform a calibration using well-known reference samples. A fast Monte Carlo simulation program (TRBS) developed for ion backscattering [3] has been used to determine the energy distribution of all (ions + neutrals) backscattered particles. The code accounts for multiple scattering, straggling and electronic stopping. Since it is essential to use the correct electronic stopping power, and no reliable data are available in the energy range of interest, a 3 nm TiN/Si sample was used to obtain this information on the TOF-LEIS setup ACOLISSA at Linz University.
It will be shown how the energy dependence of P^+ can be determined by combining LEIS (only backscattered ions) with the TRBS code. Using TRBS corrected for the ion fraction (TRBS-I) the in-depth profiles of ultra-thin layers of TiN and $SrTiO_3$ deposited on silicon were determined with 3 and with 7 keV He^+ scattering. These layers were grown by ALD and PVD. TRBS-I and complementary analysis using techniques such as MEIS have yielded results that serve as a guide for choosing optimum scattering conditions for in-depth analysis by LEIS in future.

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Multiple scattering effects in the MEIS analysis of buried nanoparticles systems

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The synthesis of 2-dimensional nanostructured systems buried into a solid matrix has attracted interest in connection e.g. with plasmonic or magnetic applications. For both, the properties of the nanoparticle (NP) system are strongly dependent on the size, shape, areal number density and spatial order of the NP set. Medium energy ion scattering (MEIS) is an ion beam characterization technique, which have a great potentiality to investigate such kind of systems through the use of PowerMeis software [1], that considers any geometry, size distribution, composition and density of the nanostructures, and also the asymmetry of the energy loss-distribution. However, multiple scattering effects have not been taken into account. These effects can be important for the analysis of systems of buried NPs [2] and also for new MEIS setups using ions heavier than He [3] at lower energies. In this work, the energy loss due to multiple scattering effects was included in the PowerMeis program. Our results show a large contribution of multiple scattering effects in case of the analysis of a 2D buried array of Pb and Au NPs distant from the surface by about 60nm using 100 keV He ions. [2]. The inclusion of such effects improves the precision of the MEIS analysis of buried NPs and affects the determination of the shape and mean volume of the NPs. Other examples of the importance of multiple scattering effects, in particular their dependence with the shape, volume and density of buried NPs will be discussed.

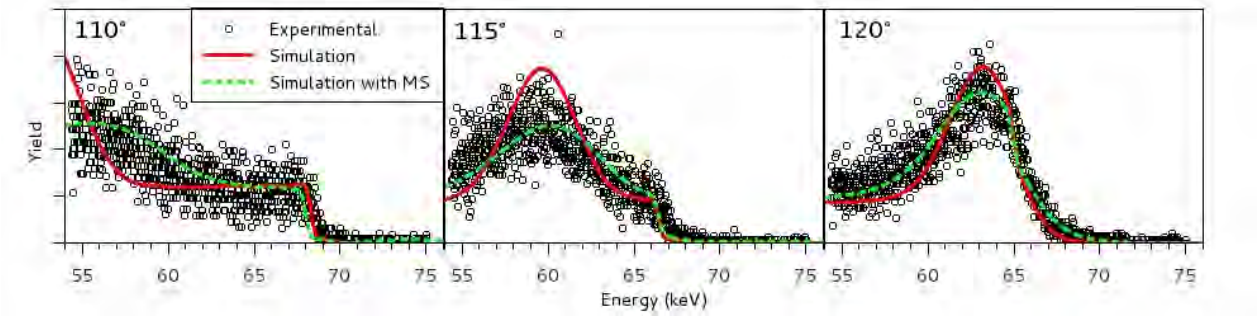

Figure 1. MEIS energy spectra of a 2D set of Pb NPs covered by 61nm SiO2 layer [2] using 100keV He^+ ions compared to PowerMEIS simulations, with and without multiple scattering effects for different scattering angles.

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Effect of Low Energy Deuterium Ion Irradiation on Iron Oxide (Fe_2O_3)

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Iron oxide (Fe_2O_3) is one of rich materials in the nature world. However, there is little knowledge about the irradiation effects on the iron oxide by low-energy ions of hydrogen-isotopes. In this study, we have measured the depth distribution of deuterium (D) and the change in the X-ray diffraction (XRD) pattern of Fe_2O_3 films by low-energy D ion irradiation and investigated the D-incorporation effect and irradiation (energy deposition) effect on Fe_2O_3. Here, D is chosen because D can be easily detected by nuclear reaction analysis (NRA), D(^{3}He,α)H.

Samples were prepared by deposition of Fe layers on SiO_2-substrates (RF-magnetron-sputter method) and followed by thermal oxidation [1]. The crystal structure of the oxide was confirmed to be α-Fe_2O_3 (hexagonal, corundum structure), and the film thickness was evaluated by Rutherford backscattering spectroscopy (RBS) of 1.8 MeV He^+. Samples were irradiated by D ions generated using D-plasma of grow discharge in D_2 gas with 60 Hz AC-applied voltage of 1.5 kV [1].

Depth distribution of D was measured by using 1 MeV ^{3}He and by detecting α-particles at the angle of 90 º measured from the incident beam direction. It appears that D's in α-Fe_2O_3 (100 nm thickness) are distributed deeper than the range distribution (< 30nm) calculated by using TRIM code, but, not uniformely distibuted in the film and more than 90 % of D's are located in the film, indicating small D diffusivity near room temperature. By integrating the D-density and consodering ^{3}He beam induced desorption, the amount of D-retention in α-Fe_2O_3 is evaluated to be 50×10^{15} cm^{-3}, in reasonable agreement with the reported value [1] and the value appears to be saturated at the D-ion irradiation time of 15 min. It appears that the XRD intensity vs the diffraction angle of α-Fe_2O_3 (60 nm thickness) becomes broader and the XRD intensity decreases to 1/3 of that of unirradiated film at D-ion irradiation time of 30 min and the patterns reveal two components. Thus, it is more likely that both D-incorporation effect and D-ion irradiation effect (limited within 30 nm) contribute to the XRD modifications.

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Damage Processes, Structure and Magnetic Moments Distribution in Fe_3O_4 Magnetic Films Irradiated by Swift Heavy Ions: Theoretical Modelisation and Experimental Results

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Swift heavy ions (SHI) irradiation is a unique and effectual tool, which is recognized to produce controlled defects (point/cluster and columnar), structural disorder, stress, and phase transformations in the thin films and to modify the physical properties of materials [1,2]. In addition, it is well known that the distribution of the magnetic moments in the films depends on the competition among magnetocrystalline anisotropy energy (E_k), demagnetization energy (E_d) and magnetoelastic energy (E_λ), and the effective magnetic anisotropy (E_{eff}) is by the above components interaction results. So, can we modify E_{eff} by SHI irradiation and model its damage processes?

The experimental were performed on the materials research terminal of the HIRFL-SSC (IMP, Lanzhou) and a micro-model of the damage were reasonably assumed to fitting experimental results. In experiment, Fe_3O_4 films were irradiated at RT with 2.03 GeV Kr^{26+} ions for fluence range from 5×10^{11} to 1×10^{13} ions/cm^2.

By means of contrast of the CEMS spectra of pristine and irradiated Fe_3O_4 films, it is found that occupancy distribution of the metallic cations in the films has changed significantly and the electronic-excitation effects result in a change of magnetic anisotropy after SHI irradiation. And the corresponding value of E_d is calculated according to the CEMS results. In consideration of the approximate infinite plane of films and a large number of columnar defects (latent tracks) in the films induced by SHI irradiation, we assumed that the modification of E_d is dominated by SHI irradiation process. In order to understand the magnetic moment distributions in the films, a micro-model of the damage in the films were reasonably assumed and the E_d of the pristine and irradiated Fe_3O_4 films were calculated. The value of E_d from CEMS is very close to the calculated results from the micro-model of the damage, which indicated that our micro-model of the damage is right and SHI irradiation can modify E_d (E_{eff}) effectually.

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"The structure of $SrTiO_3$(001) surface analyzed by high-resolution medium energy ion scattering spectrometry"

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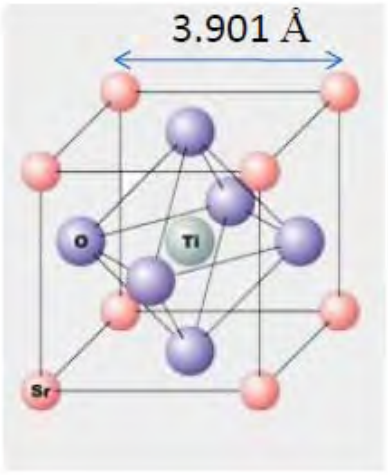
Strontium titanate ($SrTiO_3$) takes a perovskite structure with a large dielectric constant and recently attracts much attention due to formation of two-dimensional electron gas at a $LaAlO_3$(001)/$SrTiO_3$(001) interface and an H-terminated surface. The single crystal (001) surface consists of alternating TiO_2 and SrO planes. It was reported that the surface is terminated completely with a TiO_2 layer by chemical etching in a buffered NH_4F-HF (BHF: pH ~4) solution[1]. However, annealing in ultrahigh vacuum (UHV) leads to a clean surface with SrO face partly[2]. Recently, the surface X-ray diffraction analysis by Herger et al.[3] demonstrated that the single layer TiO_2 (S-TiO_2) on top is thermally unstable and the surface is terminated with a double layer TiO_2 (D-TiO_2) by annealing the chemically etched surface in UHV. We analyzed the $SrTiO_3$(001) surfaces by high-resolution medium energy ion scattering (MEIS) before and after annealing in UHV. As the results, it was shown that the surface chemically etched in the BHF is perfectly terminated with the S-TiO_2 layer and the surface annealed in UHV consists of the D- TiO_2 and SrO faces. Interestingly, re-etching the annealed sample in hot water at 50°C and then annealing again at 600°C in UHV led to almost D-TiO_2 termination although a small fraction of SrO face still existed. The present high-resolution MEIS checked the validity of the surface structure proposed by Herger et al. and found a significantly different structure.



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Surface Modification of Teflon by Nitrogen Ion Beam Irradiation

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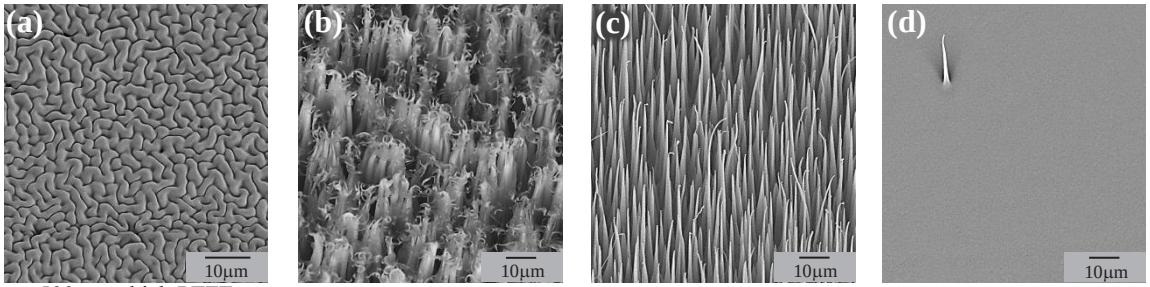
Polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP) are typical fluoropolymers and well known as Teflon®. FEP has the excellent optical transparency unlike PTFE, and the melting temperature is lower than that of PTFE. When these surfaces are irradiated with ion beam, both are covered with a large number of small protrusions and show the superhydrophobicity due to lotus effect. Previously, we reported the morphological change of these surfaces by 80keV N_2^+ ion beam irradiation and sample heating [1]. At a low fluence, the melted layer and micropores were formed on the surface. When the fluence increased, the melted layer gradually diminished and the micropores enlarged. After the melted layer vanished, the surface was finally covered with small protrusions. In this study, we investigated the difference in densities and the sizes of the protrusions caused by the changes of the ion energy, the current density and the sample thickness.

PTFE and FEP films (50-500 μm in thickness) were irradiated with N_2^+ ions using an ion accelerator. The ion energy was controlled in the range from 80 to 380 keV. The current density was also controlled in the range from 0.3 to 1.0 μA/cm^2. The surface morphology and chemical bonding were observed with a scanning electron microscopy (SEM), an optical microscope, and an attenuated total reflectance/Fourier transform infrared (ATR/FT-IR).

When 500-μm-thick PTFE sheet was irradiated with 380keV N_2^+ ion beam at the current of 1.0 μA/cm^2, the flat surface became wrinkly at the fluence of 5×10^{15} ions/cm^2 (Fig. 1(a)). Up to 1×10^{16} ions/cm^2, many protrusions with a shaggy top were formed (Fig. 1(b)). When 100-μm-thick PTFE was irradiated with N_2^+ ion beam with the same condition, the protrusions were spiny as shown in Fig. 1(c). In the case of 100-μm-thick FEP, only at 1×10^{15} ions/cm^2, the surface was nearly flat with very few protrusions (Fig. 1(d)). From the results, the surface morphology was controlled by the beam condition and the sample thickness. We will also discuss the chemical bonding of these surfaces.



500-μm-thick PTFE 5×10^{15} ions/cm^2 | 100-μm-thick PTFE 1×10^{16} ions/cm^2 | 500-μm-thick PTFE 1×10^{16} ions/cm^2 | 100-μm-thick FEP 1×10^{15} ions/cm^2

Fig. 1 SEM images of the surfaces irradiated with 380 keV N_2^+ ion beam. The uppers were sample and the lower were the fluence.

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Guiding effect of tapered glass capillary optics for MeV ion beam

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Rutherford backscattering spectroscopy is known to be useful for the depth profiling and compositional analysis of materials. However, the lateral resolution is limited by the diameter of ion beam. For this limitation, Nebiki *et.al*.[1] proposed the tapered glass capillary as a compact optics of beam transport. Indeed, they demonstrated that this optics can focus the MeV ion beam to sub-μm size with a significantly enhanced current density (focusing effect).

We performed similar experiments to ref.[1], by using 1.5 MeV He^+ ion beam. Then, in addition to the focusing effect, we found a new effect. It is the *guiding effect*, by which the MeV ion beam can be tilted from the initial beam direction. For the glass capillary, the ion beam could be guided by $\pm 3.5^\circ$ with respect to the initial beam direction (solid circles in Fig.1), and the ion beam was transported without degrading the quality of beam over this angular range. For better understandings of the effects, the same experiment was performed by using the electrically conductive capillary, instead of the non-conductive glass capillary. The size and shape of the conductive capillary was practically the same as the non-conductive glass capillary, since it was prepared by silver-plating on the inner and outer surfaces of the tapered glass capillary used. Both focusing and guiding effects could not be observed for the conductive capillary (open circles in Fig.1), which was electrically held on the ground level. Therefore, the electric charging-up of the insulating capillary surface would be primarily responsible for both effects, even for the MeV ion beam.

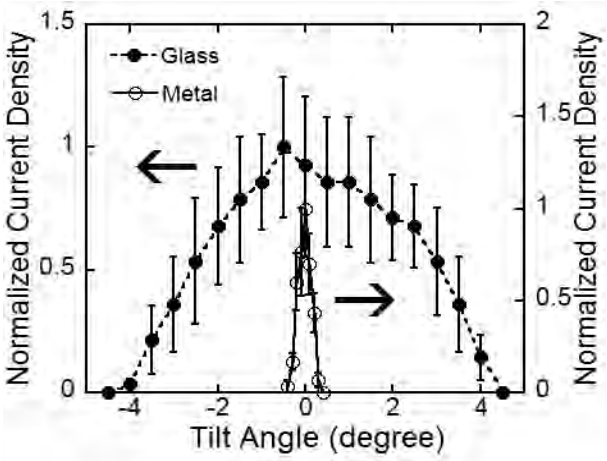

Figure 1. the guiding effect by glass capillary(solid circles) and silver plated capillary(open circles).

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Spectroscopic Characterization of Ion-irradiated Multi-layer Graphenes

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Graphenes have been attracting attention as new semiconductor materials with intriguing properties, basic and applied researches have been intensively carried out in the world[1]. Interesting properties of graphenes can be employed in numerous potential applications such as transparent conductors and quantum devices. On the other hand, control of electrical and optical properties is essential to realize the graphene devices. It was reported that the band gap of the graphenes was controlled by introduction of defects into the graphenes. Soft X-ray absorption spectroscopy (XAS) has been one of powerful tools since it provides not only information on the local electronic structure surrounding excited carbon atom, but also orientation of the π bonds of carbon. However, there were a limited number of soft X-ray spectroscopic studies on multi-layer graphenes into which defects are introduced by ions.

In this study, multi-layer graphenes grown by catalytic CVD were irradiated with low energy Ar ions with different ion doses, and characterized by XAS, X-ray photoelectron spectroscopy (XPS), and Raman spectroscopy. Number of layers of graphenes used in this study was estimated to be 3 to 5 from 2D peak position and shape of Raman spectra of as-prepared graphenes. In order to investigate local bonding configurations and electronic states of the irradiated graphenes, XAS and XPS were used. The results revealed that π* peak intensity was decreased with increasing dose of the ion in the XAS spectra (Fig. 1). This suggests that sp^2 component in the graphenes is decreased by the ion irradiation.

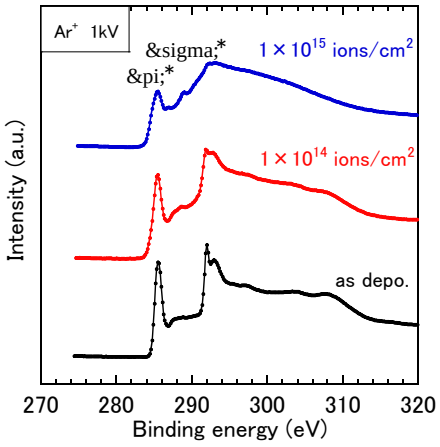

Figure 1. Soft X-ray absorption spectra of Ar ion irradiated multi-layer graphenes

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Ion-induced luminescence and damage process of $LiTaO_3$

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Lithium-based oxide ceramics are promising candidates for tritium breedimg materials in a fusion reactor utilizing the D-T reaction. The tritium recovery strongly depends on the release behavior of tritium affeted by the defects that MeV energetic particles from the Li-n nuclear reactions bring about. Therefore the damage accumulation and its interaction with hydrogen isotopes are needed to be clarified. Among the conventional ion beam analysis techniques, the ion-induced luminescence is a potentially powerful tool capable of examining modifications and their evolution under irradiation conditions[1]. In the present study, the ion induced luminescence measurements were carried out to examine its basic characteristics of the light emission and the damage accumulation in Li oxide materials.

Samples used in the present work were commercially available $LiTaO_3$ single crystals having <0001> axis normal to the surface, with a size of $10\times10\times0.5$ mm^3. The sample was placed in a scattering chamber connected with a 1.7 MV tandem accelerator. The light emitted from the sample in the scattering chamber was collected through a synthesized silica window and a lens focused on a silica fiber connected to an optical spectrometer, which consists of a monochromator equipped with a CCD camera. The evolution of the ion-beam-induced luminescence spectrum was monitored for wavelengths from 300 to 900 nm during the irradiation of H, He and O ions for the various incident energies between 0.3 and 4 MeV. The photo-stimulated luminescence (PL) was also obtained in the same chamber using 266 nm (4.7 eV) photons from the fourth harmonic wave of an Nd:YAG laser.

A broad peak centered at about 500 nm was observed in a $LiTaO_3$ crystal under the ion bombardment and was essentially the same as the UV photon irradiation. The intensity of the luminescence drastically enhanced with a decrease of the temperature, with an activation energy of 0.15 eV estimated for the non-radiative transition process. The analysis of decay curves of the luminescence showed two components of lifetime, 5 and 50 ns. During the ion bombardment at room temperature the peak intensity from the $LiTaO_3$ crystal monotonically decreased with a relatively slower reduction rate in comparison to that of Li_2ZrO_3[2]. Assuming first-order kinetics of the annihilation process of the luminescence centers, the annihilation rate constants of the luminescence centers is proportional to the nuclear energy deposition of the incident ions, while the recovery of the damaged ones is effectively occured by the electronic energy deposition.

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Surface Composition Analysis of Binary Mixtures of Ionic Liquids

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Ionic liquids (ILs) are composed entirely of cations and anions, and in a liquid state near room temperature (below 100°C in a broad sense). There are more than 10^6 different ILs with various combinations of cations and anions. ILs commonly have some unique properties such as high ionic conductivity, negligible vapor pressure, incombustibility, and good thermal stability of wide temperature range. However, their properties can be turned in a wide range by varying the combination of cations and anions. This diversity of the properties allows them to be promising for applications in many fields, for example, as safer electrolyte of lithium secondary battery, lubricating oil under severe conditions where usual lubricating oil does not work, and so on. Furthermore, mixing two or more kinds of ILs is also considered to be effective to tailor the properties precisely for a specific application. For some applications, it is of great importance to understand the relation between the surface structure of ILs and their properties to select or design an IL with desirable properties. In the last decade the surface structure of ILs were intensively investigated with various techniques of surface analysis. However, there are only a few studies on surface structure of IL mixtures [1-3], and even the surface composition is not fully elucidated.

In this study, we analyzed surface composition of several binary mixtures of imidazolium-based ILs by two different techniques, time-of-flight secondary ion mass spectrometry (TOF-SIMS) with grazing incidence of MeV ions and high-resolution Rutherford backscattering spectroscopy (HRBS). Surface sensitivity in SIMS and high quantitativity in HRBS revealed the molecular composition and orientation at the surface of IL mixtures.

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Surface structural analysis of MgO(111) using low energy atom scattering spectroscopy

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Fundamental concepts for surface science are well-established and their applications are straightforward for metals and semiconductors, but not for insulators and materials in the electric/magnetic fields. Bombardment of insulator surfaces by charged ions can be induced a charge on their surfaces. One can see the charging/discharging dynamics of the insulating material during this ion-beam bombardment. Sometimes, an electron shower using a tungsten filament placed nearby a sample is used to reduce the sample charging. However, electron-shower failure can cause sample damage. Therefore, we developed a low-energy atom scattering spectroscopy system for the analysis of these insulator surfaces [1]. Low-energy atom beams were produced using ion beams. Atom beams were converted from ion beams by charge exchange while the ion beams passed through a small gas chamber.

MgO is an exceptionally important material, which used in catalyst, toxic-waste remediation agent, or as an additive in refractory, paint as well as for fundamental and application studies. The 111 surface gives a hexagonal arrangement of atoms. We have been wondered which atoms, that is to say, Magnesium or Oxygen atoms are more dominant on topmost surfaces ? Here, low energy atom scattering spectroscopy will give answer and show experimental results on MgO(111) surfaces. Figure 1 shows the image of Mg atoms obtained from clean MgO(111) surfaces. In details will be shown in the conference.

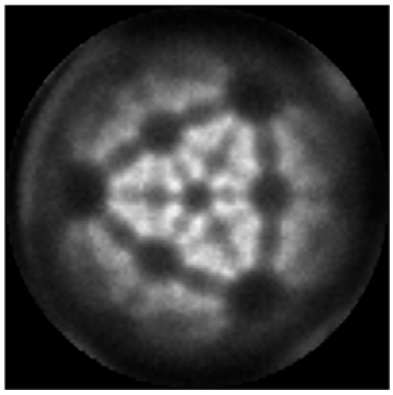

Figure 1. the Mg image of clean MgO(111) surfaces

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Intensity Distributions of Reflected Surface-channeling Protons Scattered on Surfaces of Electron-bombarded Alkali Halide Crystals

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Surface-channeling at grazing incidence of 550keV protons on electron-bombarded surfaces of alkali halide crystals is investigated. Electron-stimulated desorption (ESD) resulting from the irradiation of electrons changes the morphology of the surface. As the result of the ESD, the surface is covered by rectangular holes of monolayer depth with edges oriented along the crystallographic directions of <100> and <010> on the (001) plane [1]. In order to investigate the change of the surface morphology by the electron irradiation, the luminous intensity distributions (scattering patterns) of reflected protons on a fluorescent screen under the surface-channeling conditions is observed. The samples are KCl(001) and KBr(001). Figure 1 shows an example of the measured scattering patterns. The intensity profiles containing the incident and the scattered beams along the direction normal to the crystal surface are inserted on the top of the figure. The peak-angle of the scattered beam profile depends slightly on the irradiation dose. It shifts to lower angle and comes to a standstill. The peak-angles are compared with calculated results of a computer simulation. The modeled ESD surface is obtained by a section of the computer simulation. An example of the obtained surface morphologies is shown in Figure 2(a). Figure 2(b) shows calculated scattering pattern on the surface shown in Figure 2(a). The calculated scattering pattern reflects the changes of the morphologies of the ESD surfaces. This tendency is similar to the experimental results.

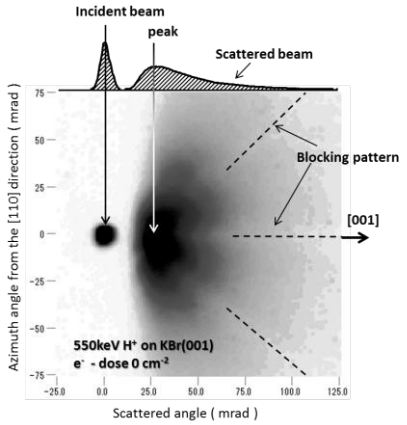

Figure 1 An example of measured scattering patterns.

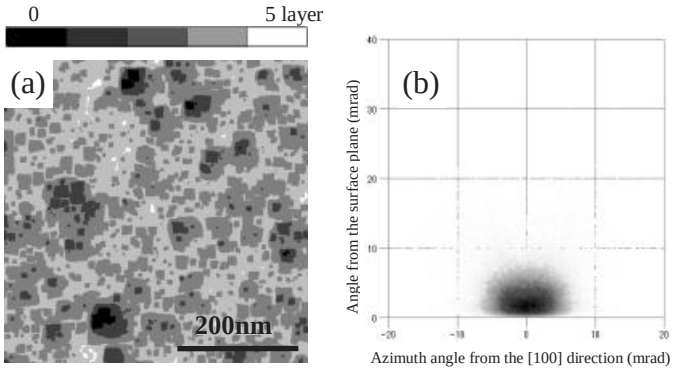

Figure 2 (a) Calculated surface for the irradiation dose of 1.5×10^{15} cm^{-2}. (b) Calculated scattering pattern on the surface.

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Direct Observation of Fine Structure in Ion Tracks in Amorpous Thin Films by TEM

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There are a lot of studies on the ion tracks produced in crystalline substrates because they can be easily observed using transmission electron microscopy (TEM). On the other hand, ion tracks produced in amorphous materials have not been observed by TEM. It has been thought that direct observation is difficult due to a lack of sufficient contrast. In this study, thin films of amorphous Si_3N_4 were irradiated with 120 – 720 keV $C_{60}^{+,\ 2+}$ ions and observed using TEM. The ion tracks produced in the amorphous material was directly observed by TEM for the first time. Figure 1 shows the observed TEM image. For quantitative analysis, the ion tracks were also observed using high-angle annular dark field scanning transmission electron microscopy (HAADF-STEM). The observed ion tracks consist of a low density core (radius ~ 2.5 nm) and a high density shell (width ~ 2.5 nm), which is very similar to the ion tracks in amorphous SiO_2 irradiated with high energy heavy ions observed by small angle x-ray scattering (SAXS) [1]. This suggests that the core-shell structure is a universal feature of the ion tracks produced in amorphous materials irrespective of the material and the ion. The observed track radius is almost independent of the incident energy in the observed energy region, where the electronic stopping power increases rapidly with energy while the nuclear stopping power decreases. This indicates that the nuclear stopping power is also responsible for the track formation and is more effective than the electronic stopping power.

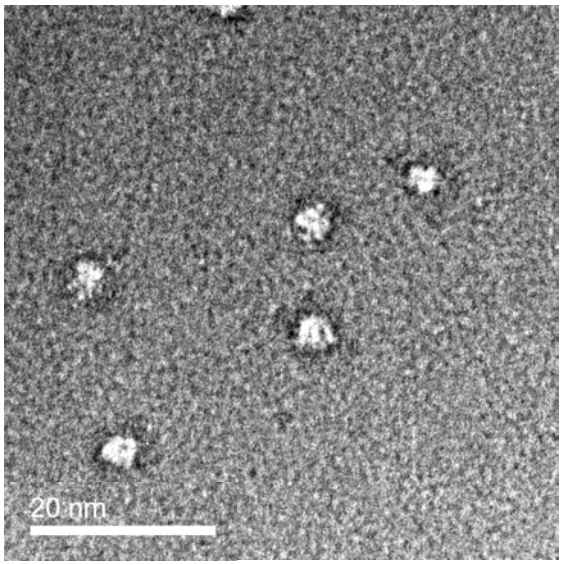

Figure 1. Observed TEM image of the amorphous Si_3N_4 irradiated with 720 keV C_{60}^{2+} . Sample thickness is 20nm.

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Measurements of Electron Attachment to Oxygen in Proportional Counter

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We have developed a proportional counter for measurements of low-energy β-rays and faced a problem on electron attachments which shows a clear energy-shift of the same event on spectra. This phenomenon is well-known as the negative-ion formation by electronegative molecule such as O_2 and H_2O contaminated in the counter gas, which causes some deterioration of time resolution and detection efficiency. Recently these influences in a long drift counter and in gaseous plasma have been investigated to optimize the performance of the detection system. In the long proportional counter, the electron attachments were studied by the pulse height as a function of drift time for different values of the oxygen contamination in counter gases.

However, as shown in Fig.1, we clearly observed a similar phenomenon of electron attachments by measurements of 5-keV Auger electrons from thin Fe-55 source by varying the concentration of oxygen gases, actually by that of dry air. It is thought that our data indicate sensitive response to the electron attachment, because the primary electrons drafting through oxygen gases are finally multiplied just around anode wire by a factor of about 10^4, i.e., a huge amplification known as a Townsend avalanche. We now systematically perform some meaurements to evaluate the electron attachment rate at different oxygen concentrations and also try to extract new information from these peak profiles on energy spectra. At this conference, we present our experimental method and newly obtained results.

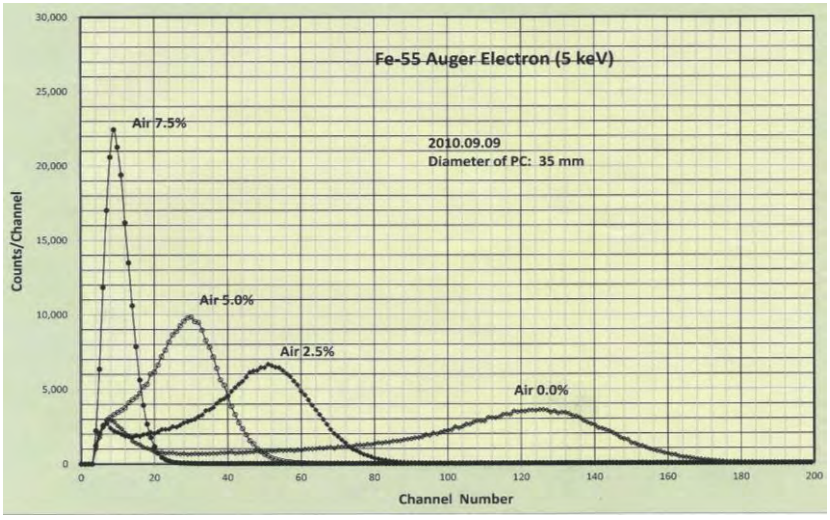

Figure 1. Energy spectra of 5-keV Auger electrons for differnt values of the oxyzen concentration controlled by that of dry air using the proprtional counter filled with CH_4. Fe-55 source was set on inner wall of the counter(50-cm-long and 3.5-cm-diam of cylindrical with 20-μm-diam tungsten wire).

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Tu-082

Positron energy loss and the interaction between positrons and soliton-like electron density in Graphite-Alkali Metal Intercalation Compounds

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Alkali-metal graphite intercalation compounds(AGICs) are interesting and important materials, which have quasi-two dimensional electron structure. Cartier et al.[1] have reported very interesting results of the angular correlation of positron annihilation radiation (ACAR) for AGICs. That is, it is seen that a strong anisotropic and narrow component appears in the center of the ACAR of C8K and C24K. Then hydrogen chemisorption effect in AGICs have been studied by means of positron annihilation [2,3]. So far the origin of the narrow compound in the positron annihilation spectra has not been confirmed. Recently the present authors [4] have analyzed the narrow components of the positron annihilation spectra with the theoretical formula, which is extended from "topological quasi-positronium model" [5]. In this study, we will discuss positron energy loss and the interaction between positrons and Skyrmion-like electron density in Graphite-Alkali metal intercalation compounds.

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WITHDRAWN

On the role of d-electrons in electronic stopping of slow light ions

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When ions traverse matter, they lose energy according to the stopping power S = dE/dx. These energy losses can be attributed to either collisions with target nuclei (nuclear stopping, S_n) or excitations of electrons (electronic stopping, S_e). For a free electron gas and projectile velocities below the Fermi velocity, S_e is expected to scale linearly with projectile velocity: $S_e = Q \cdot v$, with the friction coefficient Q as proportionality factor [1]. In recent years, many experiments have revealed, that for light ions and low projectile velocities the specific band structure of a target may lead to pronounced deviations from velocity proportional stopping [2,3].

This investigation focuses on the particular role of the d-electrons in the interplay between band-structure and electronic stopping. It has been shown for Au and Cu that the onset of the excitation of d-electrons may cause a significant increase in Q. This behavior leads to a pronounced kink in S_e at a certain projectile velocity. To gain a complete picture of the correlation between d-electrons and stopping power, materials with a different d-band configuration have been investigated, namely Ag and Pt. Ag is very similar to Au and Cu, except that the onset of the d-electrons is ~ 4 eV below E_F compared to ~ 2 eV for Au and Cu. Pt, on the contrary, features d-electrons with energies ranging from 8 eV below E_F up to E_F.

Experiments have been performed in backscattering geometry employing thin film targets. Electronic stopping has been deduced in two ways. First, at sufficiently high energy, electronic stopping was deduced from the width of the peak due to backscattering from the thin film, taking the influence of nuclear stopping and multiple scattering into account. The film thickness was determined quantitatively by RBS. Second, relative measurements were performed, relating the height of the backscattering spectrum to that of Au. In this case, no information on the film thickness was needed, but the absolute value of gold stopping was required instead.

Results are presented on electronic stopping of H and He ions in Ag and in Pt. To elucidate the role of the d-electrons, the present results are compared to the corresponding stopping values in gold. It is analyzed, to which extent surface impurities or the correction for nuclear stopping may introduce an uncertainty to the presented data.

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XMCD-PEEM observation of focused ion beam induced magnetic patterns on FeRh surfaces

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Equiatomic ordered FeRh alloy with the B2 (CsCl type) structure is of much interest due to the first order anti-ferromagnetic (AF) – ferromagnetic (FM) phase transition near the room temperature. In our previous studies, we reported that deposited energy through elastic collision by ion irradiation induced the FM state in FeRh films below room temperature where they were originally in the AFM state. [1] Such ferromagnetic ordering was found to be ascribed to the lattice defects introduced in the B2 structure due to the keV-MeV ion irradiation. And we have successfully produced micrometer-size lateral magnetic modulation by 10 MeV I ion microbeam rradiation.[2][3]

In the present study, we have demonstrated the fabrication of micron scale magnetic patterns by 30keV Ga ion irradiation using a focused ion beam system (FIB). We also discuss the magnetic domain structure of the irradiation induced ferromagnetic regions by using the X-ray magnetic circular dichroism-photoemission electron microscopy (XMCD-PEEM).Thin FeRh films were deposited on MgO(001) substrates by using an ion beam sputtering from Fe-50at.%Rh target. In order to make magnetic modulations, we irradiated huge numbers of 5-30 μ m square regions at the surface of the FeRh thin films. The fluences were 1×10^{12}/cm^2, 5×10^{12}/cm^2, 1×10^{13}/cm^2 and 3×10^{13}/cm^2.

We successfully confirmed the formation of the designated ferromagnetic dot patterns by a magnetic force microscope. As for the magnetic domain structures of ferromagnetic patterns, we observed the corresponding bright square regions in the XMCD-PEEM images. We also confirmed that the contrast become absolutely clear with increasing in the ion fluence. This result suggests that ion-irradiated microm-scaled areas definitely show the ferromagnetic state, magnetization of which increases with increasing ion fluence. We will discuss these magnetic domain structures in conjunction with the ion irradiation fluence.

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A new facility for *in-situ* analyses of slow highly charged ion modifications of various materials

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The interaction of highly charged ions (HCI) with materials has been investigated intensively in recent years. On different materials local topographic modifications at the ion's impact site could be identified by means of atomic force microscopy (AFM). The type of the produced nano-structures varies from pit-like (KBr, PMMA) to craters (TiO_2) and hillock-like structures on CaF_2 and others ([1, 2]). Most of the studies so far were performed under ex-situ conditions, meaning the target material was transported under ambient conditions from the place of irradiation to an AFM or scanning tunneling microscope. We present a new experimental set-up for in-situ investigations on HCI induced nano-structures. The set-up is based on an assembly of a Dresden-EBIT (Electron Beam Ion Trap) ion source and an Omicron ultra-high-vacuum-AFM. Samples can be mounted in the AFM and analyzed by means of AFM and STM before, during and after the irradiation with HCI. Samples can be heated in-vacuum to prepare clean surfaces before irradiation. The EBIT delivers highly charged ions with Xe charge states up to q=40+, which can be decelerated to kinetic energies of only 10 eVq.
Figure 1 shows a drawing of the set-up. The dimensions of the set-up are small compared to other HCI experimental set-ups. The EBIT is mounted in a high voltage cave and so a negative potential can be applied, while the AFM chamber is kept on ground potential. The final kinetic energy of the ions is defined by the difference of the extraction potential (respective to ground) and the target potential (ground) by $E^{final}_{kin} = (U_{ext} * U_{beamline}) * q$. A lens system focusses the beam onto the target with a beam diameter of less than 1 mm.

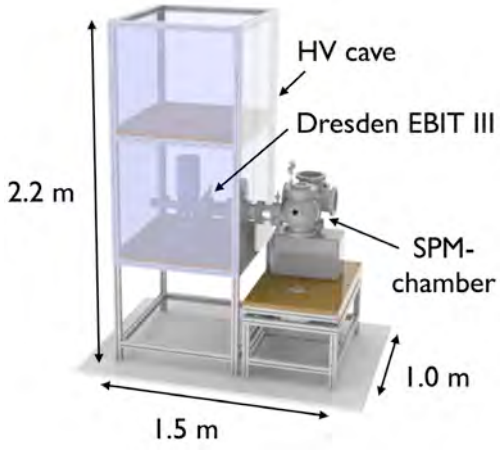

Figure 1. Schematic view of the set-up. The dimensions are indicated as well as the high voltage cave holding the ion source.

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Characterization of the monoclinic-tetragonal phase transition of zirconia by using proton implantation

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The tetragonal (t)–monoclinic (m) transformation of zirconia has a great technological importance for mechanical application since it is the basis for the transformation toughening of ceramic components[1, 2]. As a result of the typically potential room temperature of high temperature polymorphs (tetragonal and cubic) of ZrO_2, their stabilization at low temperatures and understanding the associated phase stabilization mechanisms has been of intense interests[3]. Here, oxygen ion vacancies or strain energy is also one of factors associated t-phase stabilization. Therefore, the implantation parameters (energy, ion dose, substrate temperature, and ex-situ annealed temperature) could play a vital role to study the resultant phase transition of zirconia. In this study, zirconia of monoclinic (m) phase was first prepared by Sol-Gel sythesis and the internal oxidation of Ag-$AgZr_2$ alloys, respectively, to study the phase transition of zirconia under irradiation with free surface and nano-confinement situations. Here, the particles size or grains size of pure monoclinic zirconia are ranging from 20 to 60 nm. The two kinds of specimens, i.e., pure monoclinic zirconia particles with and without Ag cladding, were followed by using protons implantation of 1.5 MeV and 50 keV energy. The fluences are from 1×10^{14} to 1×10^{16} ions/cm^2. The effect of implanted doses, were studied and characterized by using transmission electron microscopy (TEM) and x-ray diffraction (XRD). Consequentially, tetragonal (t) zirconia characteristic peak appeared on the free particles of zirconia after proton implantation of 1.5 MeV energy at the proton doses above 1×10^{15} ions/cm^2, while tetragonal zirconia characteristic peak all appeared on the Ag-cladding zirconia at the proton doses range from 1×10^{14} to 1×10^{16} ions/cm^2. Apparently, the m→t phase transition for zirconia free particle can be accomplished with the above threshold of requiring dose (1×10^{15} ions/cm^2), while the Ag-cladding zirconia could show the m→t phase transition at lower proton dose (1×10^{14} ions/cm^2) due to constraint effect. Moreover, there is no tetragonal zirconia characteristic peak appeared on the free particles and Ag-cladding zirconia at the same proton doses of 50 keV energy. It suggests that the implantation-induced lattice defects were not conducive to m→t phase transition. The further results and study on the m→t phase transition to the two kinds of zirconia will be discussed.

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Damage and recovery process of PEN films irradiated by MeV ions

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Polymers consisting of benzene rings are known to effectively absorb UV light and some of them are accompanied by photo emission in visible wavelengths, which can be utilized for monitoring the intensity and special distribution of the ionizing radiation. Polyethylene naphthalate (PEN) film, exhibiting superior and desirable properties such as Young's modulus and permeability to water, also shows irradiation induced blue luminescence. On the other hand, the ion bombardment of the polymer materials causes drastic changes in the optical properties of the PEN films, depending on the energy deposition process[1]. Moreover, particle irradiation causes irreversible degradation of the films accompanying significant release of O and H atoms, especially in vacuum condition[2]. In the present study, we measured evolution of MeV ion and UV photo induced luminescence of PEN films to examine the relationship between energy deposition and damage/recovery of luminescence characteristics of the films.

The samples were commercially available PEN (Teonex@, Teijin DuPont Japan) films with a thickness of about 9 μm. Irradiation of 0.3–2.0 MeV H^+ and 2.8 MeV He^{++} ions, which can penetrate the entire thickness of the sample film, was performed at room temperature in a scattering chamber connected with a 1.7 MV tandem accelerator. An area of about 100 mm^2 of the sample was irradiated with a current density less than 1 nA/mm^2 to prevent heating effects during the irradiation. The photo-stimulated luminescence (PL) was also obtained in the same chamber using 355 nm (3.5 eV) photons of a light emitted diode (LED) and of the third harmonic wave of an Nd:YAG laser. The evolution of the ion-beam-induced luminescence spectrum was monitored for wavelengths from 300 to 900 nm during the irradiation. Immediately after the irradiation, the PL measuements were continuosly carried out to observe recovery phanomena in the sacattering chamber filled with the air at a temperature range between 290 and 400 K

The PEN film exhibited characteristic luminescence bands mainly in the 400-500 nm wavelengths under the both ion and photon irradiation. At the beginning of the ion irradiation to a fluence of 10^{13} $ions/cm^2$, the peak intensity immediately diminished, followed by a smaller decrease rate at higher fluence. Similar two step reduction behavior of the PL intensity was found during the LED exposition where the energy fluence of photons was comparable to the total energy deposition of the incident ions. This indicates that the damage process of the luminescence centers is essentially the same for ions and photons. After stopping irradiation, the PL intensity recovered as a function of time with a rate depending on the deposited energy fluence. The elevating temperature, however, prevented the damaged luminescence centers from being annealed, probably owing to the formation of a non-irradiative structure.

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Deposition of Ionic Liquid Ion Beams on Solid Substrate

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The ionic liquid(ILs) known as room-temperature molten solt show moderate electrical conductivity (1-100 S/m), high thermal stability (up to ~300 °C) and extremely low vapor pressure (< $1x10^{-9}$ Pa). Due to the typical ILs includes halogens in safety, reactive etching, surface modification and ILs deposition could be expected for silicon, silicon oxides and glasses. We developed an ionic liquid ion source(ILIS) with porous medium [1] known as a high current and stable method in the field of liquid metal ion sources. In this study, deposition of thin IL layer and surface modification of glass and silicon substrate by irradiation of IL ion beam was characterized.

1-butyl-3-methylimidazolium hexafluorophosphate(BMI-PF_6) was used for the source liquid. Positive and negative ion beams generated from an ILIS with porous emitter[1] were irradiated to a borosilicate glass substrate (Matsunami #7059) and a single crystalline Si (100) substrate. The positive ion beam was accelerated to 4, 6, 8 kV, and the negative ion beam was accelerated to -4, -6, -8 kV. The irradiations ware carried out under dose of $1x10^{13}$ - $1x10^{15}$ ions/cm^2 assumed as a single charge. Contact angle of pure water on the substrates were measured by sessile drop method before and after remove of deposited IL layer.

Surface liquid layer on the glass and Si substrate irradiated with positive and negative ion beam was observed. This is probably caused by mass of BMI-PF_6 ion which consists of at least 17 cation-anion pairs. Figure 1 shows dose dependences of contact angle of glass substrates irradiated with positive ion beam at acceleration voltage of 6 kV. Increase of the angle was observed for IL-removed, but not for as-irradiated. This means formation of thin IL layer on the surface-modificated glass substrate.

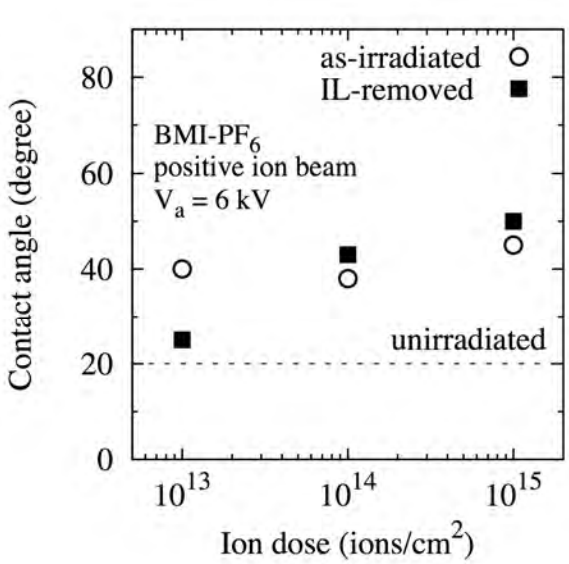

Figure 1. Dose dependences of contact angle of glass substrates irradiated with BMI-PF_6 positive ion beam.

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Ion Induced Patterns on Crystalline Ge Surfaces

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Low energy ion irradiations of surfaces can induce the formation of patterns with periodicities in the range of tens to hundreds of nanometers. These patterns have been used as templates for growing thin films with interesting anisotropic properties resulting from the modulation of their interface and surface [1].

At off-normal angle of incidence between around 55° and 70° and at room temperature ripple patterns oriented perpendicular to the ion beam direction are observed. At normal incidence or for incidence angles smaller than 55° smoothing dominates on elemental materials, like Si and Ge. However, additional surface instabilities can exist due to the presence of a second atomic species on the surface. Furthermore, on crystalline surfaces anisotropic diffusion or kinetic restrictions can also lead to additional instabilities.

We studied ion induced pattern formation on Ge surfaces with 1 keV Ar^+ at elevated temperature. In contrast to irradiations at room temperature we found pattern formation even at normal ion incidence. Similar to the case of ion irradiated crystalline metal surfaces a new instability appears at higher temperature due to the Ehrlich-Schwoebel barrier [2]. Depending on the surface orientation checkerboard or isotropic hole patterns with the symmetry of the patterns reflecting the crystal structure of the irradiated surface are observed (see Fig. 1a, b).

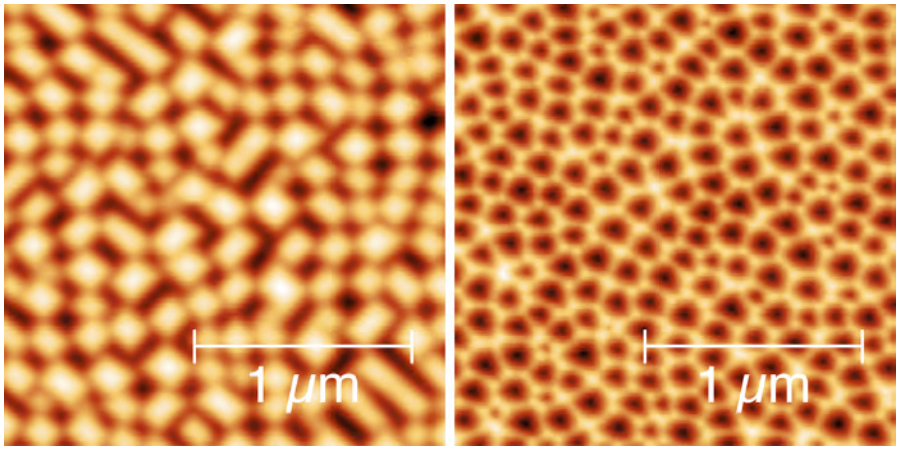

Figure 1. Atomic force microscopy images of ion induced patterns on crystalline (a) Ge (001) and (b) Ge(111) surface.

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Development of Ionic Liquid Ion Source with Porous Emitter for Surface Modification

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Ionic liquid ion source (ILIS) has attracted attention for a space propulsion, a focused ion beam and a primary ion of secondary ion mass spectroscopy. The ionic liquid(ILs) known as room-temperature molten solt show moderate electrical conductivity (1-100 S/m), high thermal stability (up to ~300 °C) and extremely low vapor pressure (< 1x10-9 Pa). Due to the typical ILs includes halogens in safety, reactive etching and surface modification of semiconductor materials could be expected. Several types of ILIS, such as an externally wetted needle made of tungsten and a capillary, have been reported. We developed an ILIS with emitter of porous medium[1] known as a high current and stable method in the field of liquid metal ion sources. In this study, ion beam properties and mass spectra of positive and negative ionic liquid ion beams extracted from the porous emitter were evaluated.

1-butyl-3-methylimidazolium hexafluorophosphate(BMI-PF_6) and 1-ethyl-3-methylimidazo- lium tetrafluoroborate(EMI-BF_4) were used for the source liquid. The ion beams were extracted by field-emission from a carbon needle with the porous carbon felt connected to a IL reservoir. Mass spectra of positive and negative ion beam of BMI-PF_6 and EMI-BF_4 with 4-8 kV of acceleration voltages were evaluated by means of time of flight method. Extraction current of the ILIS with porous carbon felt were measured with respect to beam stubility.

Figure 1 shows a mass spectrum of positive or negative ion beam of BMI-PF_6. The modes of the mass spectra were about 5-10x10^3 mass/charge. With regard to molecular masses of 139 for cation and 145 for anion, the mass/charge of the modes corresponds to cluster ion with 17-34 cation-anion pairs.

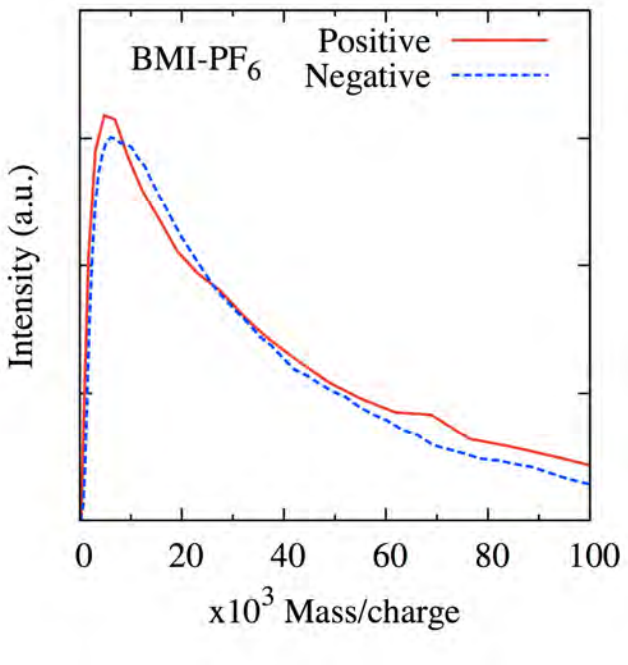

Figure 1. Mass spectra for positive or negative ion beam of BMI-PF6.

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Measurements of ^{4}He Elastic Scattering Cross Sections from Nitrogen for TOF-ERDA Using He beam

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A Time-of-flight Elastic Recoil Detection Analysis (TOF-ERDA) is one of the promising methods for the simultaneous measurements of multi light elements with good depth resolution [1,2]. We are developing a TOF-ERDA measurement system using He beams for the elemental analysis and depth profiling of light elements [3]. For quantitative measurements of elemental concentrations by the TOF-ERDA, reliable data of recoil cross sections are needed. For the TOF-ERDA using He beams of above about 2 MeV, the recoil cross sections are known to be non-Rutherford. In such case, experimental data for the recoil cross sections are necessary. Therefore, we plan to measure recoil cross sections for light elements such as Li, B, C, N, O bombarded by ^{4}He ions. This paper presents measurements of recoil cross sections for nitrogen bombarded by ^{4}He ions.

The experiments were performed using the 2MV tandem Pelletron accelerator at the Quantum Science and Engineering Center, Kyoto University. ^{4}He ions with an energy range between 2 MeV and 5.5 MeV were utilized for the incident beam, and a silicon-nitride membrane of 50 nm thickness with a coated thin Au layer was used as a target. Scattered ^{4}He ions were detected with silicon detectors at scattering angles of 83.6° and 165°. The scattering angle of 83.6° corresponds to the recoil angle of 40°, and recoil cross sections at 40° were evaluated from scattering cross sections at 83.6° using the kinematical calculation. We also measured the scattering cross sections at 165° for the backscattering experiments of nitrogen. This paper will present results of cross section measurements as well as details of the experimental setup. Comparison between the present data and calculations will also be indicated.

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Structural characterization of planar set of buried Au nanoparticles

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In order to build nonvolatile memory devices with smaller size, faster operating speed, and larger storage capacity, the investigation of a floating gate transistor with discrete charge traps (nanocrystals (NCs)) has attracted great interest. In this case, the charge is trapped at discrete sites, and it is more stable than in a conventional conductive floating gate as the latter can lose trapped charge through a single leakage path in the gate oxide. Thus, NCs floating gate memory is expected to have a longer retention time than the conventional devices. One way to synthesize a sandwich structure with a 2-dimensional set of NCs between two dielectrics is by physical deposition of an ultrathin metal (such as less than 1 nm of Au, Ag, Ni, Pt and Co) [1]. The device efficiency depends, among other factors, on electric isolation of the NCs for the charge retention. Therefore, the understanding of the relationship between the amount of metal, which nucleates as NCs, and amount of metal retained in the dielectric around the particles, which can decrease the charge retention of the NCs, is of major importance. In this work we investigate a planar set of Au NCs buried ~30 nm into a SiO_2 matrix, synthesized by sputtering deposition of 1.8×10^{15}, 3.1×10^{15} and 7.4×10^{15} Au/cm^2, over a silica thin film over a Si (001) substrate and followed by a deposition of another SiO_2 thin film. The size distribution and areal number density of the NCs for each case were well characterized through transmission electron microscopy (TEM) and grazing incidence small angle X-ray scattering (GISAXS). The amount of Au not nucleated as NCs and the corresponding depth profile distribution around the NCs was measured by medium energy ion scattering (MEIS). The typical mean size, FHWM of the size distribution and areal number density obtained were 3 nm, 20% and 13×10^{11} NCs/cm^2, respectively. The amount of non-nucleated Au is about 60-70% for some cases, and the highest concentration of atomic Au around the NCs is about 5 atomic percent. The MEIS data were analyzed through the PowerMeis software [2], where the structural information obtained from TEM and GISAXS was taken into account.

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Study of optical, structural, chemical and dielectric properties of 145 MeV Ne^{6+} ions irradiated PTFE polymer

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Abstract

The bombardment of the polymeric materials with Swift Heavy Ions (SHI) results in the change of their significant optical, structural, chemical and electrical properties in the form of rearrangement of bonding, cross-linking, chain scission, formation of carbon rich clusters and changes in dielectric properties etc. Modification depends on the ion beam parameters (ion, energy and fluence) and the polymeric material itself. In the present work characterization of the optical, chemical, structural electrical modifications in PTFE induced by 145 MeV Ne^{6+} ions were carried out through UV-Visible spectroscopy, Fourier Transform Infra Red spectroscopy (FTIR), X-Ray Diffraction (XRD) and LCR meter. 100 μm thick PTFE polymer procured from Good fellow, Cambridge Ltd. England (UK), were irradiated by 145 MeV Ne^{6+} ions to various fluences at Variable Energy Cyclotron Centre (VECC), Kolkata, India.

From UV-Vis spectra the optical band gap (E_g), calculated from the absorption edge of the UV spectra of the films in 200-800 nm region varied from 2.23 eV to 1.63 eV for pristine and irradiated samples. At the highest fluence of 10^{13} ions/cm^2 the maximum change in optical band gap ~26% has been observed. The cluster size changes from 236 to 443 carbon atoms per cluster. Carbon enriched domains created in the polymer during irradiation may be responsible for the decrease in the band gap. In FTIR spectra, appreciable changes have been observed after irradiation, indicating molecular fragmentation, cross-linking, formation of unsaturated group and free radicals. X-Ray Diffraction (XRD) analyses show significant change in crystallinity with fluence. Dielectric constant (ε') decreases with frequency whereas it increases with the ion fluence. Variation of loss factor (tanδ) with frequency reveals that tan δ increases as the frequency increases. Tanδ also increases with fluence. Tan δ has positive values indicating the dominance of inductive behavior. A sharp increase in A. C. conductivity in pristine as well as in irradiated samples is observed with frequency. Due to irradiation the increase in conductivity with fluence at a given frequency may be attributed to scissoring of polymer chains, resulting in an increase of free radicals, unsaturation, etc.

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Ion-induced Modification of Glassy Carbon Structure and Morphology

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The ion-induced modification of high-temperature glassy-carbon SU-2500 under 5-30 keV Ar^+ ion irradiation at high fluences (10^{18}-10^{19} ion/cm^2) has been studied from room temperature (RT) to ~ 400 °C. The structure changes of glassy carbon surface layer has been carried out using *in situ* analysis of the temperature dependences of ion-induced electron emission yield $\gamma(T)$ and reflection high energy electron diffraction (RHEED) [1]. The morphology changes have been studied by scanning electron microscopy (SEM). The temperature dependences $\gamma(T)$ show a transition from a step-like behaviour with a jump at damage annealing temperature T_a ~ 130°C for 30 keV ion energy to the temperature independent curves as ion energy decreases. The reason of such transformation is the decrease of disordering of a fullerene-related structure of high-temperature glassy carbons with decreasing of ion energy as a consequence of decreasing level of radiation damage ν (*dpa*). The calculations of the dependence of the amorphous fraction on ν using an error function have made it possible to find the threshold values ν_{am} when the structure of glassy carbon is virtually not disordered under ion irradiation at RT. The threshold of $\nu_{am} \approx 60$ *dpa*. At elevated temperatures ($T > T_a$) and ion energy > 15 keV the graphitization of SU-2500 surface layer takes place as the RHEED shows. SEM analysis shows that the structure changes lead to difference of ion-induced morphology. After irradiation at RT the SEM micrographs show the etch pits with pentagon and hexagon forms, Fig.1a. The elementary ordering of carbon lattice at $T > T_a$ results to the shallow-cellular pattern, Fig. 1b. At more higher temperatures SU-2500 graphitization leads to the morphology similar to irradiated polycrystalline graphite [2], Fig.1c.

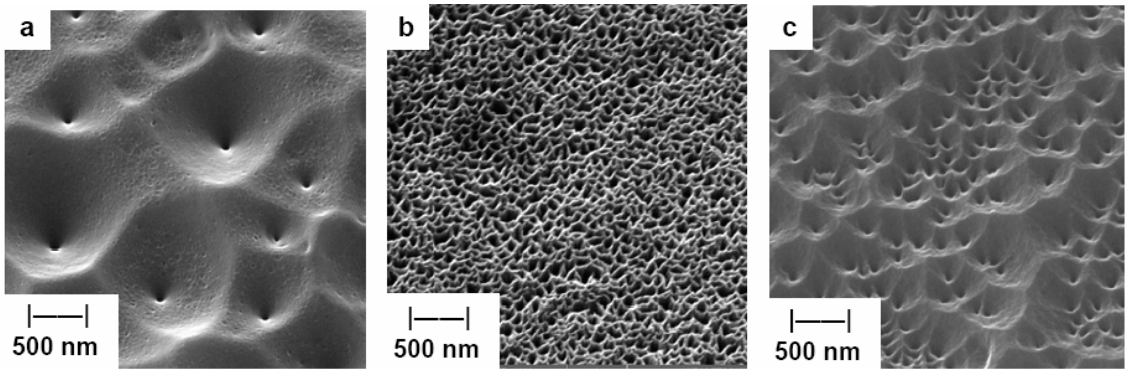

Fig.1. SEM micrographs (tilt 30°) of glassy carbon SU-2500 surface after 30 keV Ar^+ ion irradiation (normal incidence) at room temperature (a), 250 (b) and 400 ^oC (c).

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Development of novel compact spin-polarized electron gun

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We have already developed a novel high brightness and high spin-polarized low energy electron microscope (SPLEEM) and applied it to clarify the magnetic property of [CoNix]y/W(110) and Au/CoNi2/W(110) during growth of ultra thin films[1-3]. Such thin film multi-layers are important for current driven domain wall motion devices [4]. Our developed SPLEEM can make us the dynamic observation of the magnetic domain images possible. However the size of the spin-polarized electron gun is large and we have started to develop a new compact spin-polarized electron gun with new idea. It is necessary two devices to operate 3 dimensional spin direction. One is a spin manipulator which changes the out of plain spin direction and another one is a spin rotator which can change the in plain spin direction. We have proposed a multi-pole Wien filter which can make 3 dimensional spin operation with one device possible. Fig.1 shows a drawing of the developing 3D multi-pole spin manipulator which has 8 poles.

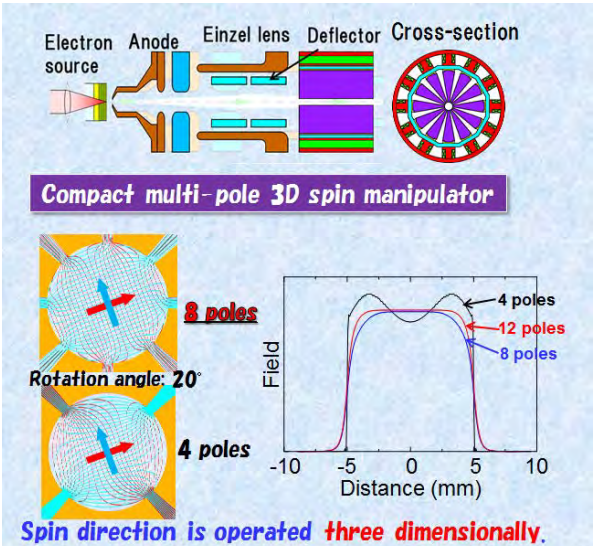

Fig. 1: 3D eight-pole spin manipulator and uniformity of magnetic and electric field

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Harvesting and Storing Laser Irradiation Energy with Graphene-Cu Compound Structure

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Graphene-metal compound structure has been reported as a novel and outstanding component used in electrical and optical devices. We report on a first-principles study of graphene-cu compound structure, showing its capacity of converting laser energy into electrical power and storing the harvested energy for a long time. A real-time and real-space time-dependent density functional method (TDDFT) is applied for the simulation of electrons dynamics and energy absorption. The laser-induced charge transfer from copper layer to graphene layer is observed and represented by plane-averaged electron difference and dipoles. The effects of laser frequency on the excitation energy and charge transfer are studied as well. The enhancement of C-C σ-bond and decreasing of electron density corresponding to π-bond within graphene layer indicate the way in which the transferred-charges are stored. In addition, the shift and oscillations of dipole along z-direction after the application of laser pulse offer a concept that the compound structure has the ability of storing the harvested energy for a long time.

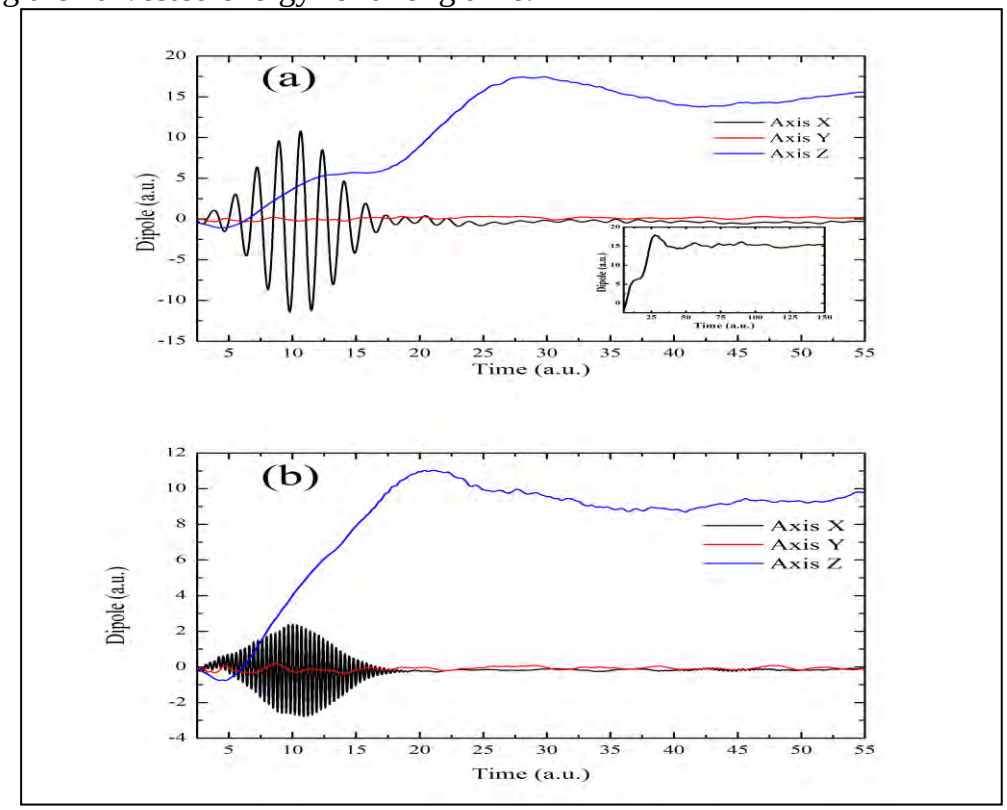

Figure 1. Dipoles along the 3 axes as a function of time under the irradiation of laser pulse with energy of (a) 100 eV and (b) 500 eV. The insert in (a) shows the changes of dipole along z axis for a relatively long time up to 150 a.u. (about 3.7 fs).

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Magnetic Effects Following Proton Irradiation in Diamond

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Following recent experiments involving proton induced magnetization in graphite [1,2], we demonstrate related experiments in diamond. A proton micro-beam of 2.2 MeV energy generated using a nuclear microprobe is used to create microscale magnetic domains in ultra pure single crystal synthetic diamond. Characterization of the magnetized domains is achieved using Atomic/Magnetic Force microscopy analysis (AFM/MFM) and Raman Spectroscopy. Preliminary measurements using the Superconducting Quantum Interference Device (SQUID) are also presented. Sources of possible AFM/MFM induced artifacts are considered and discussed in detail.

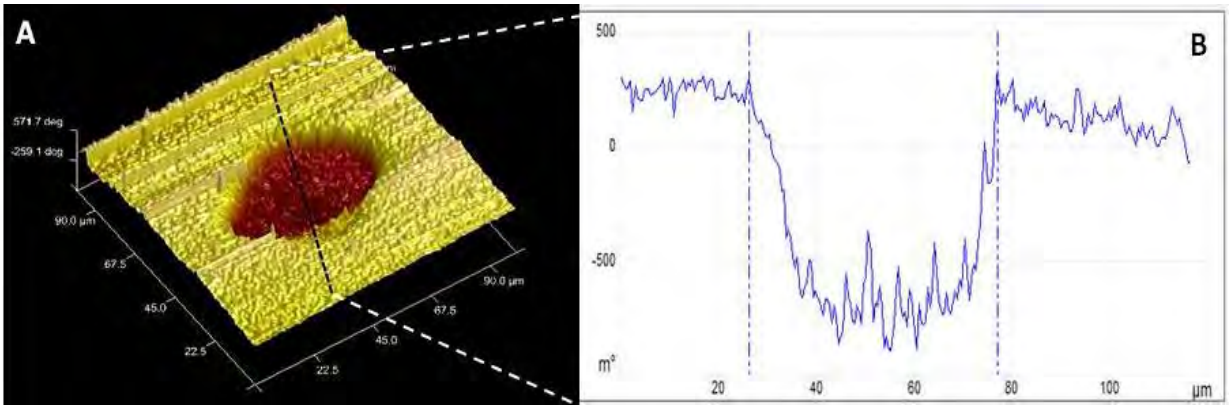

Figure 1. Example of a MFM phase image (A) showing a proton induced magnetic microscale domain together with a line profile across the microscale domain (B) in Diamond.

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Photoluminescence and Thermoluminescence study of $K_2Ca_2(SO_4)_3$: Cu nanophosphor for gamma ray dosimetry

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Nanocrytstalline $K_2Ca_2(SO_4)_3$:Cu was synthesized by chemical co-precipitation method and annealed at 700 ^oC. XRD spectra shows the orthorhombic structure and the crystallite size ~ 20 nm. The same was also confirmed with TEM and shows nanorods of $K_2Ca_2(SO_4)_3$:Cu having diameter 20nm and length 200nm. These nanocrytstalline samples were irradiated with gamma radiation for the dose varying from 1Gy to 20kGy and their thermoluminescence (TL) and photoluminescence (PL) characteristics have been studied. In PL spectra, the emission bands are observed at 403 and 419 nm respectively and their respective intensity increases linearly with the increase in the gamma dose. The glow curve of the nanocrystalline material shows a major peak at around 163^{0}C and one small peak at 290 ^{0}C. Moreover, one peak at higher temperature around 365^{0}C has been observed after the gamma dose of 100Gy. The TL response shows a linear behavior up to 1kGy and further saturates with increase in the gamma dose .This saturation occurs may be due to the generation of new peak. Moreover, a significant shift in the peak towards lower temperature has been observed. This indicates the disorganization of the initial energy bands in the $K_2Ca_2(SO_4)_3$:Cu nanophosphor.Computerized Glow Curve Deconvolution (CGCD) program was used for the analysis of TL glow curves. Trapping parameters for all the TL glow curves of $K_2Ca_2(SO_4)_3$:Cu nanophosphor from 0.1Gy to 20kGy have been calculated and correlated with the gamma dose. The property of linearity, simple glow curve and negligible fading makes the nanocrystalline phosphor useful for the estimation of high doses of gamma rays.

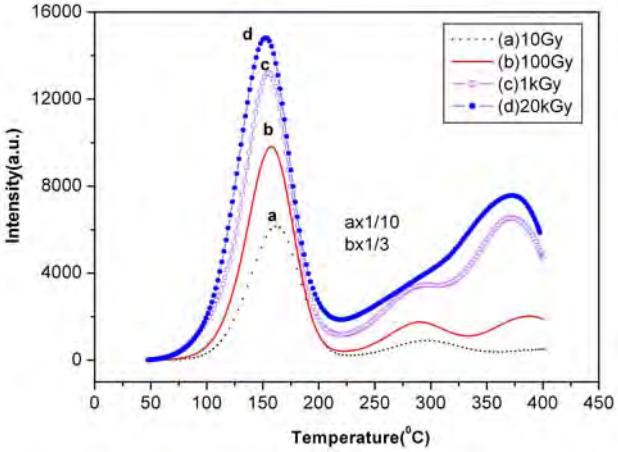

Figure 1. TL Glow curves of nanocrytstalline $K_2Ca_2(SO_4)_3$:Cu irradiated with different gamma doses.

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Effects of Electron Beam Irradiation on Micro-porous Materials

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Zeolite is an aluminosilicate micro-porous material with periodically arranged nano-space in the structure. The general chemical formula of zeolite is $M_xSi_{n-x}Al_xO_{2n}{\cdot}mH_2O$, where the framework is composed of covalently bonded Si, Al and O atoms, M may be monovalent cations, usually alkali metals, and water molecules exist in the space as zeolitic water. It is well-known that zeolite has been widely used as industrial applications such as catalysts, ion-exchangers, and separation membranes. There have been more than 200 framework types registered in the Database of Zeolite Structures [1], and also many efforts devoted to synthesize new type of zeolite frameworks, especially with larger and three-dimensionally connected micro-pores. Thus, it is of particular importance to characterize their structures, and transmission electron microscopy (TEM) is one of the essential methods to clarify their framework structures (Figure 1). There is, however, always difficulty in their structural characterization since electron beam irradiation easily vitrifies their structures, which is caused by electron beam damage [2]. There are two kinds of damage processes have been reported, that is, radiolytic and knock-on [3]. Here, I have investigated effects of electron beam irradiation on micro-porous materials, and their damage processes under the electron beam accelerated by 300 kV. Dependence of (i) Si/Al ratio of their frameworks and (ii) electron beam irradiance level will be discussed, and other micro-porous materials such as aluminophosphate will also be investigated.

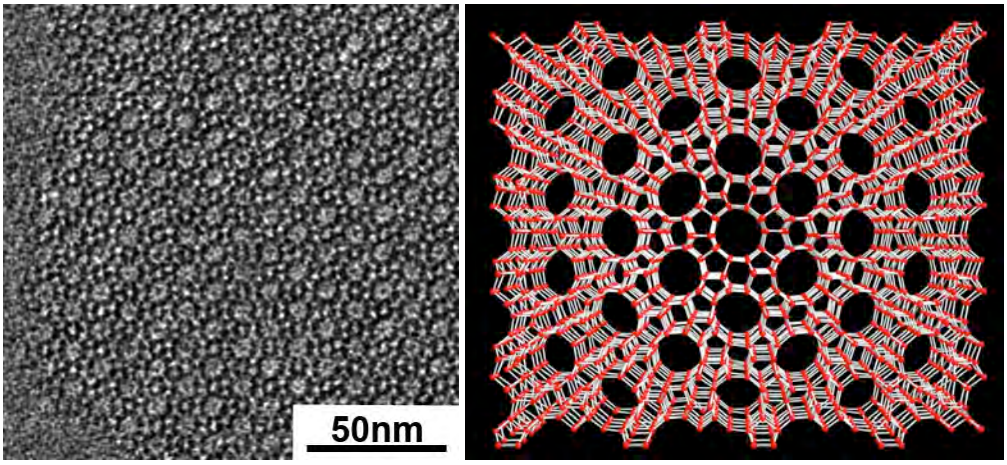

Figure 1. High resolution TEM image of zeolite MFI (left) and the framework structure (right).

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γ-radiations effect on the electrical and structural properties of low dimensional Resonant tunneling diodes

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The total dose effect of γ-radiation effect on the electrical and structural properties of single barrier low dimensional resonant tunneling diodes (RTDs) have been studied. The morphology of the diodes was characterized by scanning electron microscope (SEM). The I-V characteristics of RTDs have been measured at room temperature by leaving the hetrostructures embedded in the insulating template membrane. The γ-radiation causes significant change in the electrical properties of the RTDs. The peak to valley ratio dropes by a factor 3.8 as compared to pre-irradiated samples. The magnitude of this effect is proportional to gamma dose. The X-ray diffraction study also shows the pronounced changes in the structural properties of the post –irradiation low dimensional RTDs.

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WEDNESDAY POSTER PRESENTATIONS

ICACS-25

We-001 ~ We-077

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SHIM2012

We-078 ~ We-099

Molecular Dynamic Simulation of KeV Hydrogen Molecular Ions Interaction With Solids

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The study of ion and atomic cluster beams interaction with solid targets has been a topic of interest for many years due to both practical and fundamental reasons [1]. As experimental as theoretical studies show that the effect of the cluster impact on solids is often different from just a sum of single atoms interaction with the solid. Molecular ions consisting of two or three constituents are a limiting case of large clusters. They demonstrate a similar nonlinear behavior comparing to single atom-solid interactions. For example, bombardment of thin (20-70 Å) carbon films by 2-12 keV H^+, H_2^+, H_3^+ ions [2] has shown that the larger an amount of ions constituents, the greater the width of energy loss spectra peaks for transmitted particles ("a molecular effect").

We present a molecular dynamic simulation of H^+, H_2^+ transmission through thin carbon layers. The calculations were carried out using the PARCAS code [3]. The Brenner's potential [4] was used to describe all kinds of elastic C-H interactions while the classical Lindhard's model was employed to account for the electronic stopping of protons in the film [5]. We see that the widths of simulated energy loss spectra for H_2^+ are larger than those for H^+ in correspondence with experimental findings (fig. 1). The origin the broadening of the energy spectra is H_2^+ disintegration due to which the ion fragments get the kinetic energy of order of several eV in the center of mass frame of references. It corresponds to energy straggling of fragments in the laboratory system of reference about of 100 eV, which finally causes the peaks broadening.

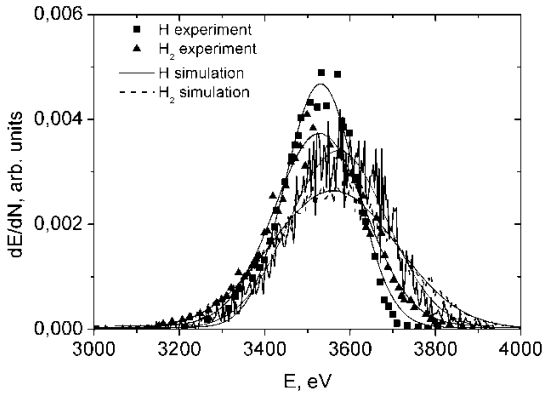

Figure 1. Energy loss spectra for penetration of H_2^+ and H^+ with an initial energy 3860 eV/nucleus through 40 Å carbon film. The markers sorrespond to experimental results taken from [2].

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Phase diagram for nanostructuring CaF_2 surfaces by slow highly charged ions

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Slow highly charged ion (HCI) irradiation on insulating surfaces can cause local changes in the surface morphology, commonly known as nanostructures [1,2]. On CaF_2 recent studies [3] showed the creation of nanometer-sized hillocks with a strong dependence on the potential energy of the impinging HCI. Below a Xe charge state of q=28 no such hillocks have been found. However, below this threshold for hillock formation defects are created, which become visible by means of scanning force microscopy (SFM) only after chemical etching. These results show that a new regime in the phase diagram of hillock formation exists. For much lower charge states (q<18) and small kinetic energies (<10 keV) neither hillocks nor etch-pits could be found. An extended phase diagram for nanostructure formation on CaF2 due to HCI irradiation is presented and the three obtained phases are discussed in terms of kinetic and potential energy dependence.

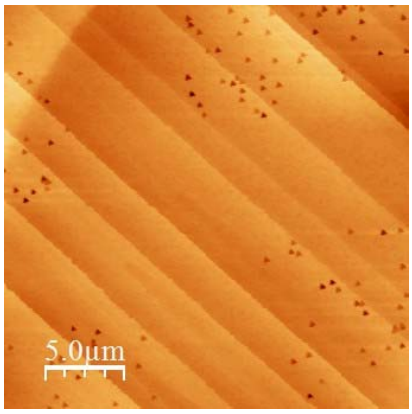

Figure 1. SFM topographic image of a CaF_2 surface showing etch pits after exposure, through a mask, to 1.15 keV/amu Xe^{33+} and subsequently chemically etched using HNO_3.

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Absolute Detection Efficiencies of keV Energy Atoms Incident on a Microchannel Plate Detector

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A microchannel plate (MCP) detector is widely used to detect keV energy ions and neutrals. The absolute detection efficiency of the MCP detector is known to depend on the incident energy and charge state for individual ionic species. Knowledge about the detection efficiency is therefore essential to determine the absolute counts of the particles incident on the MCP. The absolute detection efficiencies of the MCP detectors for ions are usually obtained by measuring the ion beam current with a Faraday cup and the count rate from the MCP consecutively. However, the detection efficiencies for neutrals are scarce, mainly because of the difficulty in measuring the incident neutral beam current. We developed a new method that enables us to determine the absolute detection efficiencies for neutrals in keV energies [1]. This method uses the single-electron capture process in collisions of ions with gas targets. Using this method, we determined the detection efficiencies for rare gas atoms with energies of 0.5-5 keV [1]. We report here the absolute detection efficiencies for hydrogen, carbon, and tungsten atoms with energies of 0.5-4.5 keV. In addition, we report a scaling relation for our data obtained so far.

The experimental procedure will be described briefly. The charge-changed incident ion and the singly ionized target atom are detected using two identical MCP detectors in coincidence mode. The measured number of coincidences dose not coincide with the measured number of target ions because of the detection efficiencies of the MCP detectors. The absolute detection efficiencies (of the MCP for incident ions) are then given as the ratio of the number of coincidences to the number of target ions.

The results for H^0, C^0, and W^0 showed similar energy and mass dependencies as for the rare gas atoms. The detection efficiencies increased with increasing impact energy and converged to the open area ratio (~50%) of the MCP used. The efficiencies at fixed energies decreased as the mass of the atom increased.

The detection efficiency of a MCP depends on the yield of an average secondary electron emission from a surface by incoming particles [2]. The ion-induced secondary electron yield is expected to depend largely on the electronic energy loss of the incoming particles on MCP materials. It is shown that our data can scale with the electronic energy loss estimated using the formulas for electronic and nuclear stopping power by Lindhard et al [3, 4].

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Radiolysis of H_2O : H_2CO : CH_3OH ice mixture by 220 MeV $^{16}O^{7+}$ bombardment

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220 MeV $^{16}O^{7+}$ ion induced radiolysis of H_2O:H_2CO:CH_3OH (10:9:1 mixture) ice is studied in laboratory by infrared spectroscopy (FTIR). The molecular species CH_3OH, H_2CO_3, CO_2, H_2O_2, CO, HCO, CH_3COOH and HCOOH are formed with rates shown in Figure 1. The formation and dissociation cross sections of all observed daughter molecules in the mixture are determined using the procedure described in [1]. The radiation chemical effects led to a general observation that the destruction cross sections by fast ions depend on the electronic stopping power as $\sigma_d = S_e^n$. Moreover, it seems that this power law can be extended to formation cross sections since this rule is followed at least by H_2O_2, one abundant daughter species. As astrophysical implication, the abundance ratios of H_2CO and CO, relative to CH_3OH and obtained with oxygen beam, are compared with hydrogenation data of literature. This result helps the understanding of the ratios observed in interstellar ices, comets, and the Orion hot core.

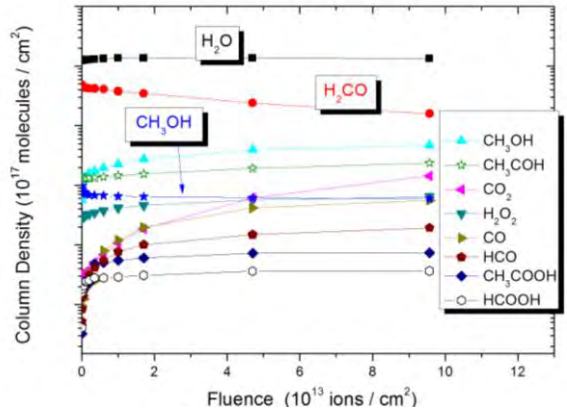

Figure 1.Column density dependence on beam fluence for some species detected on H_2O:H_2CO:CH_3OH ice by infrared bands.

References:

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The Increase in Thermonuclear Reaction Yield Due to Ion Channeling in Microcrystals

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Cross section of the thermonuclear reaction is $\sigma = F(E)/E \exp\{-\eta(E)\}$, where E is the collision energy, F(E) is the so called astrophysical factor weakly depending on E, and η is the probability of transmission through the Coulomb barrier. In the case of atomic collisions, electron screening of nuclei interaction must be taken into account. According to [1], in this case we need to substitute variable E in the formula considered with effective energy $E' = E+U$, where $U = e^2/R$ = 20-30 eV (R is the atom radius). The reaction cross sections were measured at small collision energies E<20 keV [2] to study cold thermonuclear synthesis. In bombarding a number of metals (Zr, Pd, Pt, Co) saturated with deuterium by deuterium ions, authors of [2] observed an increase in factors F(E) with the decrease in collision energy. To fit the experimental data, the authors were forced to assume that U=200-600 eV; they explained such high values by a strong increase in deuterium nuclei screening due to high electron density in a metal. In our opinion, such explanation is doubtful. To compress an electron cloud to such extent, a strong potential field is required (of about U), which breaks molecular bounds in metal.

It is well known that hydrogen atoms occupy free positions along the metal crystal axes. We suggest that the increase in thermonuclear yield is caused by ion focusing in crystal channeling. This focusing increases the effective beam density near crystal axes and, therefore, the corresponding cross section. We have performed a numerical simulation of ion trajectories in Pt crystal saturated by deuterium at collision energies of 3 to 24 keV and confirmed our suggestion. Fig. 1 shows that the proposed model fits satisfactory the experimental data. The fact that channeling particles undulate between the channel potential walls, contributes to the increase in the beam density near the crystal axis. We took into account also a thermal motion of ions in crystals. When temperature increases, the channel effective size becomes smaller, and a smaller part of particles participate in focusing. Since at small energies mean free paths are only 30 to 300 monolyers, focusing effect can be observed even in quite small metal microcrystals. Our model predicts the existence of the orientation effect in monocrystals.

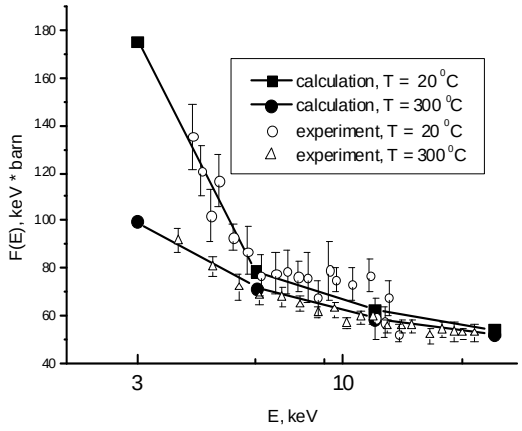

Fig. 1. Factors F (E) as a function of collision energy E and target temperature T.

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SHI Irradiation Induced Amorphization of Nanocrystalline Tin Oxide at Low Temperature

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Nanocrystalline tin oxide (SnO_2) thin films were fabricated using pulsed laser deposition (PLD) technique. The as-deposited films were irradiated at liquid nitrogen (LN_2) temperature using 100 MeV Ag ions at different fluences ranging from 3×10^{13} to 3×10^{14} ions/cm^2 and at 75º with respect to surface normal. Pristine and irradiated samples were characterized using XRD, AFM, Raman and I-V (current-voltage characteristics) for the study of modifications in structural, surface morphological, bond angle and resistivity respectively. XRD patterns show that the pristine film is highly polycrystalline and irradiation amorphizes the film systematically with increasing the irradiation fluence. The surface of the pristine film contains nanograins of tin oxide with roughness 5.14 nm. Irradiation at lower fluences (3×10^{13} and 1×10^{14} ions/cm^2) makes the surface featureless and roughness increased to 10.76 nm. Highest fluence (3×10^{14} ions/cm^2) irradiation again develops nanograins with roughness 7.412 nm. Raman spectra and I-V characteristics also confirms the irradiation induced amorphization. The observed results are explained in the frame work of thermal spike model [1,2].

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Surface Reaction between Water Cluster Ion and Silicon Substrate

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The ion beam technique has been extensively applied to the surface processing and treatment of silicon substrates in the semiconductor industry. Recently, the variety of ion beams used in the semiconductor industry is being extended from atomic ion beams to cluster ion beams. A water cluster ion beam is one of the cluster ion beams that have a high possibility of being applied in the semiconductor industry. The water cluster ion beam is effective in forming oxidized layer on silicon surface [1], or in etching polymer surfaces [2]. The incident angle dependence of the irradiation effects of water cluster ion beams on silicon surfaces was investigated to examine the possibility of further applications.

Water clusters were produced by the supersonic jet method without using a helium support gas. The water clusters were ionized by the electron impact method, and accelerated with the acceleration voltage typically from 3 to 9 kV. The monomers and water clusters with small cluster-sizes were removed by the retarding voltage method. The incident angle dependence of the contact angle of silicon surface was measured by irradiating the water cluster ion beam onto the silicon surface and measuring the contact angle by the θ/2 method.

Figure 1 shows the incident angle dependence of the contact angle of the silicon substrate irradiated with a water cluster ion beam. The contact angle decreased when the water cluster ion beam was irradiated from the vertical direction. On the other hand, the contact angles at the incident angles at 30º and 50º increased by the irradiation of the water cluster ion beam. This variation of the contact angles may be attributable to the competitive processes of the oxidation and sputtering of silicon surfaces.

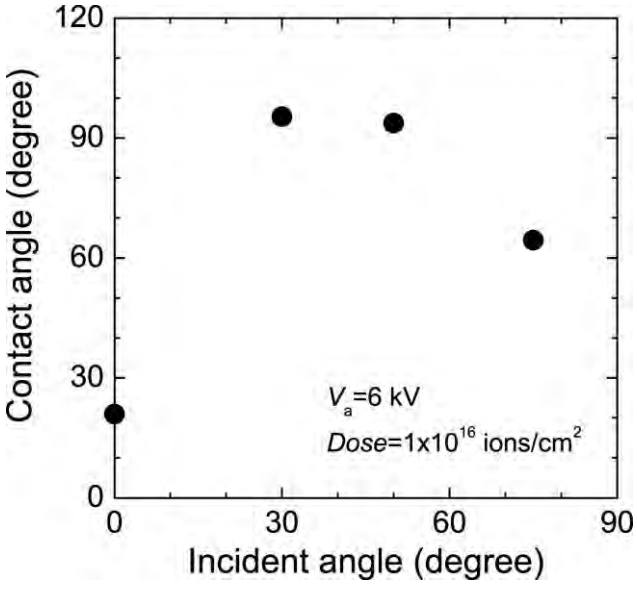

Figure 1. Incident angle dependence of contact angle of silicon surface irradiated with water cluster ion beam.

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Dynamic ERD Measurements of Depth Profile of H and Li in All Solid State Li-Battery Systems

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A variety of technologies has been developing for energy production and storage without CO_2 emission at safer, higher energy-efficient and lower cost way to protect the global environment. The catalyst for production and storage of hydrogen from water and the all solid state Li-battery are expected to be newly developed. For their realization, the information on transport behavior of H and Li in the systems of hydrogen storage and solid state Li-battery is of essential importance. So far, we have been developing Pt-covered Li_2ZrO_3 (or Li_4SiO_4) ceramics hydrogen storage materials by means of the ERD technique with 2.8MeV He ion beam [1, 2]. The aim of this work is to demonstrate the possibility of dynamic measurements of depth profile of H and Li at the surface, interface and in the bulk of solid state Li-battery systems of $Pt/LiCoO_2/Li_{1+X+Y}Al_YTi_{2-Y}Si_XP_{3-X}O_{12}$ (separator) (or $Li_{1+X+Y}Al_YTi_{2-Y}Ge_XP_{3-X}O_{12}$) under charging and discharging conditions by means of ERD and RBS using 4~9 MeV O ion beams from the Tandem Accelerators.

In experiments, since the ERD technique with O ion beams could detect H and Li atoms simultaneously and the specimens of Li-battery system including some compositions common to those of the hydrogen storage materials might absorb hydrogen from air vapor, the ERD spectra with He ion beams were also obtained to separate overlapped signals of Li and H in the ERD spectra obtained with O ion beam.

From the ERD spectra for Li-battery systems obtained with He ion beams, it has been found that the system with Si-doped separator absorbs a large amount of hydrogen comparable to the hydrogen storage oxide ceramics [1, 2], while that with Ge-doped separator hardly does. The ERD spectra obtained with O ion beams have showed the clear peaks from H and Li atoms at the surface and interface of the specimen as well as in the $LiCoO_2$ layer (anode electrode) because of its higher depth resolution, although some peaks from H and Li are overlapped. The results on ERD spectra dynamically measured with O ion beams and the other details will be presented at conference.

This work was performed under the valuable co-operations of Tandem Accelerators both at the Quantum Science and Engineering Center, Kyoto University and at the Advanced Research Center of Metallic Glasses, Institute for Materials Research, Tohoku University.

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High Fluence Ion Erosion of Carbon Composite Fibers

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The structure and morphology of carbon fibers imbedded into uni-directional composite KUP-VM (1D) have been studied under high-fluence (10^{18} – 10^{19} ion/cm^2), different irradiation geometry with 10 - 30 keV Ne^+, Ar^+ and N_2^+ ions. The target temperature has been varied during continuous irradiation from room temperature to ~ 400 ^{o}C. As for other carbon-based materials, monitoring of the crystal structure change of the carbon fiber composite surface layer has been performed using the temperature dependences of the ion-induced electron emission yield $\gamma(T)$ [1]. Analysis of the surface was performed by the RHEED, SEM and laser goniophotometry (LGP) [2, 3]. It has been found that at sufficiently high energy the ion irradiation results in a loss of an anisotropy of the fiber shell structure because of amorphization at room temperature or recrystallization at temperatures more than the radiation damage annealing temperature T_a. At $T > T_a$ crimping of the carbon fiber is observed. The reason of the modification is the increase of

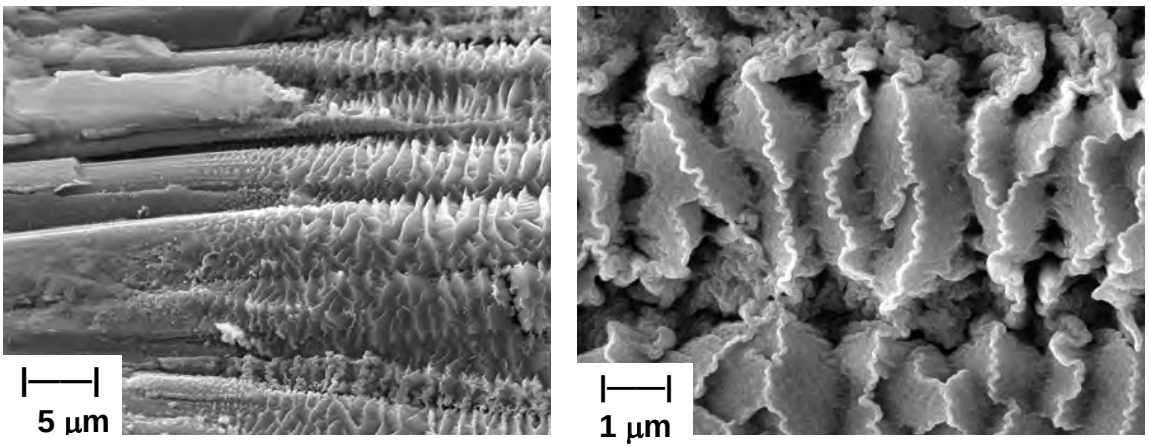

Figure 1. Carbon fiber crimping under 30 keV Ne^+ irradiation with and without mask

the carbon fiber shell disordering with ion energy as a consequence of increasing stationary level of radiation damage ν (*dpa*). Using an error function of the amorphous fraction on the level ν of radiation damage the threshold values ν_d has been found when the lattice of carbon fiber shell is virtually not disordered under ion irradiation at room temperature. For argon ions the threshold value $\nu_d \approx 40$ *dpa*. For carbon fiber recristallisation at T = 400 ^{o}C the cut-off Ar^+ ion energy ~ 20 keV that corresponds to ν ~55 *dpa*. The azimuthal target rotation and irradiation at ion oblique incidence show that the quasiperiodic relief ribs direction is connected not with fiber axis but with ion beam direction. The obtained regularities are discussed in frame of current theories of ion beam erosion.

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Energy loss distributions of proton beams interacting with multi-walled carbon nanotubes

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We study experimentally and theoretically the energy loss spectra of energetic proton beams, with energies in the 2-10 keV range, impinging normally to the axis of a multi-walled carbon nanotube (MWCNT). In the experimental setup the MWCNTs are dispersed on top of a holey amorphous carbon (a-C) thin foil. Measurements of the proton energy loss distributions are performed after MWCNT irradiation with energetic proton beams using the transmission technique. The resulting energy loss spectra observed in the forward direction show two well differentiated peaks, whose origin is elucidated by using a semi-classical simulation of the proton trajectory through the nanotube, together with a model for the electronic energy loss based on Density Functional Theory, and with a local electronic density determined by the LMTO-DFT method. We find that the observed low-energy-loss peak corresponds to quasi-planar channelling of protons passing between the outer walls of the MWCNT and exploring lower electronic densities, whereas the high-energy-loss peak is mainly due to protons with intermediate trajectories, moving across the nanotube walls and exploring regions of higher electronic densities.

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A comparative study of the effect of Li^{3+} and C^{5+} ion beam on optical and chemical properties of PADC polymer

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PADC polymers which is also known by the name of CR- 39 is homopolymers and high grade optical plastic. Its intrinsic property of ion track detection makes it widely useful for track recording properties in radiation dosimetry. It has been seen that track formation is accompanied by changes in chemical, structural, geometrical, optical and electrical parameters. Ion beam irradiation modifies the optical and chemical properties of the polymers. PADC polymer films were irradiated by 50 MeV Li^{3+} and 70 MeV C^{5+} ion beams at different fluences varying from 10^{10} to 10^{14} ions/cm^2 from 15 UD Pelletron accelerator at Inter University Accelerator Centre (IUAC), New Delhi, India. The optical and chemical properties were studied by UV- Visible spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR) respectively. The band gap was calculated using Tauc's relation [1]. The band gap decreases with increase in fluence in case of both fluences. There is 24% decrease in band gap by irradiation of C^{5+} ion as compared to 19% decrease in case of Li^{3+} ion at the fluence of 1×10^{13} ions/cm^2. The FTIR spectrum shows reduction in intensity of typical modes, indicating the degradation of polymer after irradiation in case of both the fluences.

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MCs_n^+ Cluster Formation From Organic Materials During ToF-SIMS Depth Profiling With Cesium

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Depth-profiling of organic materials has become a major topic in the SIMS community. The advent of large Ar_n^+ clusters source opens unprecedented possibilities for this task[1]. Our group has also demonstrated the possibility to depth profile organic materials (polymers and amino acids) by using low energy cesium as primary ions [1,2]. The lower sputtering yields compared to cluster sources implies slower profiles, but this drawback is sometimes compensated by a lower difference in the sputtering yields between organic and inorganic layers. The later benefits the depth resolution through a lower induced rugosity. In low energy cesium depth profiling, characteristic fragments are usually followed in the negative polarity. However, in the positive polarity, MCs_n^+ clusters are formed, were M is a characteristic fragment of the analyzed molecules and n varies from 1 to at least 4. These clusters appear to be a fingerprint of the organic material [4]. For instance, $C_6H_5OCs_2^+$ can be used for depth-profiling polycarbonate. The MCs_n^+ clusters are widely used in dynamic SIMS on inorganics for their lower sensitivity to matrix effects.

In this communication, organic layers of polystyrene and phenylalanine are prepared and studied in ToF-SIMS. Positive polarity depth profiles were acquired using a mixed cesium/xenon sputtering beam (Cs/Xe co-sputtering). The most relevant MCs_n^+ clusters were monitored as a function of the Cs concentration in the beam, up to a pure Cs beam. Finally, the effect of a pause after the cesium sputtering cycle will be discussed to evaluate their effect on the MCs_n^+ signals.

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Interaction between Defects and Deuterium in Tungsten

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In a fusion reactor, plasma-facing materials (PFMs) must withstand the damage produced by hydrogen and helium with energy up to 10 keV and heat loads from the plasma, in addition, the neutrons with high energy, high flux and high fluence similar to the structural components. Hydrogen isotopes retain in vacancy-type defects in PFMs, and this is a critical problem for fusion reactors. To know the interaction between vacancy-type defects and hydrogen isotopes is very important. In this study, the size and density of vacancy-type defects in tungsten was obtained by positron annihilation lifetime (PAL) measurements. Next, thermal desorption spectra of deuterium was obtained after deuterium charging. From these results, trapping site and dissociation energy of deuterium were identified.

The samples were 99.95% pure tungsten (A.L.M.T. Corp.). The 0.2-mm-thick sheet was cut to 10×10 mm for ion irradiation and 5mm in diameter for other experiments. These samples were annealed at 1773 K for 1 h in a vacuum of less than 10^{-4} Pa. Electron, deuterium ion and iron ion irradiations were carried out to introduce defects. 8 MeV electrons were irradiated up to 9.4×10^{17} /cm^2 (1.3×10^{-4} dpa). A displacement threshold energy used for irradiation dose calculation was 42 eV [1]. 5 keV D_2^+ ions were irradiated up to 1.0×10^{18} /cm^2 (20 dpa at defect peak) at room temperature (R.T.) and 673 K. 6 MeV Fe^{3+} ions were irradiated up to 2.3×10^{19} /cm^2 (8.4 dpa at defect peak) at 573 K at 2.0-MV tandem accelerator of Quantum Science and Engineering Center, Kyoto University. After that, 1 keV D_2^+ ions, which do not form irradiation defects, were implanted. Thermal desorption spectroscopy (TDS) was carried out from R.T. to 1523 K.

From PAL measurement, single vacancies are detected in electron-irradiated sample. Therefore, a peak around 550 K of TDS spectra denotes the elimination of deuterium from single vacancies. Peak separation analysis was performed to spectra of 5 keV D_2^+ ion- and 6 MeV Fe^{3+} ion irradiation. Spectra of 5 keV D_2^+ ion irradiation at R.T. and 673 K were resolved into three gauss functions. The peak of them was around 450 K, 560 K and 640 K. Spectra of 6 MeV Fe^{3+} ion irradiation at 573 K were also resolved into three gauss functions. The Peak of them was around 460 K, 630 K and 840 K. 450 K peak denotes the elimination of deuterium from surface. It is concluded that 560 K peak denotes the elimination of deuterium from single vacancies from result of electron-irradiated sample. 640 K peak and 840 K peak denote the elimination of deuterium from dislocations and from voids, respectively.

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Embedded ZnO Nanoparticles Irradiated with Swift Heavy Ions: Irradiation-Induced Formation of Metal Phase and Elongation

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Swift heavy ion (SHI) irradiation induces deformation of spherical nanoparticles (NPs) to spheroids of oblate or prolate shapes. The deformation modes are divided into following four categories: (i) Free-standing amorphous or amorphizable NPs, e.g., amorphous silica (a-SiO_2), on a substrate surface show the *oblate* deformation under SHI irradiation, i.e., ion hammering, while (ii) free-standing non-amorphizable crystalline NPs such as Au show almost *no deformation*. However, (iii) spherical metal NPs embedded in a-SiO_2 show *prolate* deformation. While the categories already mentioned have been extensively studied, (iv) the last case, i.e., non-metal NPs embedded in a-SiO_2, has been less studied. An exception is Ge NPs embedded in a-SiO_2. Schmidt et al. [1] observed a bimodal deformation which depends on the sizes of NPs. While larger Ge NPs show the oblate deformation, smaller ones show the prolate deformation.

In this paper, SHI irradiation effects on another example of non-metal NPs, i.e., ZnO NPs, are discussed. This is because ZnO is strong against amorphization, which is in contrast with Ge NPs. Two sets of samples of ZnO NPs were prepared. Free-standing ZnO NPs were formed mainly on a silica substrate surface by ion implantation and thermal oxidation [2]. A set of the free-standing ZnO NPs was irradiated with Xe ions of 200 MeV up to a fluence of 5×10^{13} ions/cm^2 with an incident angle of 45 deg. The elongation of ZnO NPs was detected by optical absorption spectroscopy using linearly polarized light [3]. No optical anisotropy, i.e., no elongation of NPs, was observed.

The other set of ZnO NPs were covered with an a-SiO_2 layer of 300 nm by chemical vapor deposition (CVD). The same irradiation and measurements were carried out. In contrast with the free-standing ZnO NPs on the surface, the embedded ZnO NPs showed the optical anisotropy, i.e., an indication of the elongation of NPs. Cross-sectional TEM observation combined with the electron energy loss spectroscopy (EELS) confirmed the formation of elongated *metallic Zn* NPs in addition to almost non-deformed ZnO NPs. It seems that the SHI irradiation induced a series of following processes; partial decomposition of ZnO NPs, nucleation and growth of metallic Zn NPs, and the elongation of the metallic Zn NPs.

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Raman and X-ray Absorption Spectroscopic Study on Defects in Vertically Aligned Multi-walled Carbon Nanotubes irradiated with Ar ions

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In order to realize the potential nanodevice applications, nanostructured carbon materials, such as carbon nanotube (CNT)[1] and graphene[2], have been extensively studied in the last two decades. Control of morphology of the CNTs is required depending on the nanodevice applications. For example, vertically aligned multi-walled CNT (MWCNT) is available for various nanodevices, such as LSI interconnects, sensors, supercapacitor electrodes, electron field emitters, and heat sink materials. On the other hand, defects in MWCNTs are essential to determine the device performance. Recently, it was reported that there existed the different stages in damaging process of the ion-irradiated MWCNTs by Raman spectroscopy, indicating that the different types of defects were introduced by the ion irradiation[3]. Similar stages were observed in the ion-irradiated graphite[4]. Soft X-ray absorption spectroscopy (XAS) also characterizes defects in MWCNTs introduced by the ion irradiation. Since XAS can provide information on the density of states, it has been powerful tool to characterize the local electronic states of target materials. However, there were a limited number of XAS studies on defects in vertically aligned MWCNTs into which defects are introduced by ions.

In this study, in order to introduce artificial defects into vertically aligned MWCNTs, low energy Ar ions were irradiated to the MWCNT films grown on SiO_2/Si substrates by catalytic CVD, and their structural properties and local bonding configurations were characterized by Raman spectroscopy and XAS. In addition, SEM and TEM were utilized to characterize structural properties of the irradiated MWCNT films. Angle resolved XAS spectra of as-prepared MWCNTs showed that intensity of π* peak was not strongly dependent on the incident angle of soft X-ray. The MWCNTs may have a wavy form with an averaged orientation perpendicular to the substrate surface. Analysis of Raman spectra showed that there exist the different types of defects in the irradiated MWCNT films as reported in the previous study on the ion-irradiated MWCNT and graphite[3,4]. Analysis of XAS spectra showed that intensity of π* peak decreased after the irradiation, indicating decrease of sp^2-hybridized carbon region and increase of disordered region in the MWCNT films. More detailed results of spectroscopic characterization by Raman spectroscopy and XAS will be presented.

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WITHDRAWN

Complex Dielectric Function Formalism for Description of the Electron Kinetics in Swift Heavy Ion Tracks in SiO_2, LiF, Y_2O_3, KBr and Si

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Swift heavy ions (SHI, M>20 amu., E>1 MeV/nucl) spend the largest part of their energy for electronic excitations in a target (up to 95%, 1-30 keV/nm). The cross sections of elastic and inelastic channels of scattering of a projectile and appearing fast electrons are the key parameters describing the electronic kinetics in a track.

The Dynamic Structure Factor (DSF) formalism is well appropriate for calculations of these cross sections. It takes into account spatial and temporal correlations in dynamics of target electrons during ionization/excitation of the valence band. The Fluctuation-Dissipation Theorem links the DSF of the electron subsystem with the Complex Dielectric Function (CDF) [1,2] which can be reconstructed from the experimentally accessible optical data. All the collective effects, such as excitation of the collective modes (e.g. plasmons) and dynamical screening of the interaction potential, are taken into account within this approach. The CDF formalism allows obtaining the inelastic mean free path of a charged particle (electron and ion) in solids with high accuracy. For electrons, it can also be used to obtain elastic scattering cross section [3].

A detailed description of the method of calculation of elastic (e.g. on phonon) and inelastic (electron ionization from the valence band or deep atomic shells) scattering cross-section, mean free paths and energy losses of electrons in SiO_2, LiF, Y_2O_3, KBr and Si is presented. Based on the CDF cross sections, a Monte-Carlo (MC) model of event-by-event simulations of the electronic kinetics in a SHI track is developed. Application of this MC model allows us to obtain the spectra and the radial distributions of the valence and conduction band electronic excitations in tracks of different ions (from C to U) in these materials.

The analysis of the mechanism governing creation of the internal (within ~10 nm radius) and external (> 10 nm) segments of the radial distributions of valence holes, electrons and the density of the excess energy of the electron subsystem are presented. A substantial difference in the parameters of the outer segment of these distributions obtained from CDF vs binary collision approximation (BCA) approaches is demonstrated.

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Sputtering of frozen oxygen by ion impact: Comparison of experiment and atomistic simulation

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Translational energy distributions of particles sputtered by 750 eV Ne+ ion impact into a cryogenic O2 target are studied both experimentally and using molecular-dynamics simulation. Excellent agreement between experiment and simulation is found for the low-energy spike contribution of sputtered molecules, while at higher energies ($\geq$ 0.5 eV), experiment shows a deficiency in sputtered molecules. These differences are traced back to two sources: (i) inelastic electronic excitation, which is not taken into account in the molecular-dynamics simulation (ii) high rovibrational excitation of sputtered molecules. Due to the increasing probability of molecule dissociation in the high-energy part of the collision cascade, the translational energy spectrum of emitted molecules deviates systematically from a Thompson distribution. Around 2 % of the sputtered particles consist of radicals (atomic O). These originate from direct projectile-molecule collisions; they are emitted early in the collision cascade and feature a strong high-energy contribution.

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Energy distribution of C^+ ion sputtered from graphite surface

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The energy distributions of carbon ions sputtered from the graphite (0001) surface under 1 keV Ar^+ bombardment have been studied both experimentally and involving computer simulation. In our experiments the angle between incident ion direction and the axis of energy analyzer has been fixed to be 90°. The energy spectra obtained in experiments show oscillating behavior and a shift to high energy region. In case of specular geometry (incident ion angle is 45°) we observe the energy distribution (fig.1a) with the absolute maximum at the energy of 55 eV. In addition the apparent maxima are at the energies of 30, 70, 82 and 103 eV. These results cannot be adequately explained within the framework of the theory of elastic interactions of ions with a surface. It has been supposed that the oscillating behavior of energy spectra can be related to resonance charge exchange between positive ion and the surface [1].

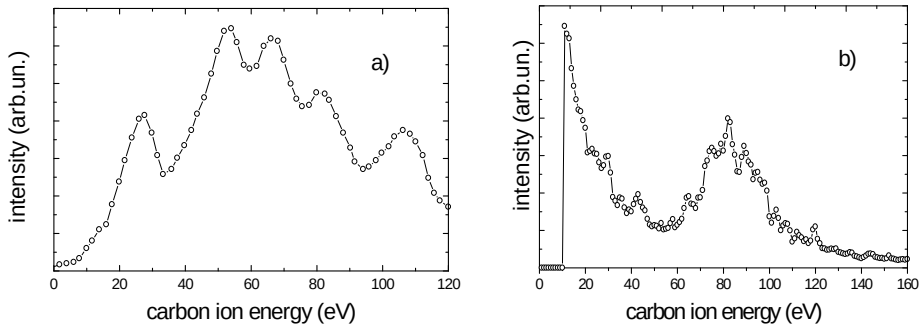

Figure 1. Experimental (a) and calculated (b) energy distributions of C^+ ions sputtered from graphite surface by 1 keV Ar+, impinging at angle $\alpha = 45°$.

We have carried out a computer simulation of the carbon ions energy distribution using the binary collision model taking into account the thermal displacements of crystal atoms [2]. The curve obtained (fig.1b) also demonstrates the similar non-monotonic character and a shift to high energy region. These results allow us to conclude the surface structure effects are important in the process of the destruction of the graphite.

This work was supported by the RFFI (10-02-00162-a, 11-02-01500-a) and (GK-14.740.11.1004).

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Mechanisms of improvement of the silicon layer crystal structure

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The silicon-on-sapphire (SOS) structures are considered to be a promising material for fabrication of radiation-resistant integrated circuits. To create modern devices the active Si layer should be about100 nm thick. However, due to the growth mechanisms Si on Al203 substrate such layers contains a lot of defects. The crystalline quality of the mentioned layer can be significantly improved with ion implantation and subsequent annealing. However, mechanisms of this phenomenon are not studied well enough up till now.

Experimental study of an influence of the ion implantation parameters (energy and fluence, as well as, temperature of implanted structure) on characteristics of the active Si layer will be presented in this report.

In these experiments, SOS-structures were irradiated by Si^+ ion beam at the accelerator HVEE-500. The analysis of the active Si layer was carried out by using RBS, SIMS and HRTEM. Results of this research allowed to make a conclusion about mechanisms of improvement of the silicon layer crystal structure due to implantation of Si^+ ion and a further temperature treatment.

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Study of Ge amorfization by using MEIS

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Thin film structures are usually used to demonstrate the high depth resolution of MEIS. However, some uncertainties can appear due to island growth of the films.

It is possible to evaluate the MEIS resolution by analyzing heterogeneity created at initially smooth single-crystal sample. To fabricate such systems an amorphous layer with a controlled thickness can be created by heavy ion bombardment of semiconductor single crystal surface.

In our experiments, surface roughness of Ge samples was controlled by using AFM before and after Ar ion bombardment. Energy of bombarding Ar ion was 500 eV. Irradiation fluence was about 10^{17} ions/cm^2 that is enough to amorphization of thin surface layer. Samples were analyzed by using MEIS. He^+ ions with energy 180 keV were used as analyzing beam.

A description of apparatuses for researching patterns with the help of medium energy ion scattering and the results of the first experiments demonstrating possibilities of the technique will be presented.

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Swift Heavy Ion induced modification in Morphological and Optical Properties of Tin Oxide Nanocomposites

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Abstract

Nanocomposite thin films of tin oxide (SnO_2)/titanium oxide (TiO_2) were grown on silicon <100> substrates by electron beam evaporation deposition technique using sintered nanocomposite pellet of SnO_2/TiO_2 in the percentage ratio of 95:5. Sintering of the nanocomposite pellet was done at 1300^0C for 24 hours. The thickness of these films were measured to be 100 nm during deposition using piezo-sensor attached with the deposition chamber. Swift heavy ion beam irradiation was done by SHI beams of 100 MeV Au using 16 MV Pelletron Accelerator at IUAC, New Delhi. Irradiation ion fluencies varies between 1×10^{11} ions.cm^{-2} and 5×10^{13} ions.cm^{-2}. Optical properties of these as deposited and ion irradiation modified thin films were carried out by UV/Vis. Spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR). FTIR peak at 610 cm^{-1} confirms the presence of O-Sn-O bridge of tin (IV) oxide signifying the composite nature of the as-deposited and irradiated thin films. Atomic force microscopy (AFM) technique in tapping mode was used to study the surface morphology and grain growth due to swift heavy ion irradiation. Grain size calculations were compared with results obtained from glancing angle X-ray diffraction (GAXRD) measurements using Scherrer's formulae. Phase transformation due to irradiation was observed from glancing angle X-ray diffraction (GAXRD) results. The prominent 2θ peaks observed in GAXRD spectrum are at 30.67^0, 32.08^0, 43.91^0, 44.91^0 and 52.35^0 in irradiate films. Detailed experimental results and their analyses will be presented.

Key words: SHI, AFM, GAXRD, UV/Visible, FTIR.

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Coincidence Measurement of Secondary Electrons with Scattered Ions under Irradiation of Fast Carbon-Cluster Ions

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The secondary electron yield of a fast atomic ion is proportional to stopping power over a broad energy range [1], while that of a cluster ion does not follow the same trend [2]. This is an example of phenomenon called as cluster effects. It is already known that the cluster effect on energy losses is so weak compared with that on secondary electron yields [3]. Therefore, it seems that the cluster effect on secondary electron yields stems mainly from the transport or transmission process, rather than the production process. However, the detailed mechanism is not yet explained.

We investigated correlation of secondary electron emission with scattering of ions in solids. The schematic setup is shown in fig. 1. The SSD is located in forward angle. The ions emitted in small angle (smaller than 3 degrees) are detected by SSD. The secondary electron yield in backward angle is measured with MCP, in coincidence with the number of detected ions by SSD. We studied the correlation between the secondary electron yield and the number of detected ions by SSD.

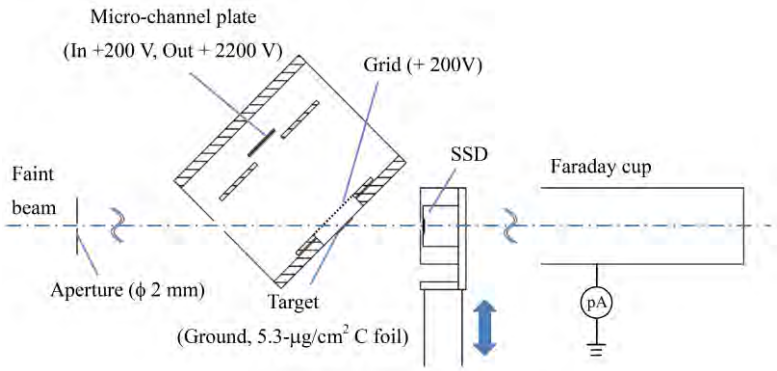

Figure 1. A schematic of the experimental setup

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Micro-PIXE Analysis for Light Elements Using He Beam

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A nuclear microprobe is widely adopted to investigate near surface structure and elemental distributions. Proton micro-beam PIXE became a popular tool above all. In the PIXE measurement, a thin foil is located just before an x-ray detector to prevent scattered protons entering the detector. This foil causes rapid decrease of characteristic x-rays from light elements. We changed the incident beam from proton to alpha particle to reduce the thickness of the foil and improved the overall detection efficiency for the light elements. We tried to measure the distributions of light elements in plant using this setup.

It is well known that aluminum have high toxicity for almost all plants. However, there are some strange plants that hyperaccumulate aluminum, such as hydrangea, tea and buckwheat. We adopted tea leaf as a specimen and tried to measure elemental distributions in it.

We used 5MV tandem-accelerator of the Wakasa Wan Energy Research Center. A combination of 2.5 MeV He micro beam and 8.5 μm thick mylar foil was used. The foil thickness was reduced to 1/10 compared with that for the same energy proton beam. The transmission of aluminum K-X ray increased by the order of 4. This improvement makes us easier to measure the elemental distribution of aluminum in the tea leaf.

The beam spot size was 10×10 μm^2. The beam current was about 200 pA. The scan area was 400×400 μm^2. Almost specimens were irradiated for about 45 min. The following elements were detected, such as Al, Si, P, S, Cl, K, Ca and Mn. We found that aluminum and silicon spatial distributions in tea leaf changed according to the growing period. In a young leaf, aluminum and silicon were found all over the mesophyll cell, however, they localized in the upper epidermis in a matured leaf.

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WITHDRAWN

The Absorption Spectra of $LiYF_4$ Crystals Irradiated at 15K

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Spectra of the induced optical absorption in nominally "pure" and doped with Nd in $LiYF_4$ crystals under irradiation with electrons flows at 15 K were studied.

Samples were irradiated with electrons, the source of radiation - high-current pulsed accelerator generating flow with 0.2 MeV average energy of electrons, the pulse duration - 10 ns, energy per pulse 10^2Gy absorbed by the crystal. Irradiation and measurement of the induced absorption were performed on the pulsed optical spectrometer. Additional absorption of the crystal during irradiation was measured with respect to non-irradiated crystal.

Figure 1 shows the spectra of the induced and measured at 15 K an additional absorption in crystals of pure $LiYF_4$ and Nd-containing with concentrations of 0.7 and 4 mol%. All crystals were irradiated with electron beam pulses, the dose of 8×10^3 Gy. In the spectrum of induced absorption in the pure crystal $LiYF_4$ bands at 2.1, 2.9 and 3.6 eV can be clearly distinguished.

In Nd-doped crystals induced absorption in the region of 2.5 ...6 eV is similar to the induced in pure crystals. There is only a band shift towards the shorter wavelengths. Additional absorption can also be observed for doped crystals in the region of 1.5 ...2.5 eV but with a pronounced split into two bands at 2 and 2.3 eV. Stability of the induced color centers was studied. The crystal was irradiated with a series of pulses of electrons with a dose of 10^4Gy, induced absorption spectrum was measured at this temperature. Then the crystal is heated to a temperature Ti > 15K, cooled to 15 K and spectrum of induced absorption was measured again. It was found that up to 45K induced absorption remains practically unchanged. At temperatures above 45K there is a sharp decline in the absorption indicating the beginning centers destruction. Maximum rate of destruction of the centers is at 60K. At 80K points and corresponding induced absorption completely disappears.

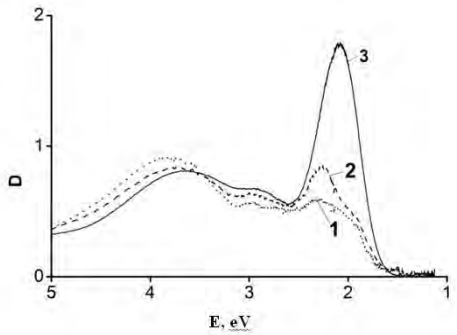

Figure 1 Spectra of the induced and measured at 15 K an additional absorption in crystals of pure $LiYF_4$ (3) and Nd-containing with concentrations of 0.7 (2) and 4 (1) mol%.

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ELECTRON EMISSION STATISTICS OF SLOW HIGHLY CHARGED IONS DURING INTERACTION WITH INSULATING SURFACES

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The important role of highly charged ions (HCI) as a promising candidate for creation of nanometer-sized surface structures has been demonstrated in several experiments in recent years. The underlying physical processes of nano structure creation strongly differ for different kind of target materials. Nevertheless, the majority of proposed models have one point in common: They underline the major role of the electrons emitted by the projectile during HCI neutralization above and below the surface.

Hence, a detailed understanding of the electron emission characteristics becomes more and more necessary. Experiments observing the electron emission statistics of very slow highly charged ions have been carried out so far only for metal surfaces [1,2]. For surfaces of insulators measurements of the total electron emission statistic exist only for moderate ion velocities between 1 and 5 keV/amu [3].

In this contribution we will present first results of electron emission statistic measurements for highly charged Xenon ions ($q \leq 44+$) impinging on insulating surfaces of CaF_2, KBr as well as LiF at kinetic energies as low as 10•eVq. This is well within a regime where kinetic electron emission is not contributing to the total electron emission yield giving us the opportunity to compare our results with predictions from the classical-over-the-barrier model. Our results reveal an unexpectedly high electron emission yield on insulators even for lowest velocities. The effect of projectile energy gain due to image charge acceleration can be derived from the velocity dependence of the electron yield.

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Straggling of MeV Kr Ions in Gases

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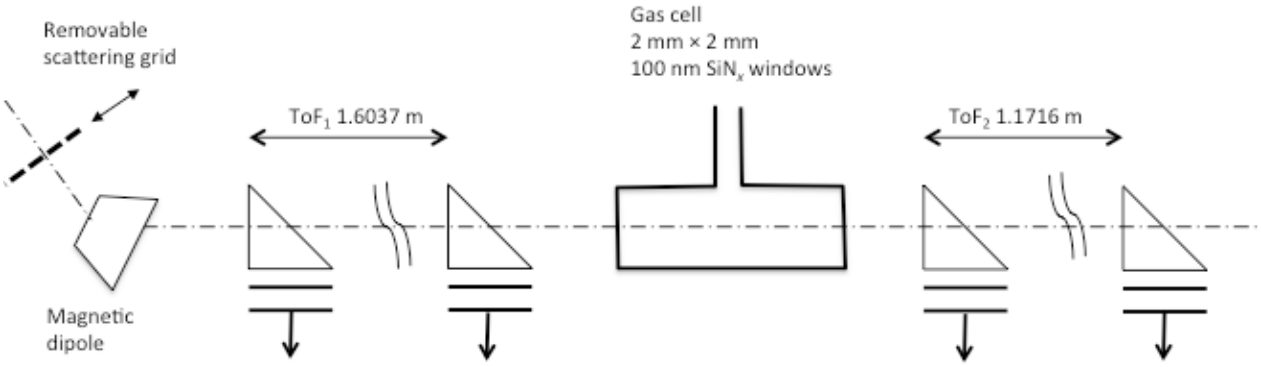
It is well established that energy-loss straggling of swift heavy ions may considerably exceed the Bohr value [1]. While both experiment and theory predict a pronounced maximum in the dependence of straggling on beam energy, there is considerable uncertainty on position and value of that maximum. Since straggling is expected to be greater in gases than in otherwise equivalent solids [2,3], we have built an apparatus to study straggling in gases at the Jyväskylä K130 cyclotron by the time-of flight technique (Fig. 1). Entrance and exit to the gas cell goes through thin SiN foils which are characterized by high uniformity. To create ion beams with a range of well defined lower energies and charge state than the primary beam, it is scattered from a removable grid and momentum-charge state separated using a magnetic dipole.

Measurements are reported for krypton ions in noble gases and nitrogen. Straggling has been determined from measured time-of-flight spectra in front of and behind the gas cell with and without gas, taking into account straggling in the entrance and exit foils.



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Study of Mechanisms of MeV Light Ion-beams Focusing by Tapered Glass Capillaries

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Many experimental results from different labs show that the tapered glass capillary not only can focus low energy (usually in magnitude of keV) highly charged ions (HCIs), but also can focus single charged light ion beams with MeV energy. It is in wide agreement that the focusing mechanism of glass capillary to HCIs is elastic scattering by Coulomb potential of self-organized state charges on the wall of the capillary. This theory is also used to explain the guiding function of nano-pores in insulator membrane to HCIs. However, the focusing mechanism for single charged light ions with MeV energy is still in discussion. Scattering by Coulomb potential of self-organized static charges, by continuous surface potential, and Rutherford scattering, are candidates.

Our experiments took 2 MeV He+ ions as incident beams. The fluence rates were quite weak, about 10-2~10-3 pA. We analyzed the energy spectra of output ions and the density distributions on ejected beam cross sections, and found that are in accord with the results of last two kind of scattering, rather than the case of self-organized electric field. We deduced the reason is that the fluence rates is too weak to form an effect self-organized electric field. We estimated the necessary fluence rate for producing an enough strong self-organized electric field. Further experiments are needed to prove it.

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Sputtering yields of Au/Si films under the impact of 20 - 160 keV Ar^+ ions

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The sputtering yields induced in Au thin films deposited onto Si substrates under the impact of swift Ar^+ ions have been measured over the (20 - 160) keV energy range. Then, the irradiated films have been analyzed by Rutherford backscattering (RBS) spectroscopy using a 2 MeV beam of $^4He^+$ ions. The obtained results were found to be consistent with previously measured data that are extended to higher bombarding energies. The whole set of experimental data is compared to numerical sputtering yields predicted by Sigmund's theory [1] and other models or derived by Monte Carlo simulation using the SRIM-2008 computer code [2], and shows to be best consistent with Yamamura et al. revised semi-empirical formula [3]. In addition, the morphology and surface state evolution of the Au films under Ar^+ ion irradiation have been investigated by means of the scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques. It was found that the irradiated Au film surfaces were drastically altered with increasing ion energy, with formation of increasingly sized grains of preferred (111) crystalline orientations. Finally, the relevance of the performed different sputtering yield calculations to account for the measured sputter yields is discussed by invoking the observed Ar^+ ion-induced surface effects.

Keys worlds: Sputtering yields, Rutherford backscattering spectrometry, Scanning electron microscopy, X-ray diffraction spectroscopy.

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NRA for hydrogen analysis in atmospheric condition

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Mg-based nano-superlattices has attracted much attention as novel hydrogen storage materials. A. Baldi *et al.* reported that hydrogen absorption process in Mg-based superlattices is strongly affected by the strain at the interfaces [1]. In order to investigate such a hydrogen absorption process in subsurface region of materials with nano-meter scale directly, we developed nuclear reaction analysis (NRA) of $^{1}H(^{15}N, \alpha\gamma)^{12}C$ for hydrogen analysis in atmospheric condition with using SiN membrane with 100 nm thickness [2]. Then we estimated the depth resolution of this system. Considering the energy struggling of ~ 6 MeV ^{15}N beam in the SiN membrane with Au coating and Doppler effect, the energy spread of the beam at the target surface was estimated as ~ 45 keV. This corresponds to the depth resolution of hydrogen analysis of ~ 30 nm in Mg and Ti film. From this estimation we prepared a following Mg-based nano-superlattice; Pd (20 nm) / Mg_1 (20 nm) / Ti (30 nm) / Mg_2 (20 nm) / Ti (30 nm) / substrate. According to the model by Baldi *et al.*, the Mg2 layer is hydrogenated at lower hydrogen gas pressure ~ 50 Pa, and then the Mg1 layer is hydrogenated at much higher pressure ~ 300 Pa [1]. Figure 1 shows the obtained NRA profiles on the Mg-based nano-superlattice taken with changing the hydrogen gas pressure from high vacuum up to 500 Pa. As results, we observed the hydrogenation of the Ti layers at 10 ~ 50 Pa, that of the Mg_2 layer at 100 Pa, then finally the Mg_1 layer was hydrogenated at ~ 500 Pa. Thus we successfully observed the strain effect in the hydrogen absorption process in nano-scale materials.

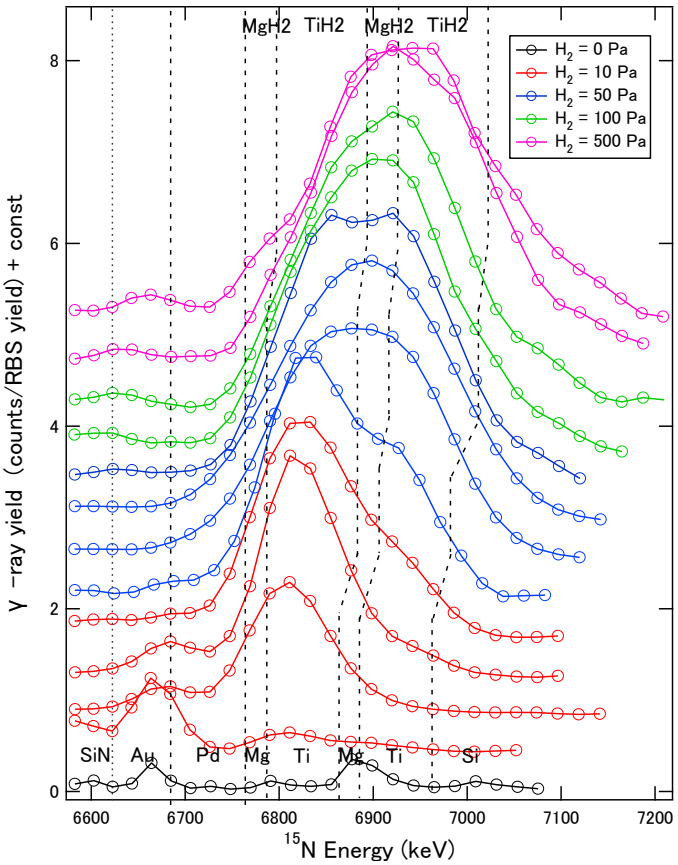

Figure 1. NRA profiles on Mg-based nano super-lattice taken with changing the hydrogen gas pressure

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The Quantum Trajectory Approach in Description of Ion-atom Collisions

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As for classical systems, where the Monte Carlo simulation is sometimes the only applicable method of calculation, analogous approach can be used in treatment of quantum atom dynamics. The possibility follows from the de Broglie-Bohm formulation of quantum theory, the quantum state of an individual system is supplemented by a deterministic trajectory in configuration space. Such interpretation of quantum theory was inspired by the fact that, with the uni-polar amplitude-phase anzatz for the wave function $\Psi(\mathbf{r},t) = R(\mathbf{r},t)e^{iS(\mathbf{r},t)/\hbar}$, the Schrödinger equation can be transformed to the classical-like continuity and Hamilton-Jacoby equations. The only specifics in the latter equation

$$\frac{\partial S}{\partial t} = -\frac{(\boldsymbol{\nabla} S)^2}{2m} - (U+Q)$$

is the additional "quantum potential" term $Q(\mathbf{r},t)$ which is determined by the curvature of the amplitude $Q = -(\hbar^2/2)(\Delta R/R)$. The motion along quantum trajectories is guided by the wave function according to the velocity field $\boldsymbol{v} = \boldsymbol{\nabla} S/m$.

When the wave function is known the quantum trajectories can be used as an effective interpretation tool. Like in the classical description this shows origin of interesting effects not easily accessible from solution of the time-dependent Schrödinger equation, TDSE. Additionally, as it was recognized in the last decade [1], the quantum trajectory method, QTM, can be used also as a method of solution of TDSE (exact in the limits of numerical accuracy). In calculation the wave function can be generated simultaneously, on the fly, the time-dependent amplitude R and the phase S of the wave function can be synthesized by the density $\rho = R^2$ and velocities $\boldsymbol{v}$ of the Bohmian particles. Compared to the straightforward numerical solution of TDSE this method is dramatically more efficient.

Up to now QTM was used mainly in the Chemical Physics domain. We explore its possibilities in description of evolution of electron state in fast ion-atom collisions. Specific problems in usage of QTM here are the following. First is due to the singular Coulomb potentials of nuclei which could result in necessity of high resolution of motion nearby. Analysis show, however, that in close electron-nucleus collisions where their interaction is dominating the singularity of the potential U is exactly compensated by equivalent singularity of the quantum potential (the Kato cusp condition). The second is the "node problem": the quantum potential Q diverges at surfaces where R is zero. Near these surfaces the trajectories closes and it is hard in numerical calculations to satisfy the condition that they never cross. As a result the numerical calculation can simply crash. Notice, however, that the quantum current $\mathbf{j} = \rho\boldsymbol{\nabla} S$ is a smooth function of coordinates, also near the node surfaces. Therefore, it is reasonable to replace the Hamilton-Jacobi equation by equivalent equation for $\mathbf{j}(\mathbf{r},t)$.

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A compact biological cell irradiation system with Van de Graaff accelerator

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A compact irradiation system for biological cells was set up with the 3MV KN Van de Graaff accelerator situated in the NTHU accelerator Laboratory. Figure 1 depicts the end station. The energetic ions produced from the accelerator are sent into the scattering chamber to bombard a 100 nm gold foil. Some of the vertically scattered incident particles would pass through a window to the cell target. The irradiating flux and area could be adjusted by altering the incident particle current and the exit window. The test results show that the system is suitable for biological cell irradiating experiments.

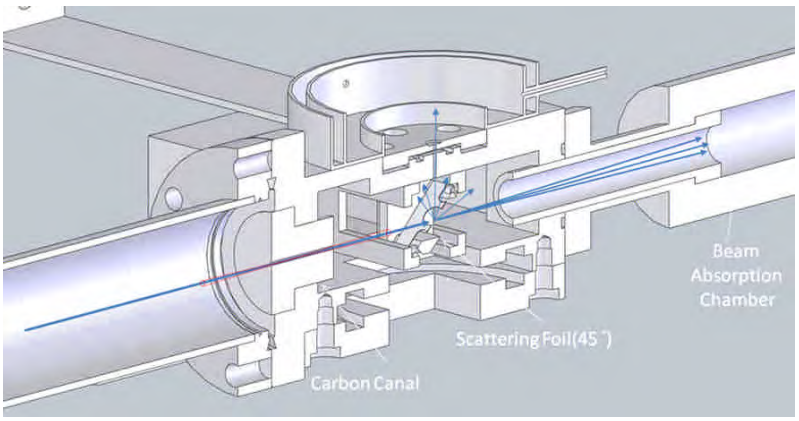

Figure 1. The end station of biological cell irradiation

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Absorption of radiation damage by interface investigated by molecular dynamics simulations

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Abstract: The properties of nano-scale interface of Fe/Cu bilayer films with and without displacement cascades initiated by energetic Fe or Cu particles have been investigated at atomic scale by molecular dynamics simulations. The high binding energies (up to 3 eV) of Fe or Cu interstitials with such interfaces demonstrate the strong absorption of interfaces to these interstitial defects. The emission of intersitital from interface to annihilate the nearby vacancy has been found as another way to reduce the possible radiation damage. The tensile stress response of such bilayer is also found to be affected by the intermixing at interface caused by the displacement cascade. All these results indicate the nano-scale Fe/Cu interfaces can act as sinks for radiation-induced point defects.

WITHDRAWN

S adsorption on Au(111) and Ag(111): a comparative study of Ion Scattering and Electron Spectroscopies

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The adsorption of S on Au and Ag surfaces is a subject of interest due to several reasons; among the most important are the poisoning effect in catalysis, the degradation of electronic contacts under S containing atmospheres, and the growth of Self Assembled Monolayers (SAMs) of thiol based molecules. The S/Au system has been studied with different electron and photon spectroscopies, with electron diffraction and by means of electrochemical techniques [1, 2], however a number of controversies still remains unsolved precluding a full understanding of the system behavior. In this work we present an ion scattering study performed in the forward direction in order to detect recoils (DRS) and forward scattered projectiles. Low energy electron diffraction patterns taken at specific exposures were used to identify the S phases. We measured the S and substrate recoiling intensities versus S dose in UHV conditions for both Au(111) and Ag(111), and compared these intensities with Auger (AES) and photoemission (XPS) Au4f and S2p signals. At low incident angles and specific doses we observed strong changes in both spectrum shape and intensity which allow determination of the critical coverages for phase transitions. The difference in the sticking coefficient in Ag and Au is discussed. A detailed study of TOF-DRS versus sample temperature for Au helped us to link previous measurements in UHV and in solution.

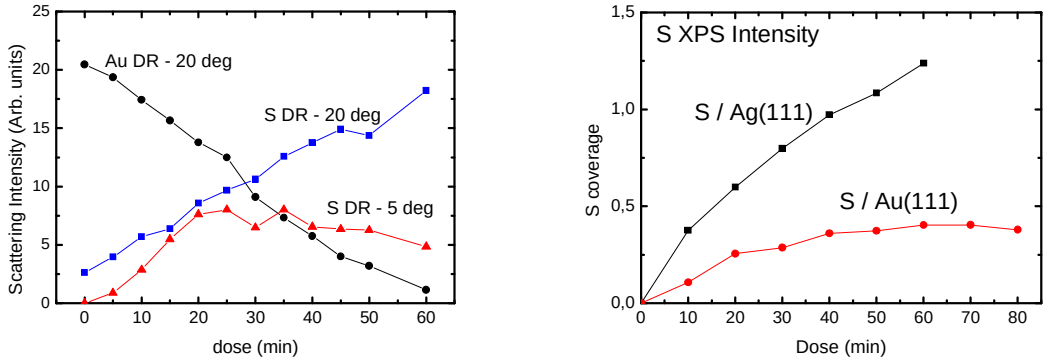

Figure 1: a) S and Au Recoiling intensity measured versus S dose at 20° incidence and S recoiling intensity measured at 5° incidence, b) S XPS intensity versus dose for Ag and Au substrates.

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Charge-State Distributions of Fast Diatomic Carbon Ions Passing through A Single Microcapillary

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By using a tapered glass capillary with micrometer-sized outlet diameters, we investigated capillary-transmission properties of fast diatomic carbon ions in an energy range 0.48-1.92 MeV. The outlet diameter of the capillary used was about 13 μm. In this work, charge state distributions of transmitted particles of C_2 and dissociated fragments of C_1 were measured by electrostatic deflection analysis.

Figure 1 shows results of charge fractions of dissociated fragments (C_1) for different projectile energies and outlet diameters of capillary. The fraction of higher charge states is found to increase with increasing the projectile velocity. On the other hand, a very weak dependence was observed for the outlet diameter of capillary. The results obtained are compared to data of equilibrium charge distribution of single carbon projectile at the same velocity [1], showing that they are almost the same. This indicates that molecular dissociation occurs via collision in bulk of the capillary wall. We also found that majority of the incident C_2 ions are transported keeping their initial charge state and their angular distributions are almost the same as a divergence of incident beam.

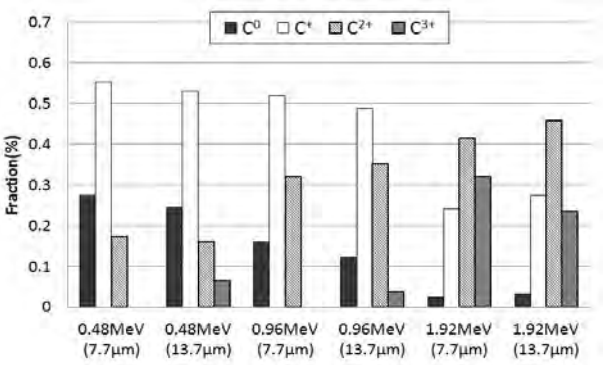

Figure 1. Charge fraction of C_1 fragments after trasmitting through a capillary

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In-situ Deuterium Observation in Deuterium-implanted Tungsten

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Tritium is a radioisotope and used as the fuel of a DT fusion reactor. For safe operation, the amount of tritium in reactor components, especially a tungsten divertor, should be reduced. It is important to know interactions between tungsten and energetic tritium from fusion plasma. In the present work, a substitute isotope of deuterium has been in-situ observed in tungsten, continuously implanted with deuterium ions. Temperature dependence of deuterium retention and desorption will be discussed.

Samples were high-pure tungsten disks with thickness of 1 mm. After annealed at 1173 K for 0.5 hr and mecanically polished, the samples were recrystallized at 1573 K for 1 hr. Under continuous implantation of 3-keV deuterium ions, deuterium depth profiles were observed by using a nuclear reaction analysis. Temperatures of the samples were 384, 473, 573 and 673 K. The surface density and the bulk concentration of deuterium were derived from the depth profile.

It is considered that there exists an intrinsic trap site for hydrogen isotopes in tungsten. Since deuterium detrapping from the trap site and desorption from the sample became active at high temperatures, the bulk concentration decreased with increasing the sample temperature. There was an exception at 384 K where the concentration was very low, probably due to a small amount of the trap sites at a very low temperature [1].

From the surface density of deuterium, a rate constant for desorption of a deuterium molecule was directly determined. It agreed well with that in the case of plasma exposure [2], where deuterium was absorbed on the surface. The agreement can be explained that all deuterium atoms in the sample are not directly desorbed from the bulk but from the surface. It is suggested that desorption behavior of tritium from tungsten would not depend on incident ion energy, in other words, plasma temperature.

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Growth direction change observation by the temperature change in Au/Ni(111) by LEEM

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It is known that Au/Ni(111) exhibits two kinds of epitaxial orientation relationships and their ratio alternatively oscillates with growth temperature, which has been shown by the low energy ion scattering [1, 2]. However, the detailed growth process has not been observed so far, and hence how areas with different orientations develope in the growth process is still open question. In the present study, dynamic observation of the growth process of Au/Ni(111) was carried out with low energy electron microscopy (LEEM).

Ni(111) substrate was cleaned by repeated Ar^+ ion sputtering and heating up to about 650^{o}C, and the clean surface was checked by AES and LEED. Au was evaporated at several substrate temperature. The dynamic observation of the growth process was performed by LEEM, and the structure of the formed thin film was observed by LEED. Areas with different orientation were distinguished using the dark-field LEEM image.

Fig. 1 shows an example of experimental results, which was observed at the substrate temperature of about 400 ^{o}C. (a) is a bright field LEEM image taken at about 4.4 ML of Au. There are several areas with different gray levels. However, the LEED pattern shows Au(111) 1×1 structure as shown in (b) in all areas. Therefore, it is considered that the different gray levels seen in the bright field LEEM image is not due to the different surface structure but by a difference in film thickness. That is, the growth mode of Au/Ni(111) is not ideal layer-by-layer mode. Because Au/Ni(111) shows three-fold symmetry in the LEED pattern, adjacent LEED spots indicated by circles in (b) produce the dark field LEEM images of two different areas with opposite orientation as shown in (c) and (d). The contrast in these dark field LEEM images is reversed with each other, so that one can distinguish two opposite epitaxial orientations using the dark field images. In the dark field image of (d), the bright area is much more dominant than the dark area. At the other substrate temperature, the ratio between the bright and dark areas was different.

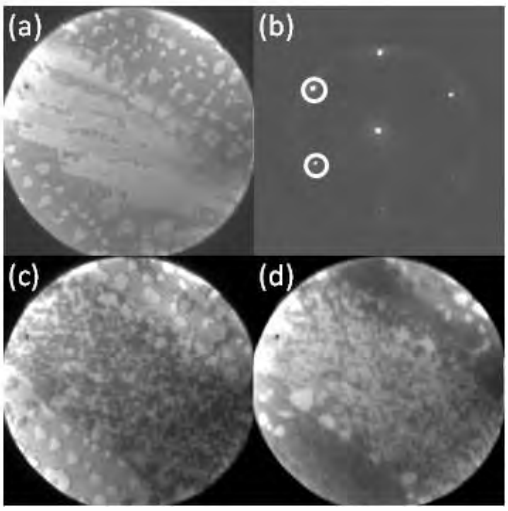

Fig. 1 (a) Bright field LEEM image, (b) LEED pattern, (c) and (d) dark field LEEM images. The coverage of Au is about 4.4 ML. The field-of-view is 10μm.

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Irradiation-induced Recovery of Plasmonic Property in Tarnished Ag Nanoparticles

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Silver nanoparticles (Ag NPs), which possess useful surface-plasmon resonance (SPR) properties for many potential applications, are rapidly tarnished even in ambient laboratory air due to adsorption of extrinsic impurities (e.g. C, N, S, Cl detected in our measurements). In our previous work [1], we demonstrated that a plasma treatment could control the SPR property for Ag NPs prepared by sputter deposition. During the treatment, Ar plasma and/or energetic Ar ions cleans up impurity contamination on the Ag surfaces, resulting in the blue shift and sharpening of an SPR band in UV-Vis optical absorption. Low energy ion irradiation can be an alternative tool to remove contaminated layer on Ag surfaces. In the present work, Ag NPs on SiO_2 are irradiated with 0.4 keV-Ar ions to purify them. As can be seen in Figure 1, an SPR band appeared in the wavelength range of 350−600 nm is found to recover significantly by Ar^+ irradiation, indicative of the reduction of impurity content. The recovery behavior of the SPR band will be discussed in terms of impurity elimination as well as morphological change in Ag NPs.

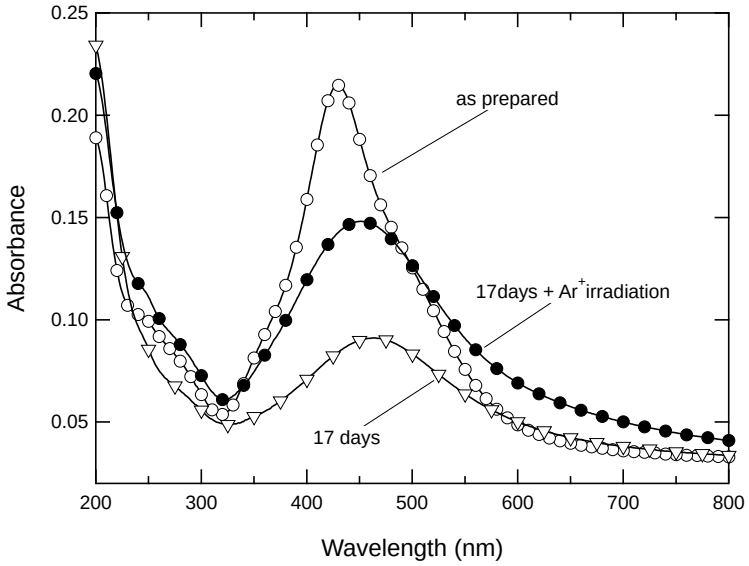

Figure 1. Optical absorption spectra of Ag NPs/SiO_2 for as prepared (open circles), stored in ambient air for 17 days (open triangles) and irradiated for 2 s (filled circles) samples.

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Anisotropy of Ly-α 1 and Ly-α 2 from H-like heavy ions aligned by resonant coherent excitation

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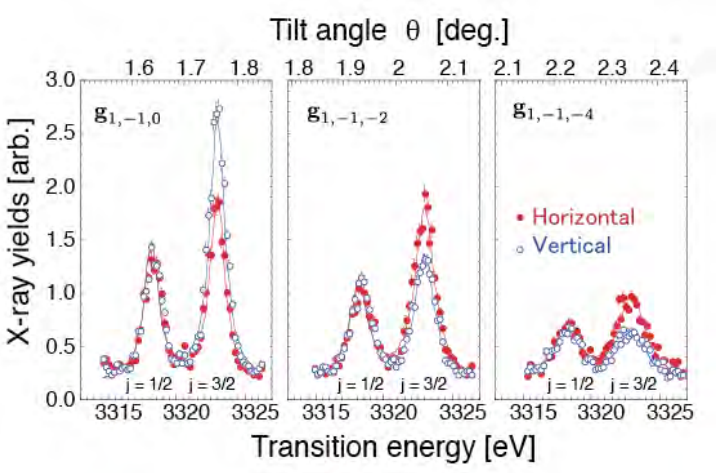
When high-energy ions are passing through a crystalline target, they experience a rapid oscillation of electric field created by regularly ordered atoms in the crystal. In a same manner as laser excitation, this oscillating field can induce the electronic excitation of the ions. This process is called resonant coherent excitation (RCE). Using polarization control technique in three-dimensional resonant coherent excitation (3D-RCE) [1,2] we can excite the heavy ions into a specific magnetic substate of certain excited states. We controlled the alignment direction of the 2p state, and observed the Ly-α_1 and Ly-α_2 by Si(Li) x-ray detectors installed at horizontal and vertical directions. As shown in Fig. 1, the x-rays from the $2p_{3/2}$ state showed large anisotropies depending on the polarization direction of the excitation field. On the other hand, the x-ray from the $2p_{1/2}$ state showed no anisotropy due to the depolarization by the spin-orbit (LS) interaction. We studied the ratios of the x-ray intensities in horizontal and vertical directions with theoretical calculations taking the depolarization effect into account.



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Measurement of the number spectrum of secondary electrons by using an avalanche photodiode detector

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Secondary electron emission from solid surfaces induced by energetic ion collisions has been studied extensively for several decades. As one of the experimental studies, the measurement of number distributions of secondary electrons (called "number spectra" hereafter) with solid-state semiconductor detectors (SSD) was well-established for studying emission statistics of electrons [1]. This technique was extended to gas-phase molecular targets too [2,3]. The measurement principle depends on the characteristic of SSD which provides output signals with pulse heights proportional to the total energy of detected particles. The energy spectra, i.e., pulse height distributions of the SSD signals, provide information of the number of secondary electrons emitted in each collision event. Thus, detectors with a higher energy resolution are desired for improving the analysis of the number spectra. In this work, we have applied an avalanche photodiode (APD) detector for a measurement of the number spectra of secondary electrons emitted from a gold target induced by 2-MeV C^+ ions. The APD has internal charge amplification mechanism in itself. This feature makes the output signals higher and relative contributions of the electronic noise in the peeks might become smaller. As a result, improvement of the energy resolution is expected.

A beam of 2-MeV C^+ ions was injected to a gold plate target to which a high voltage of -20 kV was applied. An APD or a SSD was located in front of the Au target and at the ground potential. A number spectrum of secondary electrons was successfully obtained with the APD. The spectrum with the APD shows narrower peaks in a lower number range than those with the SSD. For example, the FWHMs of the second peaks are 6.4 and 3.0 keV for the SSD and APD, respectively. Meanwhile the peak widths become broader in a higher number range. To reproduce the whole structure of the number spectra obtained with the APD, a model function used for the SSD spectra was modified. It was found that the APD spectrum is well reproduced by adding an additional broadening factor due to the charge amplification in the APD detector itself.

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Magnetization Behavior during Growth of Co/Ni Multilayer —Study with High Brightness and Highly Spin-Polarized LEEM—

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Current induced domain wall motion [1] is a key phenomenon to realize novel spintronic devices such as a race-track memory [2] and a domain wall motion magneto-resistive random access memory [3]. It has been indicated that domain walls in nanowires with perpendicular magnetic anisotropy can move with lower current density than those with in-plane magnetic anisotropy [4, 5]. Co/Ni multilayer is known to exhibit perpendicular magnetic anisotropy and is expected as a material for the devices with low operation current [6, 7]. In the present study, we investigated magnetization behavior during growth of the Co/Ni multilayer with high brightness and highly spin-polarized LEEM [8– 10].
Figure 1 shows magnetic domain images of a multilayer consisting of pairs of 2 ML of Ni and 1 ML of Co on W(110). Magnetization of one Co/Ni pair was in-plane (Fig. 1 a). The magnetization became perpendicular upon Ni deposition (Fig. 1 b). The in-plane magnetic component appeared again upon the following Co deposition (Fig. 1 c). It is indicated that the Ni and Co deposition enhance perpendicular and in-plane magnetic anisotropy, respectively. In the following growth, the in-plane magnetic contrast after Co depositions became weaker with number of Co/Ni pairs and only the perpendicular magnetic domains were observable above four Co/Ni pairs (Figs. 1 d– i). It is shown very clearly that the perpendicular magnetization is stabilized with number of Co/Ni pairs as the perpendicular magnetic anisotropy prevails against the in-plane one.

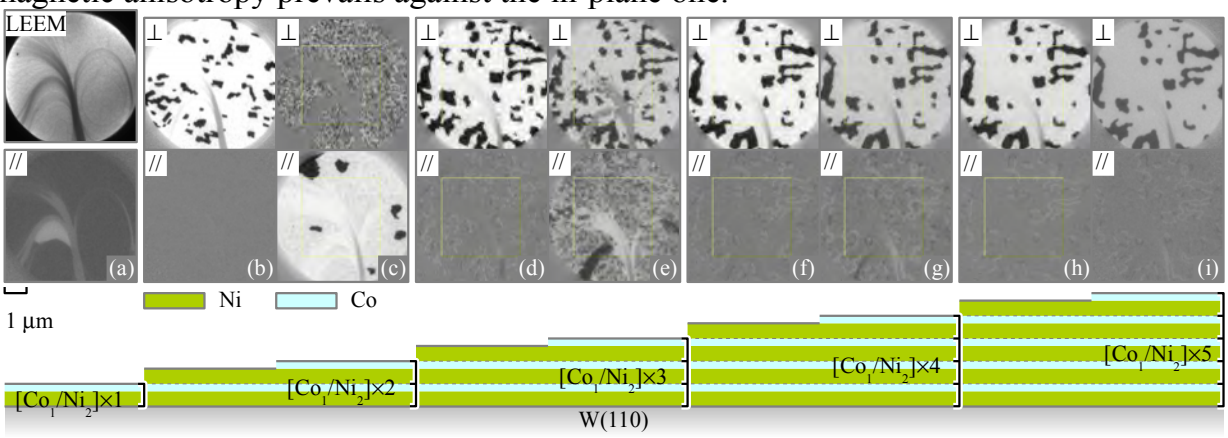

Figure 1. SPLEEM images with perpendicular (⊥) and in-plane [1 −1 0] (//) magnetization of a multilayer consisting of pairs of 2 ML of Ni and 1 ML of Co on W(110). Field of view = 6 μm ϕ.

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Microstructural and dielectric properties of PET polymer irradiated with 100 MeV Si^{8+} ions

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Abstract

Polyethylene terephthalate (PET) belongs to the polyester family of polymers and attracted due to its excellent physical and mechanical properties. In the present study we have investigated structural and dielectric properties of pristine and irradiated PET polymer using XRD, FTIR and LCR meter. PET polymer of thickness 50 μm was procured from Good fellow, Cambridge Ltd. England (UK), and irradiated with various fluences of Si^{8+} ions of 100 MeV energy using pelletron accelerator at Inter University Accelerator Center (IUAC), New Delhi. XRD analysis clear shows decrease in crystallite size with increase in fluence and no other impurity phase was observed. FTIR spectra indicate overall decrease in the intensity of typical band at higher fluence. On irradiation dielectric constant (ε') decreases with frequency whereas it increases with the ion fluence. Variation of loss factor (tan δ) with frequency for pristine and irradiated with Si ions reveals that tan δ increases as the frequency increases. Loss factor also increases with fluence. Due to irradiation the increase in conductivity with fluence at a given frequency may be attributed to scissoring of polymer chains, resulting in an increase of free radicals, unsaturation, etc.

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Etching Damage Analysis of TiO_2 Thin Film with Soft X-ray Absorption Spectroscopy

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TiO_2 thin film is expected to apply not only as photocatalyst but also as gate insulator films for MOS devices. Because of these backgrounds, it is desired to develop a damage-less etching technique. We report an etching damage analysis of TiO_2 thin films etched by N_2 and He plasmas with the use of X-ray absorption spectroscopy (XAS) technique.

The TiO_2 thin films (anatase) were prepared on glass substrates by an RF magnetron sputtering system [1]. The TiO_2 films were etched by capacitively coupled RF N_2 and He plasmas [2] at gas pressure ranging from 10 to 100 mTorr and with etching time ranging from 5 to 200 min. The surface of the etched samples was characterized with SEM, AFM, XPS etc. Here we report mainly about the results of XAS analysis. Soft X-ray absorption spectra at O-K and Ti-L edges of the etched samples were measured at the NewSUBARU SR facility at the University of Hyogo [3] with the use of total electron yield (TEY, surface sensitive) and total fluorescence yield (TFY, bulk sensitive) methods.

Figure 1 shows the XAS spectra of Ti-$L_{2,3}$ edge of the TiO_2 thin films etched by N_2 plasma. The spectra of the samples obtained by TFY method changed with increasing gas pressure. However, change in spectral shape of the same samples obtained by the TEY method was almost not observed. The fact that the spectral change did not observed in the surface sensitive TEY method could be an anomalous result comparing to the spectral change for n-GaN crystals etched with the same system [4]. According to the particle collision model (PIS) calculation, N_2 plasma etches preferentially to Ti atoms, while, He plasma etches preferentially to O atoms in TiO_2 films [5]. For the samples etched by N_2 plasma, the damaged configuration around Ti atoms near the surface might be recovered by structural relaxation to the stable crystalline configuration when the samples were exposed to the atmosphere.

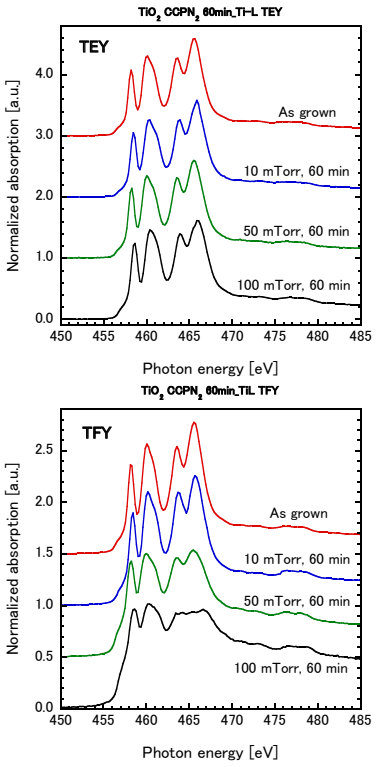

Fig. 1. Ti-L edge XAS Spectra (TEY and TFY) of TiO_2 thin film etched by N_2 plasma.

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Alanine Dosimeter Response Characteristics for Charged Particles in BNCT

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In radiation cancer therapy, it is of practical importance to achieve an accurate determination of absorbed dose distribution and localization of the radiation dosage around tissues. We are studying on dose evaluation in the radiation fields for boron neutron capture therapy (BNCT), in which a variety of secondary radiation (charged particles, neutrons, and γ-rays) are generated. The purpose of this work is to develop direct method of dose evaluation related to free radical production using alanine dosimeter. The use of alanine dosimeter allows quantitative measurements of free radicals produced by irradiation using electron spin resonance (ESR) spectroscopy. Response characteristics of the dosimeter for charged particles of H, He and Li ions generated in BNCT was investigated.

The sample used was commercially available alanine dosimeters (Kodak BioMax, USA). A sensitive layer of the sample is composed of polycrystalline L-α alanine and binder. The sample was irradiated with various projectile ions of 0.3-1.0 MeV H^+ ions, 1.47 MeV He^+ ions, and 0.84 MeV Li^+ ions. The irradiated samples were analyzed by ESR spectroscopy. From the analysis, we obtained ESR signal amplitude per unit mass of irradiated alanine (ESR/g). Figure 1 shows results of the amount of ESR/g as a function of LET for projectiles with different atomic number *Z* at the same dose of 1 kGy. One can see that in the low LET region (up to about 1000 MeVcm^2/g) the amount of ESR/g decreases with increasing the LET. Furthermore, it becomes constant in the high LET region (above 5000 MeVcm^2/g), suggesting that recombination of the generated radicals occurs because of high ionization density within an ion track. We will discuss the LET dependence for different dose.

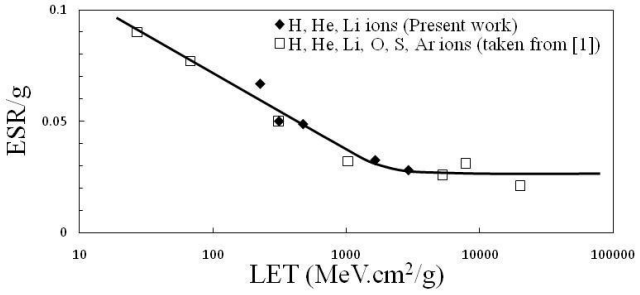

Figure 1. LET dependence of the response of alanine dosimeter

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Energy Dependence of Non-Rutherford Proton Elastic Scattering in Hafnium Nitride Thin Film

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Hafnium nitride (HfN) is expected to be used in various kinds of applications [1]. One of the important parameters of such films is the nitrogen composition. Rutherford backscattering spectrometry is a powerful tool to make a quantitative analysis of the elements in the film, but the sensitivity becomes worse for light elements. Non-Rutherford proton elastic scattering is one of the methods that can improve the sensitivities of light elements. One of the problems of this technique is such that the scattering cross section may not vary gradually with a decrease in the proton energy. For example, the scattering cross section for nitrogen (N) changes rapidly between 1.5 and 1.6 MeV [2]. This is inconvenient for the compositional analysis, and therefore, we investigated the energy dependence of the backscattering spectrum of proton elastic scattering.

A HfN thin film deposited on a silicon substrate was used as a sample. Helium RBS revealed that the areal atomic density was 5.5×10^{17} atoms cm^{-2} and the ratio of N/Hf was 0.74. Backscattering spectra were acquired at the scattering angle of 170^{o}, The energy of the proton beam was varied between 1.54 and 1.62 MeV. The backscattering yield from N together with those of C and Hf was acquired.

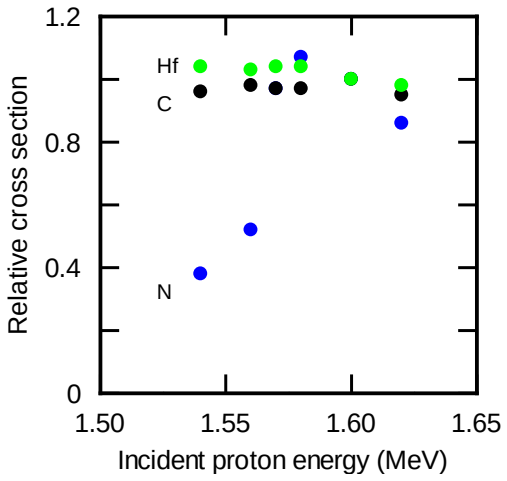

Figure 1. The ratio of the cross section to that of 1.60 MeV as a function of the incident proton energy

Figure 1 shows the energy dependence of the N/Hf ratio obtained in the above experiments. Although the changes of the relative cross sections for C and Hf were not large, that for N changed suddenly at around 1.57 MeV.

This critical energy varies when the thickness and composition of the HfN film varies. Careful determination of N composition is necessary.

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Surface Modification using Highly Charged Ions

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The interaction of slow highly charged ions (HCIs) with solid surfaces is useful for 'nanoprocess'; the modification, activation, machining and analysis in nanometer scale. The atomic scale modification of surfaces irradiated with HCIs have been observed by using STM, and the structure of irradiation traces have been investigated. The advantages of HCIs over singly charged ions (SCIs) as a tool of surface modification reside in their potential energy which is transferred to topmost surface layers of the sample. This feature appear in the high sensitivity for SEM contrast; fluence of HCI necessary for giving good SEM contrast ($10^{13\sim14}$/cm^2) is much smaller than that of SCIs ($10^{15\sim16}$/cm^2). The HCI beam produced by an electron beam ion source has low emittance which is suitable for the application of nanoprocess where the incident ion beam must be focused or limited in nanometer size. Figure 3 shows SEM image of Si wafer irradiated with HCIs (Ar^{11+}) with the fluence of 10^{14}/cm^2 through a cantilever with a window of 10μm square. The distance between the window and Si wafer is ~0.3mm. We have proved that HCIs modify the magnetic property of graphite with the fluence of 10^{14}/cm^2 for the first time. At the conference, we will present various results on the surface modification using HCIs and discuss about the strategies toward nanoprocess using HCIs.

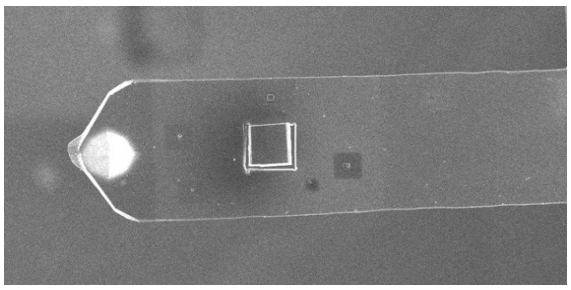

Figure 1. SEM image of cantilever with window.

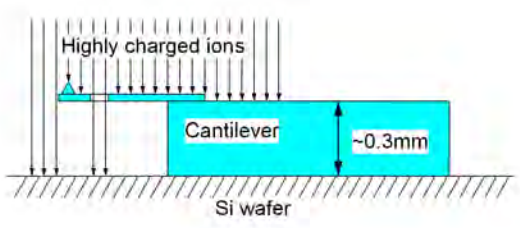

Figure 2. Shematics of irradiation condition.

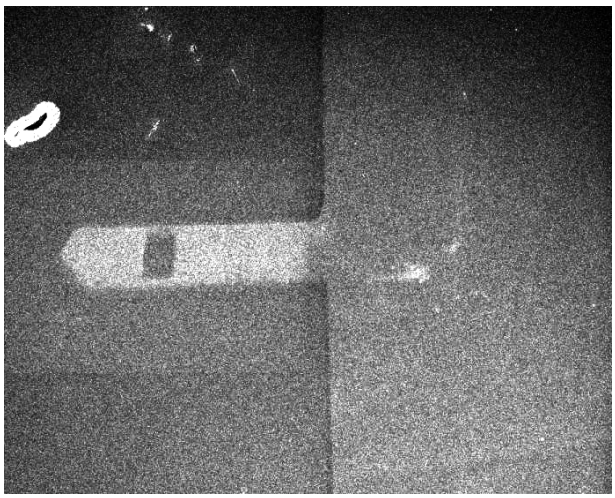

Figure 3. SEM image of Si wafer irradiated with highly charged ions through the cantilever.

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Spin Reorientation in Au/$CoNi_2$/W(110) Observed Using Spin Polarized Low Energy Electrons

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Magnetic thin films have been extensively studied because of their application to the spintronic devices. Understanding of the magnetic properties of the magnetic thin film is basically of importance, and also it is required to control them in order to achieve the highly sophisticated function. It is known that non-magnetic overlayer can modify the magnetic anisotropy of the magnetic thin films [1]. In the present study, we have observed the spin reorientation process during the deposition of Au overlayer on $CoNi_2$/W(110) with high brightness and highly spin polarized low energy electron microscopy (SPLEEM) [2].

Figure 1(a) shows out-of-plane (upper row) and in-plane (lower row) components of the magnetic domain structure of $CoNi_2$ on W(110). The $CoNi_2$ film exhibits the uniaxial in-plane anisotropy along [1 -1 0] direction. As Au deposition, the in-plane magnetic anisotropy becomes weak and almost vanishes at around a half ML of Au (fig. 1(c)). Then the out-of-plane component starts to develop after 0.5 ML, and the strong perpendicular magnetic anisotropy is established at 1 ML of Au. The domain structure observed here is completely different from that before Au deposition. We can obtain LEEM images simultaneously with the magnetic images. The intensity of LEEM image decreases with Au coverage up to around 0.5 ML and recovers after that. It would be suggested that the spin reorientation process seen in fig. 1 is relevant to the growth process of Au layer on top of $CoNi_2$ film.

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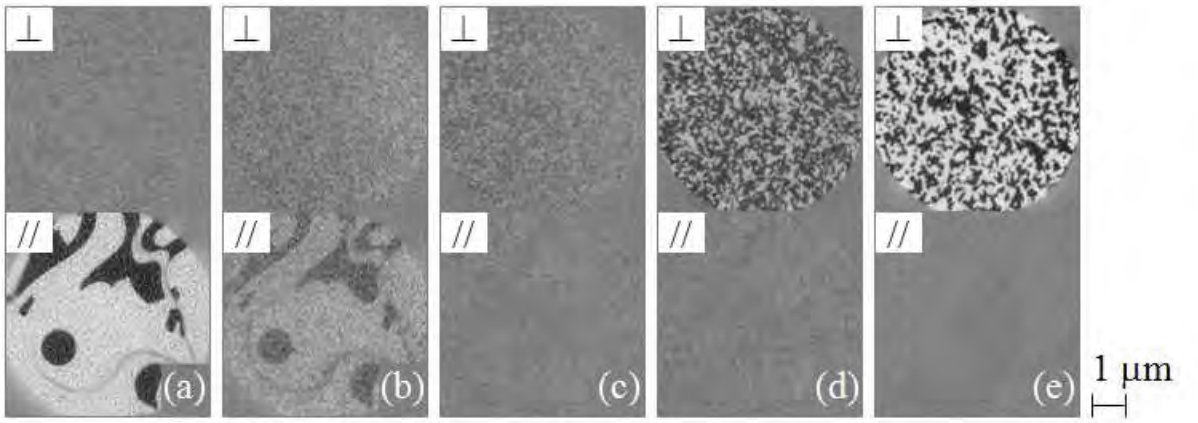

Figure 1. SPLEEM images during Au deposition on $CoNi_2$/W(110). Upper : out-of-plane, lower : in-plane component. The Au coverage is (a) 0 ML, (b) 0.25 ML, (c) 0.5 ML, (d) 0.75 ML and (e) 1 ML.

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Ionoluminescence of a thin rear-earth oxide film by slow highly-charged ions

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In the present work, ionoluminescence by highly-charged ion-beams is investigated with a thin erbium oxide (Er_2O_3) film. Previously, Tona et al. [1] observed strongly enhanced ionoluminescence of a thin organic-dye film by bombardment of highly-charged iodine ions with *L*-shell vacancies. This enhanced luminescence appears caused by energetic *L* Auger electrons emitted from the iodine ions above the target surface; the luminescence due to bombardment of the Auger electrons is added to that due to an electronic stopping power of the projectile ion in the organic-dye film. It is one of unique phenomena observed with highly-charge ions of interacting with optical materials.

Optical transitions of trivalent Er^{3+} ions in oxides have been exploited for applications in optoelectronics [2]. Recently, optical transitions useful to evaluate radiation damages in Er_2O_3 oxide coatings are also being searched for advanced nuclear fusion materials research [3]. In a visible range, a strong luminescence band due to $4f^{11}$ $^4F_{9/2}$ - $^4I_{15/2}$ transition of the Er^{3+} ions has been observed at 640-690 nm by electron and singly-charged ion bombardments [3, 4]. We will investigate the luminescence at 640-690 nm by using slow highly-charged ions, putting an emphasis on distinct excitation mechanisms of the luminescence from those by using singly-charged ion-beams. Target samples are thin polycrystalline Er_2O_3 oxide films of about 500-600 nm thickness coated on stainless steel substrates by using Metal Organic Chemical Vapor Deposition (MOCVD) [5]. Kobe Electron Beam Ion Source (Kobe-EBIS) [6] is used to produce intense highly-charged ion-beams (e.g. Ar^{12+} ion-beams of a few nA in current for acceleration voltages of 1.5 – 3 kV). We will be studying intensity variation of the luminescence with respect to charge states and kinetic energies of the projectile ions. Since degradation of the intensity is anticipated due to ion-induced damages created on target surfaces [3, 4], ion-dose dependences of the luminescence are also measured at respective charge states and kinetic energies of the incident ions.

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High-resolution Elastic Recoil Detection for Boron Depth Profiling

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High-resolution Rutherford backscattering spectroscopy (HRBS) is a powerful surface analysis technique, which has better depth resolution compared to the conventional RBS. It allows quantitative and non-destructive depth profiling of constituent elements with sub-nm depth resolution within a reasonably short measurement time (typically 10 - 20 min.) without any special pre-treatment of the sample. However, the typical sensitivity of HRBS for light elements, such as boron, is ~ 1 at.%, which is not good enough for some applications, such as for microelectronics [1].

Elastic recoil detection analysis (ERDA) is more suitable to analyze the light elements than RBS. Dollinger et al demonstrated that depth profiling of boron in silicon can be performed with sub nanometer depth resolution and high sensitivity of ~100 ppm by using their high-resolution ERDA (HERDA) setup [2]. Although the performance of their HERDA is excellent, they need a large facility including a high energy accelerator and a large magnetic spectrometer. If much smaller equipment can be used for the analysis of light elements with depth resolution and sensitivity comparable to their system, it should be useful. It was already demonstrated that our compact HRBS system can be used for high-resolution ERDA. Hydrogen depth profiling was performed with sub-nm depth resolution and a sensitivity of 0.1 at.% [3]. However, there are several issues to be solved to analyze other light elements heavier than hydrogen, such as boron.

In our hydrogen analysis, we used an electrostatic deflector to reject the scattered probe ions. Unfortunately, the electrostatic deflector cannot separate recoiled boron ions from the scattered probe ions unless very heavy ions are used. Another issue is charge state distributions of recoiled ions. Because the magnetic spectrometer cannot measure recoiled ions of all charge states simultaneously, the information of charge state distribution of the recoiled ions is necessary for quantitative analysis. However, there is almost no measurement on the charge state distribution of light elements in the relevant energy region.

In this paper, we employed two different methods to reject probe ions in boron depth profiling using HERDA. One is the use of He^+ ions as a probe. The magnetic spectrometer itself can reject the scattered He ions when the magnetic field is adjusted for the recoiled boron ions. The other is the use of a mylar foil in front of the focal plane detector as is in the conventional ERDA. Feasibility of these methods is examined and the pros and cons of these methods are discussed. The charge state distribution of the recoiled boron ions is also measured and the result is compared with an available semi-empirical formula to check the accuracy of the formula.

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Temperature dependence of low-energy electron irradiation induced nanocrystal in GaSb

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We recently found that the nanocrystal which has same orientation, are observed in GaSb low-energy electron irradiated at 373 K over [1]. There are two types variants in the matrix. The domains are pseudo-{110} planes in the matrix formed by irradiation-induced Shockley partial dislocations. The low-energy electron irradiation induces electronic excitation. It is well known that bond breaking and displacement of atoms can be induced by electron irradiation [2]. In this study, we investigate the temperature dependence of low-energy electron irradiation induced nanocrystal in GaSb.

Single crystals of GaSb were supplied in the form of 450-mm-thick wafers with the (001) plane normal. Discs of about 3 mm diameter were cut from the wafer, and the disks were thinned by a polisher until the thickness was below 100 μm. A dimple was formed at the center of the discs by a dimple grinder. Then the disks were thinned by ion milling with argon ions for TEM observation. Low-energy electron irradiation experiments and observations were performed using the same microscope (Hitachi H-7000) operating at an accelerating voltage of 125 kV. The electron flux used for the irradiations was 2×10^{21} electrons/m^2s. The temperatures of the thin films were kept at 293 K, 373 K, and 473 K during the experiments. The column vacuum was 5×10^{-5} Pa. Structural changes associated with electron irradiation were observed in situ by bright-field image (BFI), dark-field image (DFI), and selected-area electron diffraction pattern (SAED).

Structural changes were not observed in GaSb kept at 293 K during electron irradiation. The nanocrystals formed over the entire sample kept at 373 K after irradiation for 1.2 ks and 2.4 ks, respectively. The average diameter of the atomic region was approximately 3 nm (1.2 ks) and 6 nm (2.4 ks). With increasing electron fluence, the size of the crystal domains and the density increased. The size of the crystal domains was 10 nm (1.2 ks) and 18 nm (2.4 ks) in the sample kept at 473 K. The large size nanocrystals were formed in the higher irradiation temperature. The migration of dislocation in high temperature is faster than that in low temperature [3]. It is considered that the large deformation occurs in the high temperature irradiation.

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Surface and Interface Roughness Estimations by X-ray Reflectivity and RBS Measurements

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In the conventional x-ray reflectivity analysis, the reflectivity is calculated based on the Parratt formalism[1], incorporating the effect of the interface roughness according to Nevot and Croce [2]. However, estimation results of surface and interfacial roughness by x-ray reflectivity measurements did not correspond to those from TEM and AFM observations. We have also found that the calculated x-ray reflectivity show a strange behavior, i.e. the amplitude of the oscillation increases with interfacial roughness in the case of rough surfaces. The origin of the strange behavior was attributed to the fact that the diffuse scattering at the rough interface was not correctly taken into account by Nevot and Croce [3]. This might be also responsible for the disagreement between the x-ray reflectivity measurement and TEM/AFM observation. We have developed a new formalism in which the effects of the surface and interface roughness are included correctly. Using accurate formulae for $R_{j-1,\,j}$ and $R_{j,j+1}$, the x-ray reflectivity R of a multilayer consisting of N layers is given by

$$R = \left|R_{0,1}\right|^2 \ , \quad R_{j-1,j} = \frac{\Psi_{j-1,j} + (\Phi_{j-1,j}\Phi_{jj-1} - \Psi_{j-1,j}\Psi_{jj-1})R_{jj+1}}{1 - \Psi_{jj-1}R_{jj+1}} \exp(2ik_{j-1,z}h_{j-1}) \ , \quad R_{N,N+1} = 0$$

where h_j is the thickness of j-th layer, $k_{j,\,z}$ is the z component of the wave vector in the j-th layer, and $\Psi_{j-1,\,j}$ and $\Phi_{j-1,\,j}$ are the Fresnel coefficients for reflection and refraction, respectively, at the interface between (j-1)th and j-th layers. Although formula for $\Psi_{j-1,\,j}$ is well known

$$\Psi_{j-1,\,j} = \frac{k_{j-1,\,z} - k_{j,\,z}}{k_{j-1,\,z} + k_{j,\,z}} \exp\left(-2k_{j-1,\,z}k_{j,\,z}\sigma_{j-1,\,j}{}^2\right), \qquad \Psi_{j,\,j-1} = -\Psi_{j-1,\,j} \quad ,$$

where $\sigma_{j-1,\,j}$ is the interface roughness between (j-1)-th and j-th layers, an accurate analytical formula for $\Phi_{j-1,\,j}$ including the effect of the interface roughness is not available. There are several approximations proposed so far and all these results can be written as

$$\Phi_{j-1,\,j} = \frac{2k_{j-1,\,z}}{k_{j-1,\,z} + k_{j,\,z}} \exp\{-[C_1(k_{j-1,\,z} - k_{j,\,z})^2 + C_2 k_{j-1,\,z}k_{j,\,z}]\sigma_{0,1}{}^2\}, \qquad \Phi_{j,\,j-1} = \Phi_{j-1,\,j}\frac{k_{j,\,z}}{k_{j-1,\,z}} \quad ,$$

where parameters C_1, C_2 depend on the proposed approximations. In the present work, we try to determine these parameters experimentally by comparing the measurements of high-resolution RBS and x-ray reflectivity. We will present the detailed results and discuss the improvement of the x-ray reflectivity analysis using this new formalism.

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Structural changes induced by low-energy electron irradiation in III-V compound semiconductors

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Effect of structural changes on high-energy electron irradiation in bulk III-V compound semiconductors reported by some articles [1-3]. Electron irradiation induces chemical disordering, crystalline-amorphous transition, and dislocation loop in irradiated samples with 2 MeV electrons. On the other hand, low-energy electron irradiation in the sample kept at 373 K over induces the formation of nanocrystal in GaSb and InSb [4]. This phenomenon shows only GaSb and InSb. In this study, structure changes induced by low-energy electron (125 keV) irradiation in III-V compound semiconductors are investigated by transmission electron microscopy.

Single crystals of GaSb, InSb, GaP, and InP were supplied in the form of 450 mm thick wafers with the (001) and (111) plane normal. Discs of about 3mm diameter were cut from the wafer, and these were thinned by a polisher until their thickness was below 100 μm. A dimple was formed at the center of the discs by a dimple grinder. Then the discs were thinned by ion milling with argon ions for TEM observation. The electron irradiation experiments and the observations were performed using the same microscope (Hitachi H-7000, JEOL JEM-2010F, and 2100F) operating at an accelerating voltage of 125 kV. The electron flux used for the irradiations was $5x10^{24}$ electrons/m^2s. The temperatures of the thin films were kept at 473 K during the experiments. The column vacuum was $2x10^{-4}$ Pa.

The nanocrystal of In_2O_3 variant were formed in InSb kept at 474 K during 125 keV electron irradiation. The average diameter of the nanocrystal was approximately 42 nm in the sample irradiated to a fluence of $9x10^{26}$ electrons/m^2. However, no structural changes were observed in GaP and InP before or after irradiations. The single-crystal structure of zinc-blende remained in after irradiation.

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Fabrication of Ordered Nano-Cell Structure on Ge Surface by FIB

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Anomalous behaviors such as the surface elevation and the cellular structure formation have been observed in ion irradiated GaSb, InSb and Ge. Nitta *et al*. proposed the formation mechanism of the cellular structure on the basis of movement of the point defect and proved it experimentally [1]. The cellular structure is very fine, which inspire us to apply it for nano-devices. However it is lack in regularity. Then, some of the authors proposed a novel nano-technique in order to fabricate the ordered nano-cell structure, and developed the technique mainly for InSb and GaSb [2,3]. The cellular structure formation process in Ge is somewhat different from that in GaSb and InSb. In the case of Ge, the irradiated layer is amorphized prior to cell formation while the irradiated layer is amorphized after the cell formation in GaSb and InSb by ion irradiation. On the basis of this fact, in this work, two kinds of nano-cell fabrication were performed and compared. One is the method used in nano-cell fabrication of GaSb and InSb, in which two-processes, formation of initial ordered void lattice and development of the void lattice to the cell lattice. In the other method, initially the surface layer of Ge wafer was amorphized by ordinary ion irradiation and then, nano-cell structure was formed on it by the same process. These processes were performed using 30 keV Ga^+ in a focused ion beam apparatus (FIB) at room temperature. The results showed that the secondary void formation was remarkable in the initially amorphized Ge. Probably the vacancy mobility in amorphous Ge is large, which might have accelerated the formation of secondary voids between the initial voids.

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Production of C_{60} Microbeams by Single-Microcapillary Methods

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A single tapered capillary with micron-sized outlet diameter is used as a new tool of producing charged particle microbeams. This capillary-microbeam method is capable of easily producing focused beams for various types of charged particles in a wide energy range from keV to MeV. In this work, we applied this method to production of fast C_{60} microbeams. By using capillaries with two different outlet diameters of 5.5 and 14 μm, transmission properties of 360 keV C_{60}^{+} and 720 keV C_{60}^{2+} through a capillary were investigated. In order to evaluate beam qualities of the produced microbeams, we performed systematic studies on a composition of the transmitted particles.

The experiment was performed at Japan Atomic Energy Agency (JAEA)/Takasaki. A C_{60} primary ion beam obtained from a 400 kV ion implanter was introduced into a single capillary mounted on a goniometer. To obtain information about a composition of the transmitted particles, particles emerging from a capillary were deflected with electrostatic parallel plates and detected by a microchannel plate with a phosphor screen (two-dimensional imaging measurement). From the measurement, we obtained some interesting results: (1) a main component of transmitted particles is due to direct transmission of incident C_{60} beams, (2) the other component is due to transmission of neutral particles and large-sized fragments of C_{58} or C_{56} ions produced via C_2-emission from C_{60}, (3) small-sized carbon fragments of C_1 or C_2 ions resulting from C_{60}-multifragmentation are not detected.

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Auger electron emission from Si(111) surface during 11 keV Ar^+ ion sputtering

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Secondary ion mass spectroscopy is known as a useful tool for compositional analysis of material surfaces. However, for the quantitative analysis, the understanding of ion production mechanism is indispensable. We have paid an attention to the production mechanism of Si^{2+} ions during ion sputtering and have realized the importance of Si^{0*} or Si^{+*} as precursors of the Si^{2+} ion. In order to obtain the deeper insight about Si^{2+} production, we have planned a new experiment, in which the ion induced Auger electrons and the sputtered Si species are measured coincidently. Although, at this moment, we are unable to offer the detailed information obtained from such measurements, we report here a strong correlation between the penetration depth of Ar ion and the Auger electron yield.

In our experiments, a Si(111) wafer was irradiated by the 11 keV Ar^+ beam. The Auger electron yield was measured at a fixed angle of 45° with respect to the primary Ar^+ beam. We changed the incident angle of Ar^+ to the surface. Fig.1 shows the energy spectra of Auger electron for different incident angles, θ, measured from the surface normal. The positions marked by the arrows correspond to the atomic LMM-Auger or the broad spectrum of the bulk LVV-Auger (ref.[1]). Although the individual Auger peaks are not clearly distinguishable, the Auger yield significantly increases for the larger θ. This can be explained in terms of the electron escape depth (1 nm for 90 eV) and the ion range of 11 keV Ar (10 nm). For the larger θ, the collision cascades are created in the shallower place, and the more Auger electrons can escape from the surface, and the atomic Auger is also increased with the increase of sputter yield.

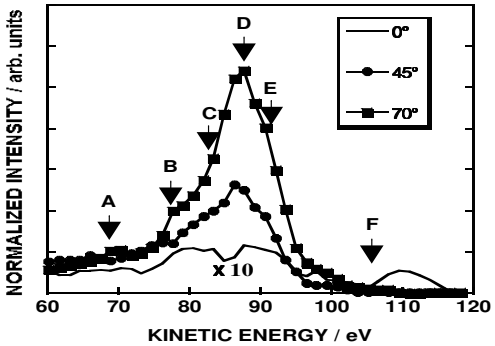

Figure 1.the Auger spectra for different incident angles. The yield for θ=0 ° has been multiplied by 10.

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Temperature dependent damage production in SIMP steel under 196 MeV Kr-ions irradiation

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Energetic heavy-ions have been widely used to assess the irradiation response of materials and to study some basic aspects of irradiation damage. Atom displacements caused by energy deposition process will produce a large amount of the point defects. Although a small fraction of the point defects will survive after the collision stage, interactions between these defects can substantially lead to irradiation induced microstructure changes. Different mechanisms control the defects motion at different temperature regimes. In the present work, we focused on the temperature dependent of defect evolution in Ferritic/Martensitic (F/M) steel under high energy heavy ion irradiation.

A F/M steel named SIMP steel was employed in this work. Specimens were irradiated with 196MeV Kr-ions at room temperature, 723 and 823 K, respectively. After irradiation, the samples were investigated using positron annihilation spectroscopy (PAS) and Conversion Electron Mössbauer Spectroscopy (CEMS). From the obtained Doppler broadening PAS spectra under the condition of positrons with different energies, vacancy-type defects and their distribution at different irradiation temperatures varying with the positrons penetrating depths are analyzed. More, the changes of the environment of iron atoms linked to irradiation damage are analyzed based on the recorded CEMS spectra. Then, the irradiation damage produced in the near-surface region of the SIMP steel were deduced, and the damage process was discussed.

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Charge State Evolution for 2 MeV/u Carbon Ions Passing through Carbon Foils

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Non-equilibrium and equilibrium charge state distributions for 2.0 MeV/u carbon ions after penetrating carbon foil have been studied experimentally, following experimental [1,2,3] and theoretical [4] studies for 2.0 MeV/u sulfur ions. The initial charge states for the carbon projectile were between 2 and 6, whereas the target foil thickness was between 0.9 and 200 μg/cm^2. The measured equilibrium mean charge state and distribution width were 5.57 and 0.58, respectively. For the projectiles with charge states lower than the equilibrium charge state, i.e., for C^{2-5+} projectile ions, all the measured charge fractions except for C^{6+} showed similar dependence on target thickness that the fractions increase to show maxima in the non-equilibrium region and turn to decrease to the equilibrium values. This trend can be explained by a difference of collision cross sections or collision rates for consecutive single-charge transfers as for the sulfur projectile ions [3] and has been reproduced by ETACHA [5] code, although ETACHA predicts a bit higher equilibrium mean charge state 5.71 and a bit narrow distribution width 0.51.

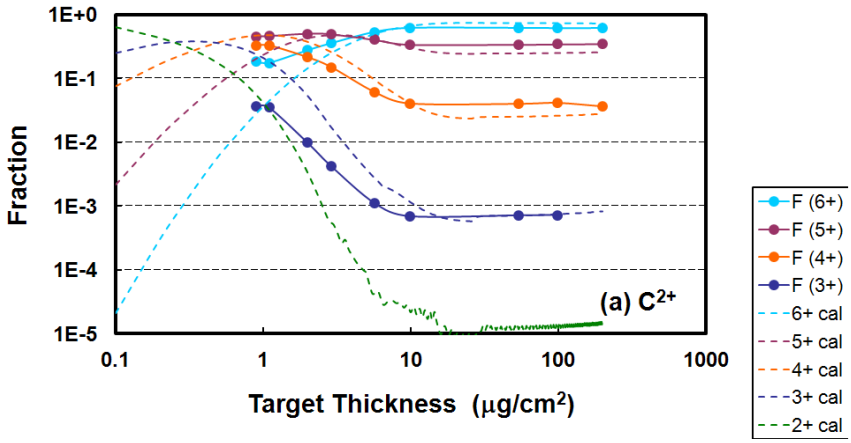

Figure 1. Charge state evolution for 2.0 MeV/u C^{2+} ion after penetrating C-foil targets. Full and dashed lines show experimental data and ETACHA calculation, respectively.

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Transmission of Fast Carbon Cluster Ions through an Al_2O_3 Nano-Capillary Foil

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The transmission of fast carbon cluster ions C_n^+ (n=1 to 4) through Al_2O_3 nano-capillary foil was studied. The experiments were conducted at the University of Tsukuba, using 1 MV Tandem accelerator. Nano-capillary foils were purchased from SmartMembaranes GmbH. The capillaries are highly ordered and have high aspect ratio; the pore size was 75 nm in diameter and the thickness was 50 um. Front surface of the film was coated with platinum avoiding charging-up of the surfaces during ion beam exposure. The transmitted ions are detected by solid state detector (SSD).

Fig. 1 shows typical spectra for 0.98 MeV C_2^+. Main peak corresponds to the transmitted C_2^+ through the nano-capillaries. At the half energy of the peak, there can be seen a peak of C. The peak has low energy tail, which is considered to be due to the fragmentation of C_2^+ scattered on the inner wall of the capillary. Comparing the intensity of these two peaks, survival ratio of C_2^+ is obtained to be nearly 90%. This high survival ratio is considered to be result of high aspect ratio which lowered the transmission of scattered particles.

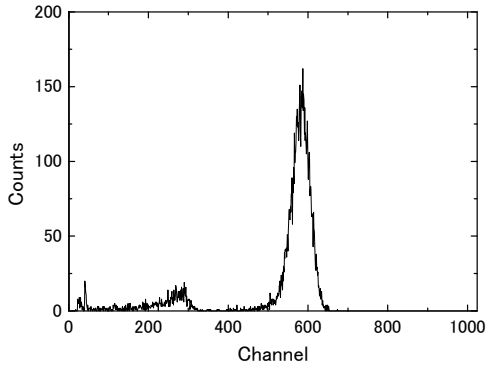

Figure 1. Typical energy spectrum of 0.98MeV C_2^+ transmitted through nano-capillary foil. The pore size was 75 nm in diameter, and the thickness is 50 μm.

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Isotope Dependence of the Equilibrium Charge State of Cl Ions Passing through Carbon Foils

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The information on the charge state distribution of different isotope ions is important for accelerator mass spectrometry (AMS), meanwhile systematic measurements of the charge state distribution of isotope ions are limited[1, 2]. The purpose of this research is that there is any isotope effect or not in the charge state distribution of Cl isotope ions at higher energy regions for ^{36}Cl AMS. Since the charge state distribution of ions passing through a foil is caused by a distant collision, an observation of the isotope effect would be a little expected even if the ion energy becomes higher. In order to confirm this query, equilibrium charge distributions of 0.607 – 2.51 MeV/u for ^{35}Cl and ^{37}Cl ions after the passage through carbon foils have been measured by a high resolution magnetic spectrograph ESP-90 with the 12UD Pelletron tandem accelerator at the University of Tsukuba.

When the equilibrium charge state distributions of ^{35}Cl and ^{37}Cl ions after the passage through carbon foils are compared at equal exit energy from carbon foils in units of MeV/u, quite a good agreement has been observed between ^{35}Cl and ^{37}Cl ions. Equilibrium mean charge of 2.51 MeV/u for ^{35}Cl and ^{37}Cl ions, for instance, is 14.04. In this work, the isotope effect of charge state distributions between ^{35}Cl and ^{37}Cl ions has not been observed at the higher energy region.

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The effects of Oxygen on Hydrogen retention in Tungsten: a first-principles investigation

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Abstract

We investigate the physical origin of hydrogen-oxygen (H–O) interaction in Tungsten (W) in terms of total energy and charge density by calculating the energetics and diffusion properties using a first-principles method. The interaction between H and O in bulk W show a strong attractive interaction with solution energy ~ 0.61eV and correspond biding energy ~ 0.341 eV along the <031> directions with the H–O distance of ~ 2.38 Å. Energetically, both a single H atom and O atom are prefer to occupy tetrahedral interstitial site (TIS). Two interstitial H atoms are attractive and tend to be paired up at two neighboring TIS with a H-H distance of 1.74 Å and O-H distance of 2.43for both two H atoms with H-$\hat{O}$-H angle ~ 42^{o} and solution energy ~ 1.26eV with corresponding biding energy ~ 0.5eV . According to the distances between O-H, H-H and H-O-H complexes and the H-O-H angle, the possibilities of format the OH, H_2 and H_2O molecules are excluded.

PACS: 21.10.Dr, 21.10.Ft, 71.15.Mb, 81.05.Bx, 61.72.-y

Keywords: Tungsten, Oxygen, Hydrogen, First principles

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Stark effect in Resonant Coherent Excitation of 2s electron of Li-like Fe^{23+} ions Channeling in a Si crystal

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In resonant coherent excitation (RCE) of the 2*s* electron to the n=3 states for Li-like Fe^{23+} ions channeling in a silicon crystal at 83.5MeV/u, it was found that the RCE corresponding to optically forbidden transitions could be seen as intense as optically allowed transitions.[1] We considered that the Stark mixing of the n=3 states due to the electric field of the static planar potential was the most possible reason for the observation of the optically forbidden transitions. This effect is very small close to the channel center and becomes more important with increasing distance from the channel center because the electric field of a planar potential increases with distance from the channel center.

We performed RCE measurement of 83MeV/u Fe^{23+} ions using a silicon surface barrier detector (SSD) as a crystal target in order to obtain information on the ion trajectory in the channel. The energy deposit (ΔE) to the SSD increases with the amplitude of oscillating ion trajectory. Therefore, RCE measurement coincident with ΔE gives information on the amplitude of ion trajectory where the optically forbidden transitions occur. This method was used by Azuma et al. for 390 MeV/u H-like Ar ions and the transition energies of RCE to the n=2 states were found to strongly depend on the ion trajectory due to Stark mixing by the planar potential.[2]

In the low ΔE, i.e., near the channel center, optically allowed 2*s*-3*p* transitions were intense compared with other transitions. Increasing ΔE, i.e., increasing the amplitude of ion trajectory, the optically forbidden 2*s*-3*s* transition rapidly became intense. On the other hand, the optically forbidden 2*s*-3*d* transitions did not become intense as rapidly as 2*s*-3*s* transition. Furthermore, it was found that the excitation energies to the n=3 states changed with ΔE, which was at least qualitatively consistent with the estimation for the energy levels of the Stark-mixed n=3 states depending on the distance from the channel center.

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Modification of Optical Band-gap of Silicon Films Induced by Ion Irradiation

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The researches about the effects of ion irradiation on the mono-crystalline silicon (c-Si) have been progressed for several decades. However, the studies about the modification of the structures and optical properties of silicon films induced by the ion irradiation are limited. In the present work, the effects of ion irradiation on the optical band-gaps of silicon films have been studied.

Hydrogenated amorphous silicon (a-Si:H), nano-crystalline silicon (nc-Si), hydrogenated nano-crystalline silicon (nc-Si:H) films and c-Si samples have been irradiated at room temperature (RT) by 2.0, 3.0, 4.0, 30, 196 MeV Kr-ions and 5.0, 6.0, 9.0, 94 MeV Xe-ions. The fluence of Kr-ions is in the range from 1.0×10^{13} to 2.0×10^{14} ions/cm^2, and the fluence of Xe-ions is in the range from 1.0×10^{11} to 1.0×10^{14} ions/cm^2. The samples were investigated by the means of X-ray diffraction (XRD), Raman spectroscopy, transmission electron microscopy (TEM) and UV-Vis-NIR spectroscope. The obtained results show that the optical band-gaps of the silicon films decrease with the increasing fluence. For a-Si:H, nc-Si and nc-Si:H films, the optical band-gaps decrease from 1.78 to 1.54 eV, from 1.76 to 1.14 eV and from 2.1 to 1.37 eV, respectively. While the optical band-gaps of c-Si samples remain identical at 1.12 eV before and after the irradiation. Possible mechanisms on the irradiation-induced modification of the optical band-gaps of silicon films with different structures are discussed.

Keywords: Ion irradiation, Silicon films, Optical band-gap

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Emission Rates of Selected L Sub-Shell Proton Induced X-Rays as a Function of Projectile Energy

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Characteristic X-Ray spectra of Gd, induced by proton impact were recorded in order to generate information on the dependence of the L-Shell X-Ray emission rates as a function of the projectile energy. For the present study, samples were prepared in the form of thin films by deposition of GdF_3 on pyrolytic carbon substrates. Proton beams were produced by means of a Van de Graaff accelerator, and the range of bombardment energies covered from 200 keV up to 750 keV.
Experimental results will be presented as relative intensities of the X-Ray lines, corresponding to some of the different L-subshell transitions on the target. By comparing these results with theoretical predictions, some disagreement can be found in the case of the L_1 and L_3 subshells, particularly for bombardment energies below 400 keV. Also, by considering relative intensities of selected individual X-Ray emission lines instead of only sub-shell multiplets, it has been possible to show with more detail the origin of such disagreement with the calculations.

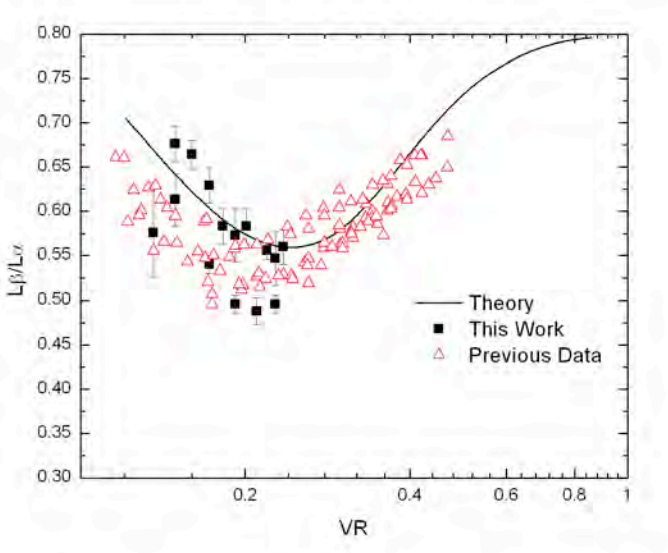

Figure 1. Relative intensity of L_β / L_α X-Ray lines, as a function of a scaling parameter defined as the *reduced velocity*. Results from this work are compared with previous measurements and theoretical calculations.

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Dynamic features of slow highly charge ion beam guiding with glass surface

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We have developed a scheme to produce microbeams of slow highly charged ions with single tapered glass capillaries based on the guiding by a self-organized charge up [1, 2]. A similar transmission experiment with thin gaps of paired glass plates has been performed as one of different types of guiding optics, where we found a peculiar oscillation feature in the beam transmission [3]. We have proposed a periodic resistive switching of the glass plates which causes drastic discharges of the accumulated charge on the glass surface when the strength of the electric field by the charge becomes strong enough. The field becomes weak after the discharge and then the charging starts again. When the switching occurs decreasing of guided transmission is observed. In order to examine the switching can occur even with a single plate, we have started an experiment of grazing incidence to a glass surface with the incidence angles of 1-10^{o} or less as shown in Fig.1. A position sensitive detector was installed not only to count the reflected ions but also to measure the deflection angles of the ions. Increasing of the number of reflected ions was observed as reported in [4], while inhomogeneous distribution within the beam spot was obtained. And some islands within the spot appeared and disappeared depending on time. According to the appearances of the islands, the counts of reflected ions fluctuated. This dynamic inhomogeneous distribution corresponds possibly to the localized discharge-positions in the irradiated area. We will report on the details of the reflected beam profile and compare the results of the experiments employing paired glass plates and single glass plate.

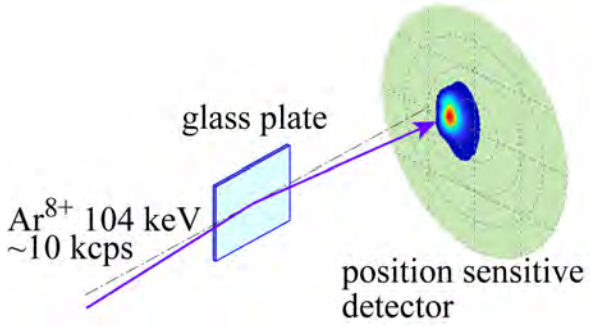

Figure 1. Setup of the experiment. The soda lime glass plates had a metal plate on the rear side connected to the ground.

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High-resolution EUV/X-ray Spectroscopy for Investigations of Ion-Surface Interactions at EBIS

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The electron beam ion traps and sources (EBIT/S) offer unique experimental conditions for the studies of interaction of highly charged ions (HCI) with plasma and solids [1]. In particular, the neutralization of slow HCI at surfaces leads to formation of exotic hollow which relaxation is accompanied by the emission of x-rays carrying information on the dynamics of this process as well as the structure and deexcitation channels of hollow atoms. Additionally, in such collisions the surface can be locally strongly modified leading to formation of nanostructures such as hillocks or crates. This process is of great fundamental and technological interest [1].

Here we report on the development of EUV/X-ray spectroscopy program at the EBIS-A facility [2] (Dreebit GmbH Dresden) which was installed recently [3] at the Institute of Physics of Jan Kochanowski University. The x-rays emitted from the recombination processes will be measured by the IncaWave diffraction x-ray spectrometer manufactured by Oxford Instruments. This spectrometer covers a wide range of photon energies from 70 eV to 15 keV including thus both the extended ultraviolet (EUV) and x-ray regions, which is important feature for the studies of ion-surface interaction. The IncaWave is a compact (R = 21 cm) x-ray spectrometer having six diffraction crystals, including two multilayers, which are installed in Johann or Johansson geometry. In order to optimize the use of this spectrometer at EBIs the simulations of its characteristics have been initiated using the ray tracing Monte Carlo approach (see Ref. [4]). The simulations covers both the geometries of the spectrometer calibration using the electron beam excited x-rays as well as the measurements of x-ray emission from HCI colliding with surfaces. In particular, the influence of the x-ray source size on the energy resolution of the spectrometer for various geometries, including grazing angle emission [5], will be studied in details. In this simulations a modeling of the crystal rocking curve will be also investigated. Finally, the results of optimization of the installation of the IncaWave x-ray diffraction spectrometer for the observation of x-rays emitted from collision of slow HCI with surfaces will be presented.

This work is supported by the Polish Ministry of Science and Higher Education under Grant No. N N202 463539.

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Ion beam Guiding with Curved Glass Tubes

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The ion beam guiding phenomena with macroscopic-size (a few cm long and some tens to hundreds μm inner diameter) single glass capillaries and tubes were reported by several groups [1,2]. In those studies, the transmission became smaller as the tilt angle became larger. The observed guiding limit in tilt angles was about 5 degrees or less. In our previous work, we have observed that curved Teflon tubes can guide ion beams to the angles larger than the guiding limit of straight Teflon tubes [3]. Recently, we have tested the guiding capability of straight and curved glass tubes. The experiment and some typical results are shown in Fig.1. The injected beam current was estimated from the current I_h+I_t and the diameter ratio of inlet to shield aperture. The inner and outer diameters ID/OD, the radii of curvature R, and the bending angle ϕ of the tubes are given in the figures. Very stable transmission was observed for bending angles much larger than the guiding limit of the straight tube. It continued for more than 40 minutes until the measurement was stopped. However, the transmission oscillated (see Fig.1d) when the entrance of the tube was slightly (0.5-1 degrees) tilted in the direction of the bottom in Fig.1a. The oscillation continued stably more than 15 minutes until the tilt angle was changed. This phenomena might be caused by 'resistive switching' of the glass as reported in Ref. [4].

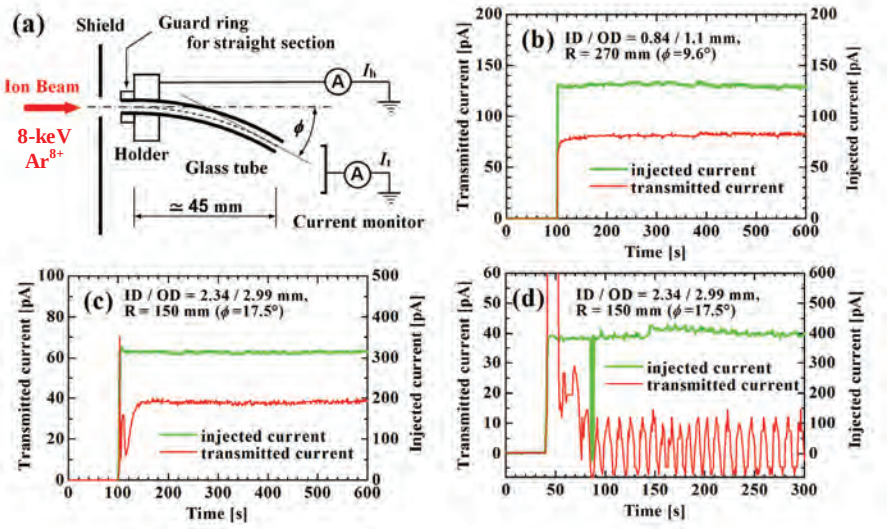

Figure 1. (a) Experimental setup. (b)-(d) Time dependence of ion beam transmission with curved glass tubes. The primary beam was turned on at around 100 s in b and c, and 40 s in d.

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Medium-Energy Helium Ion-Stimulated Desorption

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We have investigated an interaction between medium-energy helium ion beam and lithium-containing materials. Lithium-containing materials used in this investigation have been a MgLi alloy and a $LiCoO_2$ of a positive-electrode material for lithium-ion battery. The investigation has been performed using a three-dimensional medium-energy ion scattering (3D-MEIS) spectrometer[1-4]. 3D-MEIS is that a pulsed He ion beam with a pulse width of 2 ns at a medium energy of 100 keV is used as an incident beam, and emissions coinciding with the incident beam are detected using a two-dimensional position sensitive and time-resolving micro-channel plate detector. We have found for the first time that hydrogen and Li ions are emitted from sample surfaces by the He ion beam impact with a medium energy. It is considered that the mechanism of the phenomenon which has been drawn from evidences of emission energy and emission efficiency of hydrogen and Li ions is desorption induced by electronic transition. The phenomenon may be a novel method for analyzing light elements, especial Li.

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Sputtering and Erosion of Carbon and Tungsten Surfaces Exposed to Fusion-relevant Plasma

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Plasma facing materials for nuclear fusion devices encounter plasma-surface interaction processes such as chemical and physical erosion, re-deposition and implantation. Understanding and overcoming the detrimental effects that these phenomena can have upon component integrity, plasma stability, and the associated device performance, is key to the development of materials and components for fusion devices.

The MAGnetised Plasma Interaction Experiment (MAGPIE) at the Australian National University (ANU) is a high density (n_e = 10^{17} - 10^{19} m^{-3}), low temperature (T_e ~ 5 eV), and high flux (~ 10^{17} ions cm^{-2} s^{-1}) linear plasma device for plasma surface interaction studies. This prototype device uses an external RF helicon antenna capable of delivering plasma power of up to ~2.5 kW in continuous operation or up to ~5kW pulsed. A series of external coils are used to magnetically confine the plasma and create conditions similar to that of the divertor region of a fusion device.

We report on the sputtering and erosion processes of carbon and tungsten materials from some of the first materials-exposure experiments in MAGPIE. Surface morphologies of the samples have been characterised using scanning electron microscopy, revealing erosion and blistering. Changes to the nature of chemical bonding are observed via Raman spectroscopy. Ion beam analysis is used to measure the elemental composition of the exposed surfaces.

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Muon Acceleration in Cosmic-ray Sources

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The sites of cosmic-ray acceleration seem to require extreme conditions involving turbulent plasmas. Protons, pions and muons may interact with the matter and fields in these sites, and be accelerated to high energies, up to 10^{20} eV. Several mechanisms are proposed for accelerating cosmic-rays with gradients up to 10^{13} keV/cm. At gradients above 1.6 keV/cm, the muons produced by hadronic interactions undergo significant acceleration before decay. We study the effect of muon acceleration on neutrino production. The resulting constraints preclude models of linear acceleration and by this set strong constraints on plasma wakefield accelerators and on specific sources for linear accelerators like Gamma Ray Bursts and magnetars.

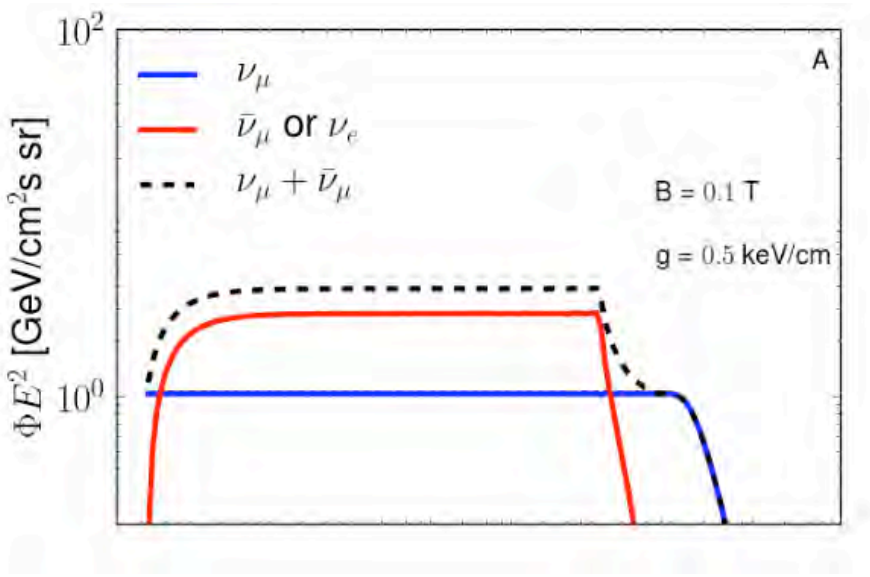

Figure 1. Enhancement factors for different neutrino flavors.

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Anomalous Deep Ion-induced Modification of HOPG

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The ion-induced structure and morphology changes of highly oriented pyrolytic graphite (HOPG) are different from ones for less ordered carbon-based materials and these changes manifest inherent differences in the temperature range from RT to ~ 400 °C. This displays the temperature dependences of ion-induced electron emission yield $\gamma(T)$ which are essentially different from each other during heating and following cooling [1].The purpose of the presented work is to study the regularities of high-fluence (10^{18}–10^{19} ion/cm^2) 10 - 30 keV Ar^+ ion modification of HOPG (grade UPV-1T) basal plane. The Rutherford Backscattering (RBS) has been applied to estimate the modified layer depth h. The morphology changes have been studied by scanning electron microscopy (SEM). It has been found that at sufficiently high ion energy h can be ten times more then the ion projectile range R_p. The different effects of deep modification with h > 1000 nm are observed in two temperature intervals. Firstly, at the temperatures smaller then the temperature of ion-induced texture transition $T < T_t \approx 150$°C and the topography is not significantly changed from initial one and modified layer becomes in polycrystalline state according to RBS in channelling regime. Secondly, at $T_t < T < 400$ °C when the SEM shows the development of needle and ridge-like elements and deep argon incorporation takes place. The ion irradiation at temperature of texture transition T_t, as the irradiation at sufficiently high $T \geq 400$ °C, does not lead to deep modification effect and the depth h of disordered layer is about R_p. The influence of ion energy on the deep modification effect is seen from Figure 1. There are the energy thresholds of deep modification which correspond to threshold values of stationary level of radiation damage – about 45 and 65 displacements per atom accordingly for deep modification at RT and at T ~ 250 °C.

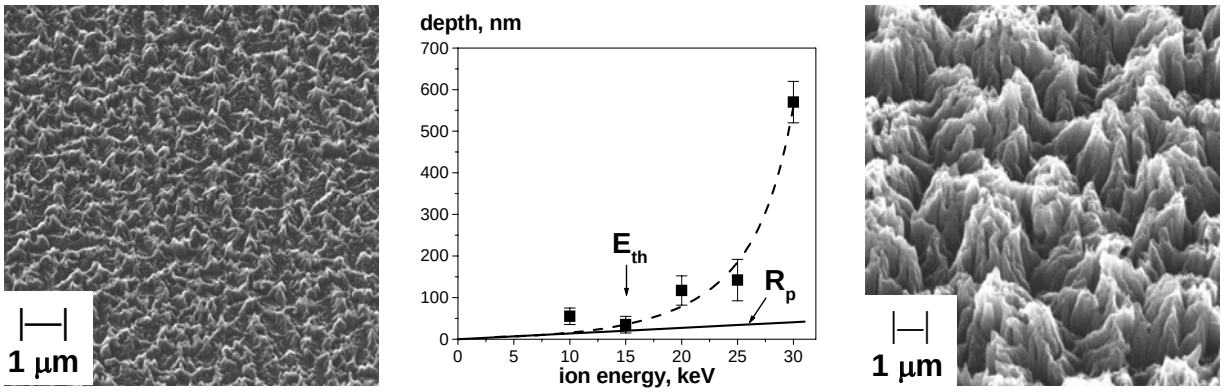

Figure 1. FWHM of argon concentration profile in HOPG versus Ar^+ ion energy E at T = 250 °C. SEM-micrographs of HOPG surface after irradiation at E = 10 keV (left) and E = 30 keV (right)

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Electrical Resistivity Change due to High-Energy X-ray Irradiation of Oxide Ceramics

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Electrical properties of $YBa_2Cu_3O_{6+x}$ can be easily changed over a wide range, from dielectric to metallic, by varying the oxygen concentration within the limits of $0 \leq x \leq 1$. In addition to variation of chemical composition, its conductivity can be influenced by visible light [1,2]. The excess conductivity persists for a long time even after switching off the light, and this phenomenon is called persistent photoconductivity (PPC). The importance of this finding is that light irradiation can be an alternative method of carrier doping. Although there are many literatures concerning visible light irradiation effect, there has been a few literature concerning X-ray irradiation effect of $YBa_2Cu_3O_{6+x}$ in the energy range of more than keV. The objective of this study is to investigate whether or not the high-energy X-ray (5-9keV) irradiation makes any difference compared with the visible light irradiation.

Distinguished feature of high-energy X-ray in the order of keV is its ability to excite inner shell electrons. Another important aspect of the present study is to elucidate whether or not the excitation of inner shell electrons generates a specific influence on the irradiation effect.

In this study $EuBa_2Cu_3O_7$, which has a same crystallographic structure as $YBa_2Cu_3O_7$, was irradiated with high-energy (5-9keV) X-ray at low temperature (100K), and the electrical resistivity was measured in situ. The low temperature irradiation is to minimize the thermal annihilation of defects created by X-ray. In fact, the irradiation-induced change in the resistivity observed at 100K is completely recovered after thermal annealing at 300K. The result of the in-situ measurement shows that electrical resistivity increases as increasing photon dose, suggesting that the atomic displacements are taken place due to the electron excitations. The effect has quite the opposite trend compared with that observed for the visible light irradiation. It is found also that the resistivity increase scales with the absorbed energy whether the energy level is near Cu K-edge (9.0 keV), Eu L3-edge (7.0 keV) and Ba L3-edge (5.2 keV). These results suggest that, irrespective of whether the high-energy X-ray causes inner shell electron excitation or not, the atomic displacements are caused as the relaxation process of the energy absorbed by the electron system of $EuBa_2Cu_3O_7$ sample.

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Low Energy Metal Ion Beam Injection to SiO_2 Thin Films for Development of Novel Catalysts

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It has been pointed out that interaction of different metal atoms such as Indium (In) and Silicon (Si) located in close proximity shows high catalytic abilities for certain organic chemical reactions [1-3]. Recently, we have proposed a "physical" approach, i.e., metal ion implantation into target materials, as a technique to prepare materials that contain different metal atoms in close proximity as potential candidates for catalysts [4]. In this study, we have developed a metal ion beam production system with a low energy mass-selected ion beam machine. The obtained mass-selected ion beam is identified to be that of pure metal with no impurity in the range of 0-500 eV. The full width at half maximum of the energy distribution is about 5 eV. We currently attempt to develop novel catalysts by injecting metal ions such as Indium (In) and Gallium (Ga) into SiO_2 thin films. In conventional experiments of metal ion beam injection, a solid-state metal is heated to produce liquid or gaseous metal atoms and then metal ions are produced. On the contrary, we modified a Freeman-type ion source so that a solid-state material can be set inside the ion source chamber as a sputter target. In the ion source, metal ions can be obtained from sputtering of the target by Ar ions generated from an Ar plasma [5]. We have measured the sticking probabilities or the self-sputtering yields of metal ions with energies in the range of 50-500 eV using a quartz crystal microbalance. For example, in the In ion beam experiment, we used In_2O_3 as the target in the ion source because the melting temperature of metal solid In is too low. Interaction of In and Si atoms are known to catalyze certain organic chemical reactions [1-3]. In an attempt of creating a material that manifests the interaction, In implanted SiO_2 films were prepared. It has been found that In implanted SiO_2 film can catalyze an organic chemical reaction. It has been also shown that there are optimal ion energies and optimal ion doses for the highest catalytic ability in the film preparation process [6]. Furthermore, we have found that catalytic ability of In implanted SiO_2 thin film is strongly dependent on the substrate temperature.

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Slow HCI Nanobeam Produced trough an Insulating Tapered Glass Capillary

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In the last decade microbeam fabrication for biological cell radiation and ion surface interaction has attracted considerable attention [1-3]. Low priced and unconventional insulating glass capillaries have been developed to produce slow HCI microbeams for ion beam analysis (IBA) [2,3]. Very recently we have performed measurements at the GANIL facility (Caen, France) with 27 keV Ar^{9+} ions transmitted through a tapered glass capillary for the purpose of producing nanometer sized beams. The capillary had an inlet diameter of ~800 μm, an outlet diameter of ~500 nm and overall length of ~8 cm, with a region near its center where the taper goes from the larger radius (800 μm) to the smaller radius (500 nm) in a relatively short distance (~4 mm). Using a well aligned primary ion beam, a transmitted beam of intensity 1.5 x 10^8 ions$\cdot$cm$^{-2}\cdot$s^{-1} and having a diameter of several hundred nanometers was obtained at the capillary exit. Transmission was measured for tilt angles over a range up to 1.2° with a 2-dimensional position sensitive detector (2-D PSD). Further results will be presented at the conference.

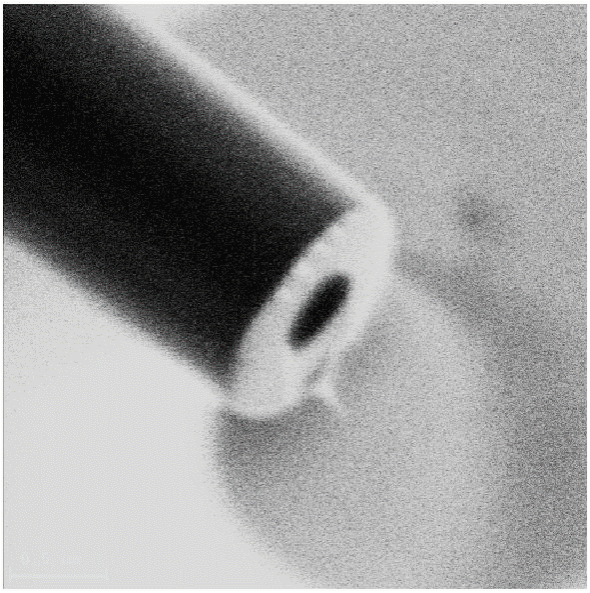

Figure 1: Exit of glass capillary with a diameter of 500nm.

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Raman Spectroscopic Study of Rutile TiO_2 Irradiatied by Swift Heavy Ions

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Titanium dioxide has drawn much research attention for its various applications in photocatalysis, photovoltaics, photochromics,[1] etc. Many fabrication techniques aiming at material property modification have been proposed. Here we present a method by irradiating single crystal rutile TiO_2 with swift heavy ions. The irradiated rutile samples with (100) face orientation were tested by raman spectroscopy. Figure 1 shows spectrum peak broadening of the irradiated samples which indicates the rutile crystal lattice damage by ion irradiation. An other significant phenomenon is that the spectrum expands greatly at the site of anatase $E_{g(1)}$ mode which implies that the rutlie crystal transits to the anatase phase while irradiating.[2] The expansion grows bigger as the irradiating fluence becomes higher at the same irradiating ion energy. The samples with (001) and (110) face have also been tested and there appears the same tendency in the spectrum profile. Other testing method is now being taken to establish the conclusion and deeper insight into the material damage mechanism of irradiation needs to be analyzed.

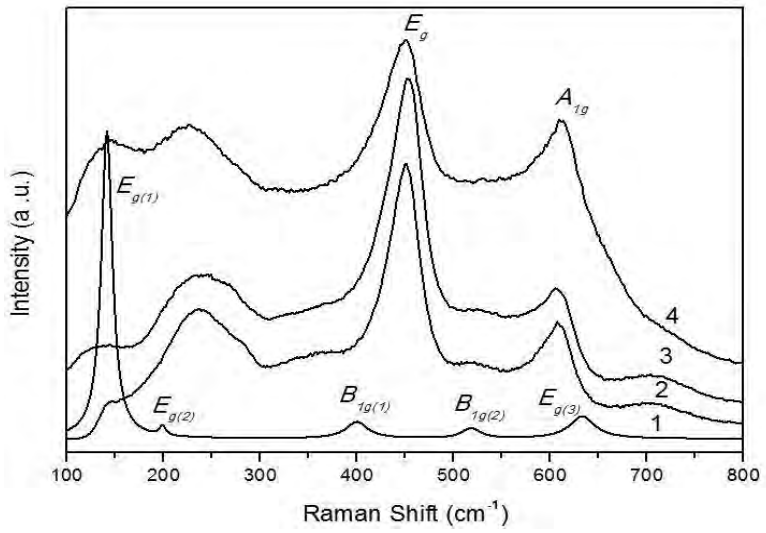

Figure 1. Raman spectrum of TiO_2 samples.1.anatase pristine 2.rutile pristine with (100) face orientation 3.rutile TiO_2 with (100) face irradiated by 370 MeV U ions at 5×10^{12} ions/cm^2 4. rutile TiO_2 with (100) face irradiated by 370 MeV U ions at 1×10^{12} ions/cm^2

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Low Energy Ar^{8+} Scattering on ZnO (0001) and (000$\bar{1}$) Surfaces

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Lattice-polarized compound-semiconductors with two atomic elements, for example GaN, ZnO, AlN, and so on, have been available recently. They are attractiing attention because of the wide band gap and some excellent optical properties. The two elements of the crystals align along with a specific axis of the surface. A lattice-polarized ZnO crystal has the (0001) and (000$\bar{1}$) surfaces which are at right angle to the *c*-axis. The former is terminated by heavier Zn atoms, and the latter is terminated by lighter O atoms [1]. It is natural to consider that the scattering mechanisms between multicharged ions and the two surfaces are different because the surface dipoles or the electron affinities are different. We carried out an ion scattering experiment of ZnO(0001) and (000$\bar{1}$) surfaces in order to study the influence of the first atomic layer on the collision processes [2]. The goal of this study is to develop a particle-beam-transportation technique by utilizing the surfaces of paired semiconducting plates [3].

The experiment was performed at an ion-beam line (BL3) of RIKEN. Ar^{8+} ($\leq$ 32keV) ion beam with a rectangular cross-sectional shape (0.16mm in horizontal width and 0.6mm in vertical height) entered onto the single crystalline ZnO(0001) and (000$\bar{1}$) surfaces. The number of scattered particles was measured with a channel electron multiplier. Figs. 1(a) and (b) show the numbers of detected particles as a function of the scattering angle in three different angles of incidence. The vertical axes of these figures were normalized by a constant dose of Ar^{8+} ions. The angle at the maximum intensity, which is very close to the specular reflection angle, increases with an increase of the angle of incidence for both surfaces. Every maximum intensity of the (000$\bar{1}$) surface is larger than that of the (0001) surface in the specific angle of incidence.

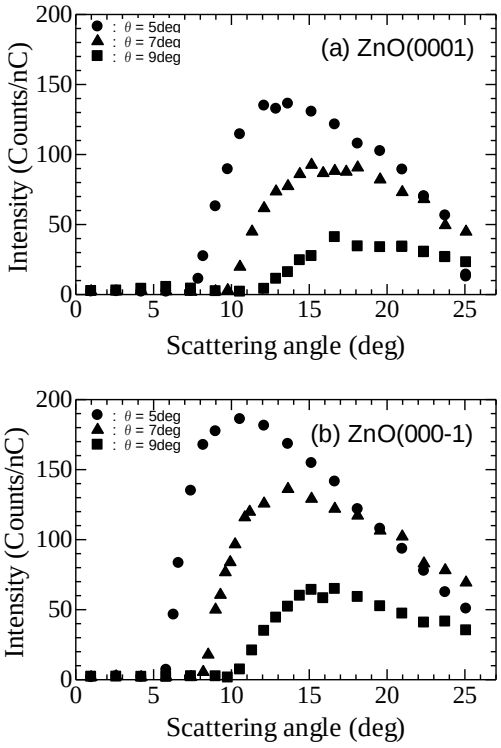

Fig. 1 Intensity of scattered particles in incidence of Ar^{8+} (32keV) on ZnO (0001) and (000$\bar{1}$) surfaces.

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Fragmentation of protein using collision with Xe^{q+} multicharged ions.

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Fragmentations of protein have been investigated using a new set-up developed to the KVI laboratory [1]. We have studied electron multicapture processes and dissociation of a trapped protonated Cythochrome C (Cyt-C) as induced by keV Xenon multicharged ions (q = 5 to12). Collisions between selected charge state of Cyt-C (from 15+ to 18+) and Xe^{q+} present a very simple fragmentation patterns. An example is shown on figure 1 for Xe^{12+} on Cyt-C^{18+}. As expected, Cyt-C^{19+} and Cyt-C^{20+} peaks are mainly attributed to the single and double capture processes, while the Cyt-C^{17+} is attributed tentatively to a large deprotonation of the highest charge states of Cyt-C produced in the collision. This new and no expected fragmentation channel has never been observed for the other smaller biological molecule. Higher mass resolution spectra will be necessary to confirm this mechanism.

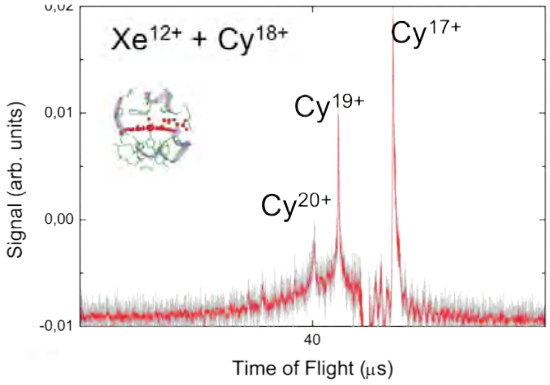

Figure 1. Fragmentation Spectrum of Xe^{12+}+Cyt-C^{18+}

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Theoretical Study for DNA Damage Due to Radiation: Are Plasmas Produced from Heavy Ion Irradiation useful for the Understanding of RBE ?

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Cancer therapy using carbon ions has a powerful therapeutic effect.. This is based on the fact that relative biological effectiveness (RBE) of carbon ions is higher than that of protons and X-rays. A hypothesis has been proposed that clustered DNA damage, which is refractory to repair, is highly relevant to RBE values. Although evidence on the biological significance of clustered DNA damage has been accumulated, it remains largely unknown how clustered DNA damage is generated after irradiation [1]. We proposed and quantified that the electric field traps the emitted electrons near a radiation track, which, in turn, may lead to a clustering of DNA leasions [2].

Our model on the production of clustered DNA damage due to the composite electric fields is as follows. (i) The mean path between ionization events becomes shorter as the cross sections increase. (ii) A shorter mean paths between ionization events form the stronger electric field. (iii) This electric field traps electrons near the track of the incident ion, which form plasma. According to our calculations based on this model in the case of the irradiations of a carbon ion with an energy of 3 MeV/u, plasma with the electronic temperature of about 10 eV and the density of $10^{21}/cm^3$ appears within the diameter of 2 nm from this track. The electrons in this plasma may more often interact with DNA which is located near the track and may produced the larger number of clustered DNA damages than the case where electric field is not considered and plasma is not formed [comparison of Fig.1(a) with Fig.1(b)].

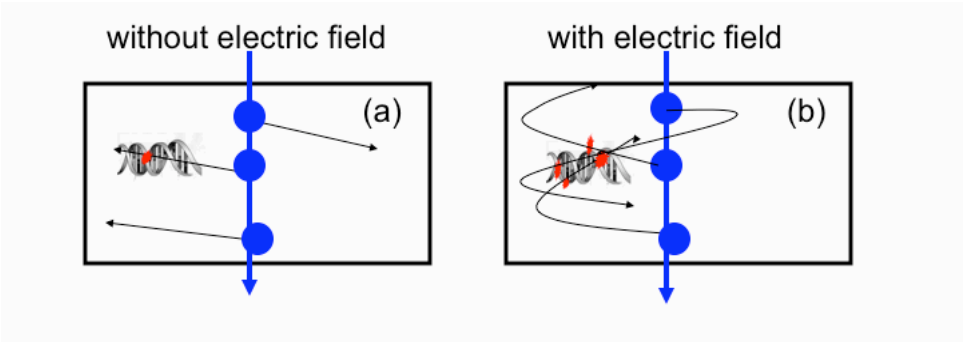

Figure 1. Images for the places of water molecule ions produced from the incident ion impact ionization, the tracks of electrons, and the DNA damage produced from the electron impact. The tracks of electrons are treated (a) without and (b) with the electric field. ➔: Track of an incident ion, →: track of an electron, ●: water molecular ions, ✸:DNA damage.

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Ion Beam Surface Nanostructuring of Ag–Au Bilayers Deposited on SiO_2 Glass

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Metallic nanoparticles either sustained on the surfaces or dispersed in dielectric matrices have been extensively studied because of their pronounced optical and electrical properties. Most of the studies have focused on surface plasmon excitation, which dominates the photoabsorbance spectra in the UV/visible range. In recent years, there are many interests in synthesizing silica glass based bimetallic–silica nanocomposites for their considerable applications in nano–optical devices [1]. However, from the viewpoint of practical applications, controlling in the size, shape, and volume fraction of the bimetallic nanoparticles embedded in the silica substrate still remains a challenge.

Recently, we successfully fabricated a layer of photosensitive Ag–Au compound nanoballs embedded in a SiO_2 glass substrate by 100 keV Ar ion irradiation and consequent annealing of Au film (20nm) and Ag (25nm) film consecutively thermal deposited on SiO_2 glass. Thermal annealing was carried out in high vacuum at 1073 K for one hour. The effects of the irradiation dose on the nanoballs formation was studied by increase the dose from $1.0 \times 10^{16}/cm^2$ to $10.0 \times 10^{16}/cm^2$. A scanning electron microscope (SEM) was used to study the ion–beam–induced surface nanostructuring. The microstructural evolution and the chemical concentration of Ag–Au nanoballs were investigated using a transmission electron microscope (TEM) equipped with an energy dispersive X–ray spectrum (EDS). With the increase of the irradiation dose, the dewetting of the Ag–Au films on the SiO_2 glass substrate was occurred and finally a layer of Ag–Au compound nanoballs with highly spherical shape embedded in the substrate was obtained. High resolution TEM (HRTEM) image of Ag–Au nanoballs before and after the thermal annealing were obtained, and the annealing effects was studied. Also, irradiation induced interface ion–mixing was observed, and a numerical estimation of the interface ion–mixing was carried out by the SRIM 2011 codes.

In addition, photo absorbance spectra were obtained to characterize the optical properties. Surface plasmon resonance (SPR) peaks were observed after the irradiation and the peaks became narrowing after the thermal annealing. In summary, ion irradiation has been considered as an effective approach in surface nanostructuring and also in fabrication of metal–silica nanocomposites, and the potential implications of these nanocomposites in optical device is expected.

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Interaction of Deuterium with Vacancies induced by Ion Irradiation in W

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Plasma-facing materials (PFMs) in a fusion reactor suffer two types of damage: displacement damage caused by high energy neutrons, and surface damage, such as erosion, sputtering and blistering, caused by hydrogen and helium from plasma. Important criteria for choosing PFMs are high melting point, high thermal conductivity and low sputtering erosion. Metallic materials, such as tungsten and molybdenum, are potential candidates for PFMs according to the results of recent studies. The damage induced by intense fluxes of energetic deuterium and tritium particles, as well as 14 MeV neutrons, will influence tritium retention in PFMs. In the present study, deuterium retention instead of tritium retention in ion-irradiated W was investigated.

The samples were prepared from polycrystalline W (99.95 wt.% purity) delivered by Allied Material Corporation. A 0.2 mm thick W plate was cut into 10 x 10 mm^2 size samples, and mechanically polished to mirror-like finish. The samples were then annealed at 1773 K for 1 h in vacuum with a background pressure of $1x10^{-4}$ Pa. After electropolishing in 4% NaOH water solution with 15 V, the samples were irradiated with 2.4 MeV Cu^{2+} ions using a Tandem type accelerator in Kyushu University. The damage induced by the ions in the matrix was not uniform, and the damage peak was about 400 nm from the irradiation surface. The damage rate was $2.5x10^{-4}$ dpa/s and the total damage was 0.3 dpa at the peak position. Deuterium implantation was subsequently carried out in samples using a mono-energetic D_2^+ ion beam at room temperature. To avoid displacement damage, implantation was performed at 1 keV. The nominal deuterium dose was $1x10^{21}$ D/m^2. In order to investigate the irradiation depth dependence of microstructural evolution, the Doppler broadening of annihilation radiation measurements were performed using a mono-energetic positron beam apparatus.

In the present study, we introduced a parameter, namely *S*, defined as the ratio of the low-momentum ($|P_L|<1.5x10^{-3}$ mc) region in the Doppler broadening spectrum to the total region, where m is the electron rest mass and c is the velocity of light. *S* represents the smaller Doppler shift resulting from the annihilation of valence electrons. The increase in *S* in the same materials compared with that in a well-annealed sample is due to the annihilation at vacancy-type defects. The *S* parameter increased in Cu ion irradiated W compared with well-annealed one. However, it decreased after deuterium implantation. The results indicated that deuterium implanted in W was trapped by vacancies induced by Cu ion irradiation. The stability of deuterium in vacancies was also investigated.

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In-Situ Analysis System to Detect Vacancy-Type Defects during Ion Beam Irradiation

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Defects induced by ion irradiation are initially formed as point defects (i.e., monovacancies and interstitial atoms). Concentrations and depth distributions of such point defects can be calculated by Monte-Carlo simulations. However, except for the low-temperature irradiations, point defects annihilate or grow to secondary defects through migration, recombination and clustering. It is difficult to experimentally characterize such defect behaviors during irradiation. To date, various in-situ analysis techniques, such as transmission electron microscopy combined with ion irradiation, have been developed. In this study, we employed a positron annihilation lifetime spectroscopy (PALS) as a probe of vacancy-type defects for in-situ analysis during ion beam irradiation.

An electron linear accelerator was used to generate a thermalized positron beam. Positrons were magnetically guided to a target chamber connected to an ion accelerator, followed by chopping and bunching to obtain pulsed positrons necessary for PALS measurements. Positrons can be accelerated up to 30 keV after the pulsing electrodes. Ar ions at energies up to 150 keV were used to introduce defects near the surface of samples. The ion beam is pulsed by chopper electrodes and its irradiation can be synchronized with positron irradiation. The incident directions of positron and ion beams were 0 and 45^{o} to the surface normal, respectively [1].

As a preliminary experiment, PALS spectra of a thermal oxide layer on Si (SiO_2) were collected during 150 keV Ar^+ irradiation. The irradiation-induced change of PALS spectra was observed with increasing ion fluence, indicating that the in-situ measurement during ion irradiation was successfully achieved. Similar experiments were also performed for metal samples. The spectrum change associated with positron diffusion length was observed in this case.

Acknowledgement: This work was supported by a Grand-in-Aid for Scientific Research (24310080) from Japan Society for the Promotion of Science.

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Measurement of electronic sputtering yield of amorphous ^{13}C thin film

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Electronic sputtering yield measurements of carbon films are uncertain because of various factors which makes it challenging. The problem which affects the yield is the presence of hydrocarbon contamination on the surface of the materials either on the irradiated material or on the catcher on which the sputtered atoms are collected. In order to avoid this complication, the carbon sputtering yield was quantified by measuring the thickness decrease of a 80 nm ^{13}C thin film (with 16% ^{12}C content) using high resolution online ERDA. The measurements showed that 194 MeV Au ions produce a sputtering yield of 33±8 of ^{13}C/ion along with a deposition rate of 5±2 ^{12}C/ion, which is caused by beam induced beak-up of hydrocarbons. Moreover, inelastic thermal spike simulations fit to the sputtering yield from the present measurement and other published measurements [1], by using a sublimation energy of ^{13}C film of 2.5±0.5 eV/at. Extrapolation of the inelastic thermal spike model will be done for several values of electronic energy losses with different beam energies.

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Advanced SiC fiber strain behaviour during ion beam irradiation in the electronic slowing down regime

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Abstract

Third generation SiC fibers have significantly improved the thermo-mechanical properties of SiC_f/SiC_m ceramic matrix composite which are considered as advanced materials for fission reactor applications. These materials exhibit interesting features such as a low activation level and a higher operating temperature in comparison to ferritic steels and V alloys. However, their thermo-mechanical performances strongly depend on their complex microstructure which undergoes significant changes when they are irradiated. Thus, the possible use of SiC_f/SiC_m composites points out the need to carefully study their properties to determine if they can fully comply with the aimed application requirements. Consequently, a multi-scale approach is currently ongoing and aims to provide a satisfying predictive modeling of the SiC_f/SiC_m composite behaviour in a reactor. The different components of the composite, i.e. the fibers, the matrix and the interphase, are then characterized separately.

As a first step, the *in-situ* strain behaviour under irradiation in the electronic slowing down regime of a Tyranno SA3 SiC fiber (UBE Industries Ltd Japan) was investigated in real time. For this purpose, a tensile test device suitable for micrometrical samples was developed with the JANNUS Saclay irradiation platform where the first *in-situ* test was successfully performed. The second experiment, which is the subject of this work, was achieved at the GANIL facility in Caen. A 7.44µm diameter SiC fiber was submitted to both low mechanical loading level at 300MPa and 92MeV Xe^{23+} ion beam irradiation at room temperature. The fiber has exhibited a gradual increase of its longitudinal strain reaching a maximum value of 0.50% for an average damage level of 0.1dpa. Raman spectroscopy analyses performed on fibers submitted to the same irradiation conditions have shown significant local structure modification but no total amorphisation could be evidenced. The irradiated fiber was then submitted to cyclic isochronal annealing treatments up to 1800℃ leading to a partial strain recovery of 0.45%.

This work will be taking further using complementary range of ions and energies in order to study various material damaging processes and their impact on the fiber properties. The next step will consist in coupling fiber heating and ion irradiation since creep tests can be performed with the above mentioned equipment. Consequently, these conditions will be as close as possible to the extreme conditions which could be found in nuclear reactor core. They will provide the opportunity to determine damage mechanisms involved in this material during an irradiation at high temperature.

Compositional Effects on Track Formation in A_2TiO_5 (A = La, Nd, Sm, Gd) Irradiated With Swift Heavy Ions

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Different compositions of orthorhombic A_2TiO_5 (A = La, Nd, Sm, Gd) were irradiated with swift Xe ions (1.47 GeV) to fluences from 5×10^{10} to 1×10^{13} ions/cm^2. Cylindrical tracks consisting in part of an amorphous phase were formed in all compositions. Systematic analysis of the structural modifications induced by ion track formation was completed using transmission electron microscopy, synchrotron x-ray diffraction, and Raman spectroscopy. Significant radiation-induced amorphization occurred for all compounds, but the size of the amorphous regions within the tracks, along with the degree of amorphization achieved in the bulk material for a given ion fluence, decreased as smaller cations (higher Z) occupied the A-site. This decrease in the amorphous domain size is attributed primarily to epitaxial recrystallization of a disordered defect fluorite phase at the outer edge of the initially liquid-like tracks, the stability of which is related to the ratio of the ionic radii of the A- and B-site (B = Ti) cations. While similar ion track recrystallization phenomena have been observed in pyrochlores ($A_2B_2O_7$) of varying composition [1], A_2TiO_5 is unique in that the disordered phase is not a high-temperature polymorph, suggesting kinetic control of the radiation-induced transformation.

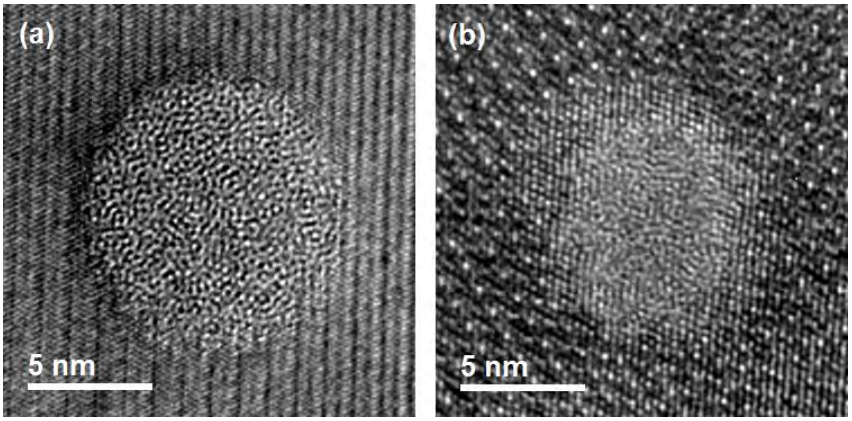

Figure 1. HRTEM images of ion track cross sections in (a) La_2TiO_5 and (b) Sm_2TiO_5 irradiated with 1.47 GeV Xe. The former shows only amorphous material within the track, while the latter features a defect fluorite track shell.

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Latent ion tracks in amorphous Ge

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We identify and characterise latent ion tracks formed in Ge by swift heavy-ion irradiation with 185 MeV Au^{+13} ions, correlating experimental results with first-principle calculations and Molecular Dynamics simulations. For our irradiation conditions, tracks were formed only in amorphous material, as attributed to much weaker electron-phonon coupling in crystalline material. Simulations indicate rapid heating following deposition of the ion energy yields a solid-to-liquid transformation within the track. The ensuing volume contraction necessary to accommodate the high-density liquid produces open volume in the form of voids interspersed along the ion path. Indeed, voids of bow-tie-like shape aligned with the incident ion direction are apparent with transmission electron microscopy and we suggest these voids are the precursor to the widely-reported swift heavy-ion irradiation-induced porosity in amorphous Ge. Experiment and simulation both indicate the latent ion track does not recrystallise but remains amorphous upon solidification. Using small-angle x-ray scattering, we show the ion track is of radius ~11 nm and comprised of an under-dense core and over-dense shell relative to unirradiated amorphous material, as consistent with a frozen-in pressure wave. Similarly, experiment and simulation can accurately fit and predict, respectively, the intriguing shape of the voids.

Thresholds of Etchable Track Formation and Chemical Damage Parameters in PI, PET, PC, and PADC Films at the Stopping Powers Ranging from 10 to 12,000 keV/μm

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The damage structure of latent tracks in Polyimide (PI) films, KAPTON and UPILEX, has been examined by Fourier transform infrared (FT-IR) measurements. Results are compared with those from previous studies on poly(ethylene terephthalate) (PET), bisphenol A polycarbonate (PC), and poly(allyl diglycol carbonate) (PADC). These polymers are exposed to protons and heavy ions (He, C, Ne, Si, Ar, Fe, Kr, and Xe) in air with energies less than 6 MeV/n, as well as gamma rays from an intense Co-60 source [1-5]. Chemical damage parameters, namely, damage density, which is the number of losses of considered functional groups per unit length of tracks, radial size of the track core, in which the considered chemical groups are lost, and radiation chemical yields (G values) for each group are evaluated as a function of the stopping power. It has been confirmed that latent tracks will be etchable when the radial track core size is larger than the distance between two adjacent breaking points of polymer chains. The predominant breaking points are the C-O bonds in diphenyl ether, ester, carbonate ester, and ether bonds.

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Optical properties in the wavelength of visible and near-infrared for chalcogenide glass waveguides formed by swift Kr ion irradiation

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Planar waveguide structures in chalcogenide glass were fabricated by 17MeV or 150MeV swift Kr ion irradiation. Photograph of the polished end facet of the Kr-irradiated chalcogenide glass was measured by metallographic microscope using reflected polarized light. SRIM 2006 was used to simulate the electronic and nuclear stopping powers for swift Kr ion irradiation, which were in agreement with the measured results. The micro-Raman spectrum were measured at atmosphere. The near-filed intensity distributions were investigated at the wavelength of visible (633nm) and near-infrared (1300nm, 1500nm, 1539nm and 1620nm) band, which makes them candidates for infrared laser devices.

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Thickness Dependence of Secondary-electron Yield from Carbon Foils Bombarded with 62.5-300-keV/u H_2^+ and C_2^+ Ions

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Secondary-electron (SE) emission from a solid surface bombarded with fast charged particles has been studied extensively for a long time and extended to various kinds of applications. Although it is a very fundamental phenomenon, it is not still understood completely. Vicinage effect on the SE emission induced by swift molecular/cluster ions is one of the unresolved problems [1, 2]. We have investigated the vicinage effect on the SE emission by measuring the SE yield emitted from an amorphous carbon foil bombarded with swift C_2^+ ions. It has been observed for the first time that the vicinage effect on the SE yield in the forward direction induced by 62.5-keV/u C_2^+ ions disappears for thicker foils than 60 μg/cm^2 [3]. This result means that a *transport* or *transmission* process of scattered electrons is very important for the appearance of the vicinage effect. In order to study the previous result further, we have investigated the vicinage effect on the SE emission induced by bombardment with H_2^+ and C_2^+ ions in the same velocity region.

62.5-300-keV/u H_2^+ and C_2^+ ions were incident on self-supporting amorphous carbon foils of 2-100 μg/cm^2 thickness, which was tilted by 45° to the beam axis. SE's emitted in the forward and backward directions from a carbon foil were detected with two microchannel-plate (MCP) detectors placed at the both sides of the target holder in parallel with the target. Particles transmitted through the foil were detected with a solid-state detector (SSD) placed at the backside of the target on the beam axis, which made it possible to measure the energy and the number of the transmitted particles. The forward and backward SE yields per incident projectile $\gamma_{F,B}$ were determined from the pulse-height distributions of the forward and backward MCP signals, respectively, which were proportional to the number of detected SE's. The vicinage effect was evaluated with the ratios of the forward and backward SE yields $R_{F,B} = \gamma_{F,B}(2)/2\gamma_{F,B}(1)$, where $\gamma_{F,B}(2)$ and $\gamma_{F,B}(1)$ are SE yields induced by bombardment with diatomic and monatomic ions with the same velocity, respectively. The origin of the vicinage effect on the SE yield will be discussed based on the observed foil-thickness and velocity dependence of the vicinage effect.

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Morphological Modification of Teflon Surface by Proton Microbeam and Nitrogen Ion Beam

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Polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP) are well known as Teflon®. They have many unique properties, which make it valuable in micro electro mechanical system (MEMS), bio-chemical and medical tools. In fabricating microstructures on their surfaces, synchrotron radiation (SR) and focused ion beam (FIB) are effective [1]. Their irradiated surfaces are generally flat, but using keV order ion beam irradiation, needle-like protrusions can be created at high density [2]. This spiky surface can be fabricated only with this technique. Recently, we could uplift the PTFE surface locally by proton microbeam irradiation [3]. The morphological change occurred only at the irradiated area, and it was quite opposite to the case of using the former processes. In this study, we fabricated microstructures on Teflon surface using proton microbeam and nitrogen ion beam irradiation.

PTFE and FEP sheets (100 μm, 250 μm and 500 μm in thickness) were used. A 3 MeV proton beam 1 μm in diameter was scanned along the square pattern, 50 μm on a side, at various rates. Subsequently, these surfaces were evenly irradiated with 250 keV N_2^+ ion beam at the fluence from 1×10^{15} ions/cm^2 to 1×10^{17} ions/cm^2. Both the irradiations were performed at TIARA (JAEA). The surface morphology of the samples was observed with scanning electron microscopy (SEM) and optical microscope.

When the proton microbeam scan rate was 500 μm/s, the morphological change of FEP surface was not ovserved by SEM. After the surface irradiated by N_2^+ ion beam at 2.5×10^{15} ions/cm^2, the surface changed as shown in Fig. 1. The protorusions were not formed at the square areas irradiated by proton beam (Fig. 1(b)). These areas were quite flat because they were selectively melted by the temperature elevation due to N_2^+ ion beam irradiation after the pattern irradiation of the proton microbeam. The result indicated the surface morphology could control using MeV proton microbeam and keV N_2^+ ion beam,. The details of the mechanism will be discussed.

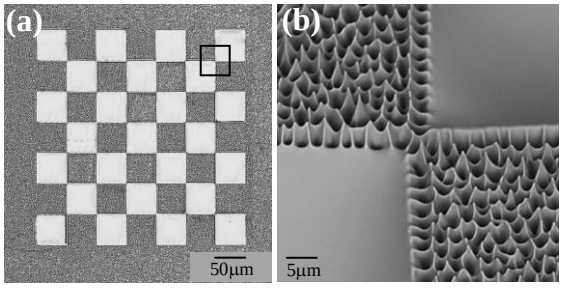

Fig. 1 SEM images of FEP surface scanned with proton microbeam followed by N_2^+ ion beam irradiation. (b) SEM image of the enlargement of the square shown in Fig. 1(a). The FEP thickness was 100 μm.

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Structural Modification of ZnO Materials induced by Xe-ion Bombardments

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Zinc oxide (ZnO) is a typical generation III semiconductor material with attractive potential applications in the fields of optical devices (LED, solar cells), piezoelectric & surface acoustic wave devices, chemical sensors and so on. It is also suggested that ZnO should be an excellent detector used in intense radiation environment. However, a series of questions such as the formation and evolution of radiation damage, the chemical effects of incident ion species, the effect of crystal structures are still open in ZnO for answer. In the present work, we pay more attention on the experimental study of the structural modification of ZnO materials induced energetic ion bombardment.

In the experiments, ZnO films and single crystal samples were bombarded at room temperature (RT) with 400keV, 3.0, 3.64 or 308 MeV Xe-ions, respectively. The Xe-ion fluences are in the range from 1.0×10^{12} to 2.0×10^{16} Xe-ions/cm^2. After Xe-ions bombardments, the ZnO samples were investigated using X-Ray diffraction (XRD), Raman spectroscopy, atomic force microscope (AFM), transmission electron microscope (TEM). From the analyses of the obtained results we found that (1) ZnO thin film is of high resistance to Xe-ion implantation/ irradiation (stable bulk structure), but its c-axis lattice constant changes depending on implantation (swelling)/irradiation (compress); (2) Intense electronic excitations could induce significant surface modification of ZnO (thin film — amorphisation; single crystal — surface swelling); (3) ΦSe plays a dominant role in bulk damage process of ZnO films under Xe-ion irradiation.

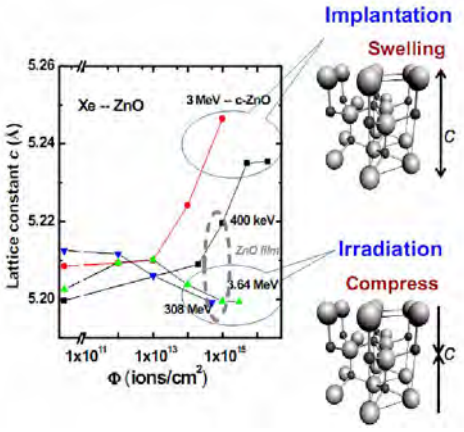

Fig.1 The *c*-axis lattice constant of ZnO materials varying with Xe-ion fluence.

Keywords: ZnO, Xe-ion bombardment, Structural modification

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Deuterium Diffusion in Zr Oxide Irradiated with Zr Ions

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Hydrogen diffusion in metals is generally affected by irradiation of energetic particles such as ions and neutrons. Meanwhile, irradiation effects on hydrogen diffusion in ceramics are not exactly known due to some difficulties in measuring low diffusion coefficients, typically 10^{-17} m^2s^{-1} or less. In the present work, deuterium diffusion in oxide layers of zirconium alloy irradiated with a self ion of Zr has been examined by using a nuclear reaction analysis (NRA) of the D(^{3}He, p)^{4}He reaction. Sample materials were Zr-based alloys of Zircaloy-2 and GNF-Ziron.

Two types of experiment were conducted. One was that a sample was corroded with steam at 673 K to be covered with a 1.7-μm thick oxide layer and subsequently irradiated with 8.3-MeV Zr ions at room temperature. An average damage in the oxide was 1.3 dpa. After that the sample was continuously exposed to deuterium RF plasma at 573 K and evolution in a deuterium depth profile was in-situ observed by the NRA. In the other experiment, oxidation and irradiation of a sample were similar to the first one but the sample was charged with deuterium from deuterium water steam. While keeping the sample temperature 623 K, decrease in the deuterium concentration was observed.

The results of the two experiments showed that the ion irradiation significantly affected deuterium diffusion, that is, deuterium migration into the oxide layer was restricted in the first experiment and deuterium desorption from the oxide layer became much lowered in the second experiment. In metals, ion irradiation newly produces deep potential sites which trap hydrogen atoms to retard hydrogen migration. Trapping was, however, not significant in the present work because the deuterium concentration was not increased by the irradiation. A plausible reason for decrease in the diffusion coefficient is compressive stress [1] introduced by the irradiation

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WITHDRAWN

Damage Cross Section Measurements on Irradiated Polyethylene with Swift Heavy Ion Beams

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When ions sudden pass through a polymeric material, they induce a very complex path of excited and ionized molecules. The large amount of deposited energy near their trajectory creates a very inhomogeneous distribution of physico-chemical effects and damage. It can lead to polymer bond breaking, free radicals, excited species and secondary chemical processes that modified the polymer structure. These effects will depend on ion parameters such as ion mass, energy, stopping power and fluence as well as polymer structure. Most of the existing works observed qualitative effects induce by the ion irradiation of polymers, only a few analyzed the chemical damage and its correlation with the energy transfer process. The works of Papaléo et al. [1] measured the damage cross section in poly(phenylene sulphide) as a function of stopping power (dE/dx). They keep the fast ions velocities constant, so the track dimensions are fixed. Following this idea we extended the study to other polymer and ion velocities. For this purpose we irradiated High Density Polyethylene (HDPE) films with swift heavy ions provided by the Tandar accelerator (Buenos Aires, Argentina): ^{7}Li, ^{12}C, ^{16}O, ^{32}S at a selected velocity of 1 and 2 MeV/amu. The analysis of the structural change produce by the irradiation was measured by mean of infrared spectroscopy in the transmission and reflectance mode. Finally we will discuss the damage cross section measurements at this new range of ion velocities.

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Computer Simulation of High-Energy-Beam Irradiation of Uranium Dioxide

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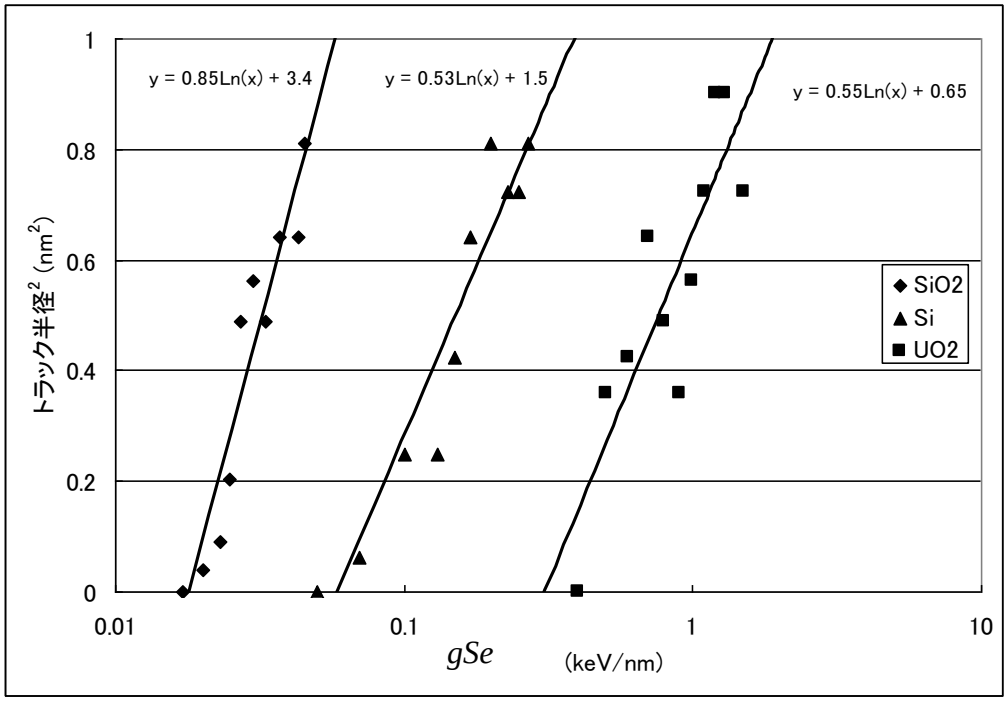
The structural relaxation caused by the high-energy-beam irradiation of single-crystalline uranium dioxide was simulated by the molecular dynamics method. As the initial condition, high thermal energy was supplied to the individual atoms within a cylindrical region of nanometer-order radius located in the center of the specimen. The potential proposed by Basak[1] was utilized to calculate interaction between atoms. The supplied thermal energy was first spent to change the crystal structure into an amorphous one within a short period of about 0.3ps, then it dissipated in the specimen. The amorphous track radius R_a was determined as a function of the energy density of the thermalized region. As shown in Fig.1, it was found that the relationship between R_a and the effective stopping power gS_e follows the relation $R_a^2 = a\log(gS_e) + b$. Compared to the case of Si and SiO_2 (β-cristobalite) single crystals, it was harder to produce amorphous track because of the long range interaction between U atoms.



R_a

Figure 1. Relationship between square of track radius R_a and effective stopping power *gSe*.

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Strain buildup and saturation in GaAs due to 100 MeV Ag Irradiation

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Structural evolution in high energy (100 MeV) silver ion irradiated undoped semi-insulating GaAs has been investigated by Raman spectroscopy, high resolution x-ray diffraction (HRXRD) and Rutherford back-scattering ion channeling (RBS) measurements. HRXRD measurements reveal the formation of compressively strained layer at the low fluence of irradiation. With further increase in fluence, both compressive and tensile strain appears in GaAs. Similar modulation of strain in the system with increase in ion fluence is observed from Raman measurements. The evolution of compressive strain in GaAs with increase in Ag ion fluence, as obtained from Raman and HRXRD measurements shows that the compressive strain in the material increases non-monotonously with fluence. The rate of evolution of the strain with increase in ion fluence reduces by an order of magnitude beyond a certain fluence of irradiation (1×10^{13} ions/cm^2). We define this as the critical fluence. Due to the increase in defect concentration, ion-irradiation induces a positive perpendicular lattice strain with an increase in ion-fluence. However, beyond the critical fluence of irradiation the rate of increase in strain with ion fluence decreases followed by an onset of a near dynamical equilibrium (NDE) between generation and annihilation of defect states in the system. At this point, some of the new vacancy type defects, generated by irradiated ions, are annihilated by the process of recombination. In the case of MeV ion irradiated GaAs, from the model of single ion-lattice collisions, it has been concluded that a combination of collision damage and electronic ionization can set in an equilibrium of defect population in the system; hence, a saturation of the surface lattice strain at a certain fluence of irradiation. Damage fraction in the crystal due to ion irradiation was estimated from Raman line-shape analysis and has been correlated with the same observed from RBS for higher fluences.

Cratering on ultra-thin polymer films: Ion tracks under confinement

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Individual fast heavy ions impacting polymer surfaces, produce nanometer-size craters and raised regions due to massive particle ejection and transport from the impact site. In this contribution, we present results on cratering produced by individual MeV heavy ions on thin (30-100 nm) and ultra-thin (2-30 nm) polymer films. We have focused on the effect of the layer thickness t, on the size and shape of the impact features produced by 0.1 MeV/u Au ions (Tandetron accelerator, Porto Alegre, Brazil) and 4.8 MeV/u Pb ions (GSI, Darmstadt, Germany). The samples were irradiated both at normal (0°) and grazing (79°) incidence and analyzed by scanning force microscopy. We have found that the size of the impact features remain basically unchanged until a thickness $t\sim$ 40 nm is reached. Below this thickness, holes start to become slightly smaller and rims quickly diminish in size. For $t<$10 nm holes are still observed but rims and tails are suppressed. Our data clearly show that excited layers as deep as ~30-40 nm below the surface contribute to the formation of the hillocks, but material excitation leading to the crater is much more restricted to the near surface. We show that the effects produced by swift heavy ions on a polymer film are *weakened* when the length of the ion track is confined to layers of few nanometers, because cooperative effects, that are of importance for mass transport induced by the swift heavy ions, are severely reduced. This behaviour is confirmed by calculations of the total outward impulse produced at the surface as a function of the layer thickness, obtained using the pressure pulse analytic model. We also compare our experimental findings to simple molecular dynamic simulations applied to a polymer-like Lennard-Jones solid.

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Study of the Single Ion Track Form by Microprobe Loss Energy Spectroscopy

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Ion energy loss spectroscopy is suggested to determine the shape of the (latent, etched and filled) ion tracks in polymers using ion probes of a various beam size. For a milli -probe, it can be considered as a one-dimensional tomography of many identical (rotationally symmetric) objects. For a micro-probe, the technique can be understood as a micro-tomography of the single ion track. In both cases, the ion energy loss spectrometry requires mono-energetic ions with a relatively low intensity (with a counting rate $<10^4$ s^{-1}) and a well defined angular beam (parallel or divergent) set-up. Here, a possible use of the ion milli- and micro-probes in a tomographic study of the ion track 3D geometry is presented and discussed.

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Structural and Optical properties of Porous Silicon prepared by anodic etching of Swift Heavy Ions Irradiated Silicon

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Porous silicon is considered to be a potential material in the field of electronics and optoelectronics because of its strong luminescence in visible region. Ion beam irradiation shows versatile effects on physical and optical properties of porous silicon. However there are only few reports on the structural and optical properties of porous silicon prepared from irradiated silicon. Here we present a study on the influence of swift heavy ion irradiation on the surface roughness of silicon and consequent effects on the formation of porous silicon. The p-type (100) Si was irradiated with 80 MeV Ni ions at various fluences ranging from $1x10^{11}$ to $5x10^{13}$ ions/cm^2. The irradiated samples were anodically etched to get porous Si. These ion induced effects are being investigated by Photoluminescence (PL), Raman Spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), AFM and FESEM and will be discussed in detail during the conference.

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FRIDAY POSTER PRESENTATIONS

SHIM2012

Set-up for time-resolved photon spectroscopy after impact of swift heavy ions

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The so-called SPORT set-up (time-resolved optical spectrometer, SPectroscopie Optique Résolue en Temps) will be presented. It is installed at the IRRSUD beamline of GANIL, Caen, France, studying the photon emission due to the impact of swift heavy ions at the equilibrium charge state and energies of about 100 MeV on a target. An ion detector located in the beam line delivers the start pulse for the delay time measurements of the photon emission, in a typical "time-of-flight" electronics. The target is located in an UHV chamber on a cryo-head, temperatures as low as 7.5 K has been achieved. This allows avoiding emission due to excited target states as well as target heating due to the primary beam. Ions hitting the cooled-down target induce photon emission; these photons are then detected. The detection consists of two optical branches, each with mirrors focusing onto spectrographs with ACH grating and 16-channel photomultipliers. Spectrographs and photomultipliers on each branch are optimized to different wavelengths; together they cover the UV-visible spectrum. Two different TDCs are used, in order to cover emission delays from several ns to several ms. First targets to be used are KBr, CsI, KI, $SrTiO_3$ and MgO. Our goal is to detect the ultrafast luminescence after swift heavy ion – surface collisions [1].

This experiment has been supported by the European Community as a Joint Research Activity within the Integrating Activity "Support of Public and Industrial Research Using Ion Beam Technology (SPIRIT)" under EC contract no. 227012; additional support was granted by the French network dedicated to Material Irradiation (EMIR).

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Surface track creation on SiC by swift heavy ion irradiation

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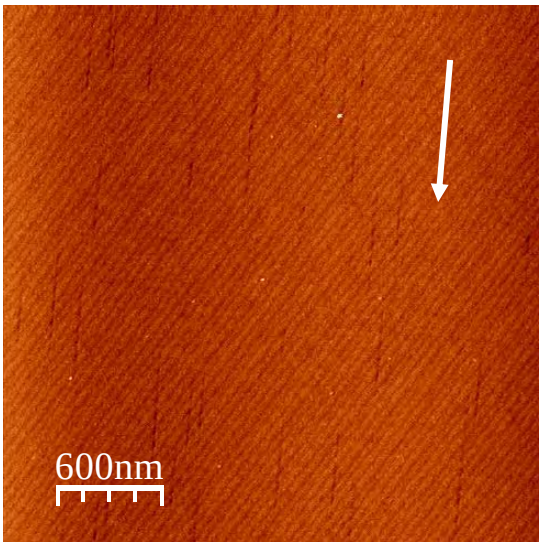
Swift heavy ions are known to induce structural modifications in many insulating materials [1]. However, some materials as e.g. SiC are rather irradiation resistant and show extended structural changes only in the high fluence regime [2,3]. On the other hand, it has recently been demonstrated, that the sensitivity to irradiation damage can be significantly enhanced if glancing angle irradiations are performed [4]. The resulting irradiation damage has been termed a "surface track". These tracks are due to individual ion impacts and offer the possibility to study track creation mechanisms from a new point of view.

Here, we have investigated the effect of individual swift heavy ions on 6H-SiC surfaces. The samples were irradiated at the IRRSUD beamline of the GANIL with 90 MeV Ta and 117 MeV Pb ions at glancing angles of incidence of 0.5° to 4.2°. The stopping powers are 17 keV/nm and 20 keV/nm [5], respectively, and are thus much lower than the reported threshold of 34 keV/nm [6]. After irradiation, the samples were investigated by atomic force microscopy (AFM) under ambient conditions.



From the AFM images it can be seen that surface tracks are indeed created under these conditions (see Fig.1).

In contrast to the materials investigated so far, the tracks do not consist of a chain of protrusions, but rather of missing material. We propose that this new type of surface track is related to the sublimation of Si similar to the process nowadays used for the production of epitaxial graphene on SiC.

Fig. 1: AFM image (tapping mode) of SiC irradiated under a glancing angle of 1.4° with 117 MeV Pb ions. The white arrow indicates the direction of the incoming ion beam. Diagonal stripes are SiC step edges, black lines are ion induced depressions (surface tracks); *z*-scale: 0 – 3.5 nm.

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Swift Heavy Ion Irradiated Nd:YAG Optical Waveguides as Integrated Laser Sources

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Irradiation of swift heavy ions has recently emerged to be a promising technique to modify the refractive index of optical materials. Optical waveguides could be therefore constructed by this method in a number of substrates. As the basic components of integrated photonics, optical waveguides can confine the light propagation in small volumes, in where high optical intensities are achieved. As a result, some performance related to the bulk materials may be considerably improved in the waveguiding structures. In addition, owing to the compact dimension of the waveguides, it is possible to integrate a few guiding components in a single chip, realizing multifunctional photonic applications. Particularly, waveguide lasers possess reduced lasing threshold and comparable efficiencies with those from the bulk laser systems.

In this work, we report on the fabrication of optical waveguides in Nd:YAG laser crystals by using swift Kr ions. The irradiation of Kr^{34+} ions at energy of 670 MeV and fluence of 5×10^{11} ions/cm^2 was performed by using the HIRFL at Lanzhou Institute of Modern Physics, Chinese Academy of Science, China. The electronic stopping power (S_e) of the Kr ions in Nd:YAG is maximally ~16 keV/nm, which is at least one order higher than those of normal ion implanted Nd:YAG. The room-temperature continuous wave waveguide laser at 1.06 μm was realized under optical pump of 808 nm light. The lasing threshold was 36 mW and the slope efficiency was 32%.

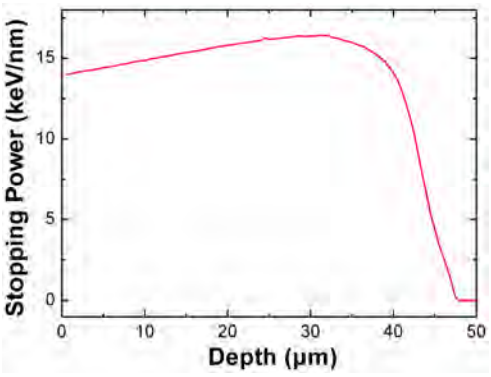

Figure 1. The S_e profile of 670 MeV Kr ions incident into Nd:YAG laser crystal.

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Ice compaction induced by heavy ions beams analyzed by IR water dangling bonds

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Compaction results of water amorphous ice during energetic ion irradiation are revisited. It is discussed the correlation between infrared absorption by dangling bonds. Three articles on this matter were reviewed: i) porosity decrease by projectiles at hundreds keV, by Raut et al. [1]; ii) OH-db disappearance in ices bombarded by 100 keV H^+ ions, by Palumbo et al. [2], and iii) comparing porosity and OH-db results for 200 keV Ar+ ions, by Baragiola et al. [3].
The decrease of the OH dangling bond feature column density is fitted by the sum of two decreasing exponentials, suggesting the occurrence of two modes of destruction mechanisms with distinct destruction cross sections, σ^{db} (Fig.1). Ice compaction data were re-analyzed successfully by using also the sum of two decreasing exponentials, reinforcing the hypothesis that porosity should be closely related with the OH-db disappearing. A statistical geometrical-type model is proposed for describing the exponential behavior.

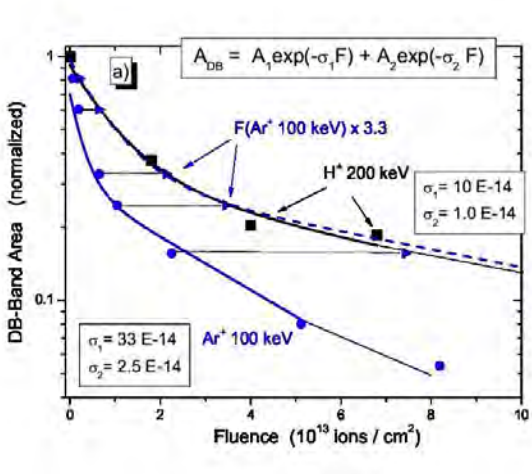

Fig. 1. (a) OH-db band area dependence on beam fluence for 200 keV H^+ and for 100 kev Ar^+ ions. Data are fitted by the sum of two exponentials. The dot line is the fitting using one exponential added to a constant.

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ION-INDUCED CHANGES IN SEMICONDUCTOR PROPERTIES OF HYDROGENATED AMORPHOUS SILICON

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Progress in high energy physics and space technologies requires the development of semiconductor devices with high resistance to radiation and extreme conditions. Hydrogenated amorphous silicon (a-Si:H) semiconductors are expected to be utilized in a material for radiation-hardened devices such as space solar cells, particle detectors, and photo sensors [1], and we have investigated radiation effects on a-Si:H thin films and devices [2, 3]. In this paper, we report variations of semiconductor properties of undoped, phosphorous doped, and boron doped a-Si:H thin films due to proton and Si ion irradiation. Electric conductivity, photoconductivity (increase in conductivity due to light illumination), and Seebeck coefficient of ion-irradiated a-Si:H are investigated in detail and their mechanisms are discussed. For example, electric conductivity and Seebeck coefficient variations of undoped a-Si:H due to 100 keV proton irradiation are shown in Figure 1. The electric conductivity has a peak at the fluence of 5.0×10^{11} cm^{-2} and the Seebeck effect is observed only in the fluence regime around the peak. This indicates that donor-centers are generated in this fluence regime by 100 keV proton irradiation.

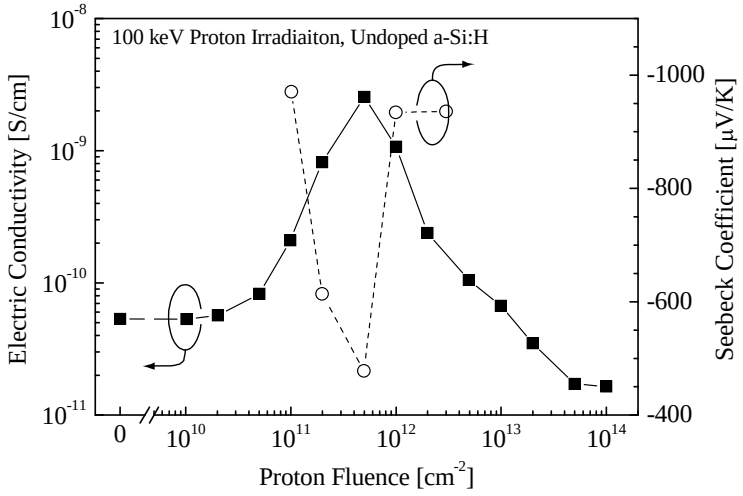

Figure 1. Electric conductivity and Seebeck coefficient variations of undoped a-Si:H as a function of 100 keV proton fluence.

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The spherical to rod-like shape transformation of metal nanoparticles induced by ion irradiation

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Swift heavy ion irradiation of silica can produce nm-wide molten ion tracks and transform embedded metal nanoparticles from a spherical to rod-like shape with aspect ratios for the latter approaching 10. For this report, we combine experiment, calculation and simulation to demonstrate the thermodynamics of both the matrix and metal have roles in this shape transformation. We show molten ion track formation in the matrix is intrinsic to the elongation process and identify metal nanoparticle melt-and-flow within the molten ion track as the operative mechanism. The elongation process is characterised for mono-elemental nanoparticles formed from ten different metals and while all metals transform, the final nano-rod dimensions are governed by the magnitude of the deposited energy density relative to that required to vapourise the elemental metal.

We also show that the shape transformation is operative not only in silica but in alternative matrices and molten ion track formation remains a prerequisite for nanoparticle elongation. While the latter is well established in silica (as above), we now probe molten ion track formation in other insulators and semiconductors. Thereafter, swift heavy ion irradiation of chemically-formed, spherical Au nanoparticles deposited at a silica/alternative-matrix interface yields a direct comparison of the matrix-dependent rate of nanoparticle elongation. Again, calculation and molecular dynamics simulations complement the experimental results.

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Effects of Ion-Track Formation and Its Overlapping in Uranium Dioxide Ceramics Irradiated with Swift Heavy Ions

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Not only neutrons but also high-energy fission fragments play an important role in radiation damages in UO_2 fuels in light water reactors. Since fission fragments have high kinetic energy of nearly 70~100-MeV, such high-energy heavy particles can cause radiation damage via high-density electronic energy deposition. Therefore, in the present study, the damage due to fission fragments is simulated by high-energy ion-accelerator experiment and the damage evolution is analyzed in terms of the electronic energy deposition.

It is already found by ion-accelerator experiments that columnar ion-tracks are formed along the ion-paths in UO_2, if the energy of heavy ions exceeds a certain threshold [1,2]. However, it is not clearly known how the ion-tack size behaves as a function of the electronic stopping power, S_e, especially in the low velocity regime of about 1 MeV/u. In such low velocity regime, it has been pointed out that the previously reported experimental data [1] does not agree with the theoretical prediction [3]. Therefore, the present experiment focuses on the low velocity region, and size of the ion-tracks was estimated by transmission electron microscope (TEM) for UO_2 irradiated with low velocity ions, such as 310-MeV Au, 210-MeV Xe, 100MeV Xe, and so on, at room temperature. It is found that the ion-track size exhibits a monotonic increase as a function of S_e. The ion-track size data obtained for low velocity regime are consistent with previously reported experimental data [1], which turns out to be reliable. The present result indicates that although the velocity effect has been previously reported in many amorphizible materials such as in $Y_3Fe_5O_{12}$ [4], such effect is absent or small, if any, in non-amorphizable UO_2.

The damage evolution at high fluence where the ion-tracks are heavily overlapped is characterized by X-ray diffraction (XRD) and by TEM. The XRD peak intensity decreases monotonically up to a high fluence of 10^{15} ions/cm^2, indicating that the damage continues to grow by the heavy overlapping of ion-tracks. The formation and entanglement of dislocation networks are found by TEM for UO_2 irradiated with 210-MeV Xe at high fluence of 2.7×10^{15} ions/cm^2. The high-density dislocations may play an important role in the formation of subdivision of grains which appear in high-burnup fuels.

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Study on charge exchange gases in tandem accelerators for cluster ion acceleration

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A mechanism of charge exchange and destruction of the MeV energy cluster ions colliding with gas targets was investigated to select the suitable charge exchange gas for a tandem accelerator. Variety of MeV energy cluster ion beams are available using a 3-MV tandem accelerator in the Takasaki Ion accelerators for Advanced Radiation Applications (TIARA), and intense cluster ion beams are required in research of surface modification applications, surface analysis applications and so on[1]. One of the key points in accelerating cluster ions using a tandem accelerator is a transmission, which is defined as a ratio of incident negative cluster ion beam current upon the tandem to accelerated intact positive cluster ion beam current. Most negative cluster ions injected into a tandem get destroyed in collisions with a target gas in a charge exchange section from negative to positive at a high voltage terminal, thus making the transmission of cluster ions much lower than that of mono-atomic ions. So destraction cross sections (σ_d) of cluster ions colliding with charge exchanging gases would play important role to increase the transmission. We evaluate destruction and charge exchange cross sections (σ_p) for carbon cluster ions (C_n : n=2, 4, 8, 10) in collisions with several gases (He, Ne, N_2, Xe) using the tandem accelerator. As a result, it was revealed that the destruction cross sections of C_n were on the order of 10^{-15} cm^2 and were proportional to the number of constituent atoms in the cluster, and those with helium are smaller than those with the others, whereas the charge exchange cross sections seem to be no significant change on cluster sizes and gas species.

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Effect of Mobility of Valence holes on Radial Distribution of Color Centers in Swift Heavy Ion Irradiated LiF and KBr

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It is demonstrated that the redistribution of the valence holes before their self-trapping crucially affects the formation of the spatial defect distributions in nanometric tracks of swift heavy ions (SHI, $M \geq 20m_p$, $E > 1$ MeV/amu, from C to U) decelerated in LiF and KBr in the electronic stopping regime.

The radial distributions of point defects are detected in the in-situ spectroscopy experiments [1]. These defects (*F*- and *H*- color centers) appear due to self-trapping of valence holes occurring during material ionizations followed by creation and decay of self-trapped excitons.

The Monte-Carlo model of event-by-event simulation is applied to determine the radial distributions of anion valence holes in tracks of different ions. This model uses the complex dielectric function (CDF) formalism [2,3] for calculation of the cross sections describing interaction of excited fast electrons and SHIs with the electronic subsystem of a target. All collective effects resulting from spatial and temporal correlations in positions and dynamics of target electrons during ionization/excitation of the valence band, such as excitation of the collective modes (plasmons) and dynamical screening of the interaction potential are taken into account within this approach.

The obtained distributions in the inner track region containing the largest part of valence holes are used as the initial conditions for the diffusion equation describing further spatial spreading of valence holes before their self-trapping. The combined model reproduces the kinetics of formation of the defect halo of a track when only the one fitting parameter is used – the value of diffusion coefficient of valence holes. The estimated values of this coefficient in relaxing tracks of different swift heavy ions correlate well with the diffusivity of holes measured in the synchrotron experiments. The efficiencies of conversion of valence holes into point defects in SHI tracks are also estimated.

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Effect of the Ion Velocity on Formation of the Spatial Distribution of Point Defects in Swift Heavy Ion Tracks in LiF

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Swift heavy ions (SHI, E>1MeV/amu) lose their energy mostly (95%) to excitation of the electronic subsystem of a solid. The linear density of the energy deposited along the ion trajectory can achieve 10 keV/nm – 70 keV/nm. Transfer of even a small part of this energy into the ionic subsystem of a target can result in structure transformations in the nanometric vicinity of the ion trajectory.

SHI of different energies generate the different spectra of the electron excitations. This difference can result in the different kinetics of structure transformations in tracks. This effect is well pronounced for ions having the same electronic energy losses but different energies (the energy values below and above the Bragg-peak).

LiF crystals were irradiated with Au and Pb swift ions in order to investigate this effect. The widest band gap of LiF supplies with the direct mechanism of point defect creation based on decay of self-trapped excitons formed during the relaxation of electron subsystem. To keep the electoneutrality, point defects catch electrons and holes forming point defect ("color centers") electron levels inside the gap. Transitions between these levels can be detected by the spectroscopy technique providing with the quantitative information, which can be used for the analysis of the electron and damage kinetics in SHI tracks.

Using the *in-situ* spectroscopy technique, the parameters of the radial distributions of color centers in tracks of ions with different energies are measured [1]. The analysis of these data is based on the results of the Monte-Carlo event-by-event simulations of the kinetics of the electronic subsystem of LiF in a SHI track. This model uses the complex dielectric function (CDF) formalism [2,3] to calculate the cross sections of interaction of excited fast electrons and SHIs with the electronic subsystem of a target.

The effect of the different initial spectra of electronic excitations which governs the electron kinetics and structure changes in tracks of SHIs having the different energies is demonstrated and investigated.

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Optical spectroscopies: a sensitive probe for the study of radiation damage in SiC?

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For the last few decades, silicon carbide (SiC) has raised interest within the international scientific community because of its wide range of applications. Indeed, SiC is not only envisioned for high-power electronic devices but also as structural material in the design of the next fusion and/or fission nuclear reactors. In both case, SiC will be subject to severe radiation and temperature environments. In this context, experimental and theoretical efforts have significantly contributed to a better understanding of radiation-damage processes. However most of the observations were based on transmission electron microscopy (TEM) and/or Rutherford Backscattering Spectrometry and channeling (RBS/C). The aim of the communication is to show that optical spectroscopies shed new light on the different processes involved from the first stage of irradiation to the recrystallisation of SiC.

Two series of samples were prepared from 6H- and 4H-SiC single-crystal wafers grown by the modified Lely method at the LETI Laboratory (CEA/Grenoble, France). Swift heavy ion irradiations were performed at the UNILAC accelerator of GSI (Darmstadt, Germany) and at the IRRSUD facility of GANIL (Caen, France). Heavy ion irradiations were performed at the JANNUS - Orsay facility. Micro-Raman investigations were carried out at RT in a backscattering geometry in the broad spectral range between 14 and 1800 cm^{-1}.

Raman probe was used to follow the structural evolution of the samples through the modifications and the rearrangement of the Si-C bonds. Thus a structural parameter related to the short-range disorder was defined in order to describe the different stages of damage. Both information extracted from Raman spectrum and structural parameter evolution were used to study the crystalline-to-amorphous transition in SiC.

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Ion Induced Structural Modifications of LiF Crystals

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Color centers and structural defects were investigated in irradiated LiF and LiF-OH crystals (LiF with 150 MeV Kr ions and 56 MeV Ar; LiF-OH with 117 MeV Kr ions and high current pulsed electron beam 0,2 Mev energy of electrons, the pulse duration 10ns). For ion irradiation in the fluence range 10^{11} - 10^{14} ions/cm^2 a cyclotron accelerator DC-60 (Astana) was used (beam current 10nA/cm^2). Color centers in LiF (F and F_n) were studied by UV-VIS spectroscopy. A saturation of F centers occurs at $\Phi \sim 10^{13}$ ions/cm^2 [1,2].

The ion-induced structure modifications in LiF crystals on the irradiated surfaces and in bulk (cross-section of the sample) were investigated using scanning electron (JSM-7500F, JEOL) and atomic force microscopy. The structural modification was studied after a chemical etching in saturated aqueous $FeCl_3$ solution.

In LiF irradiated with 150 MeV Kr ions nanoscale defects with the size of 30-50 nm were observed after irradiation above the threshold fluence of 10^{12}ions/cm^2. The structural modifications include also ion-induced formation of dislocations on the surface and in the bulk. In the formation of dislocations and nanocrystallites an important role play the ion induced mechanical stress.

Dislocations and nanograins in LiF-OH were observed only after irradiated with 117 Mev Kr ions at affluence of 10^{13} ions/cm^2. Pulsed electron beam irradiation is not efficient for nanostructering in LiF-OH .

Possible mechanisms for dislocation formation and nanostructering are discuseed.

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Materials irradiation studies by FFAG Synchrotron for ADS

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An accelerator driven system (ADS) is a coupling of a subcritical nuclear reactor with a high energy ion accelerator. In most cases, protons are used as incident ions. They are irradiated in a target and produce a large number of neutrons. These neutrons cause fission reaction in the subcritical reactor. ADS is expected for energy generation, neutron source and transmutation of minor actinide in high level waste from light water reactor fuels.

In the Research Reactor Institute, Kyoto University, ADS is being planned as a future neutron source for irradiation experiments and neutron scattering. The research activities have been performed for years. The main purpose of this R&D was a basic feasibility evaluation of ADS as an energy production device. For this project, the Kyoto University Critical Assembly was used for subcritical system and a newly developed Fixed Field Alternating Gradient (FFAG) accelerator complex was installed.

By reactions such as spallation between high energy particles and target materials, various kinds of high energy particles are formed as well as neutrons. For the development of beam window, solid target and reactor wall materials, it is necessary to understand the effect of incident particles and generated particles on defect evolution by atomic displacement, where the electronic excitation stimulated by interactions of swift charged particles and the conversion of its energy into atomic motion play an important role.

Materials irradiation experiments were performed with 100 MeV protons by FFAG synchrotron for the study of defect structural evolution and wettability changes of beam window and wall materials under proton and neutron irradiation. Irradiation temperatures were widely changed from 35 K to 300 K. By low temperature irradiation, the formation of initial cascades was studied. After irradiation, positron annihilation lifetime measurements, mechanical tests and wettability tests were performed.

The formation of vacancy clusters was detected in austenitic alloys, ferritic alloys and vanadium alloys even if a low dose irradiation of 1.3×10^{-5} dpa at room temperature. An electrical resistance change in Ni during proton irradiation was measured at 35 K. A decrease of resistance was detected at 1.4×10^{-8} dpa after initial increase. This behavior was explained by a point defect reaction. The increase of wettability after proton irradiation was detected in austenitic steels and Cu by room temperature irradiation to a dose of 1.3×10^{-5} dpa.

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Morphology and annealing kinetics of ion tracks in α-quartz

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Swift heavy ion tracks can be generated by the interaction of high energy projectile ions with target electrons when the electronic energy deposition exceeds a critical value. The use of ion tracks in quartz has been of increasing interest for nano-fabrication and micromachining of optical devices due to the different refractive indices of the tracks and the matrix material [1,2].

Previous studies of ion tracks in quartz by transmission electron microscopy and Rutherford backscattering spectroscopy in channelling geometry, revealed that the track interior is disordered and presumably amorphous [3]. This project focuses on annealing kinetics of ion tracks in quartz. So far, the thermal stability of tracks was only investigated for fission fragments after applying chemical etching [4]. To study the morphology of ion tracks as a function of annealing temperature and time, we used synchrotron small angle x-ray scattering (SAXS) combined with *in situ* and *ex situ* annealing. SAXS is well suited for studying ion track annealing because it allows us to resolve changes in the track radii with high precision [5,6,7]. The ion tracks for this study were generated in crystalline quartz using ^{197}Au, ^{207}Pb, and ^{238}U ions with energies ranging from 27 MeV to 2.2 GeV. Ion fluences between 5×10^{10} and 3×10^{11} ions/cm^2 were applied which yield well separated ion tracks with negligible overlap. The results of the SAXS measurements are consistent with an amorphous cylindrical track core presumably surrounded by a defective halo. The halo-core track structure is also supported by results from molecular dynamics simulations. At energy losses above ~12 keV/nm, the track radius is only weakly dependent on the magnitude of the energy loss. In order to estimate activation energies of the recrystallisation process, *in situ* isothermal annealing experiments were performed at several temperatures around 1000°C. Additionally, *ex situ* isochronal annealing experiments were carried out at temperatures between 250°C and 1100°C. The change in track radii as a function of time indicates a two stage recrystallization process.

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WITHDRAWN

Critical Evaluation of the Synergy Model for Elongation of Embedded Nanoparticles by Swift Heavy Ion Irradiation

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Elongation of metal nanoparticles (NPs) embedded in silica, induced by swift heavy ion irradiation, has received much attention since the discovery. While the mechanism is still under debate, one of the most likely mechanisms is the synergy effect of transient melting of NPs by thermal spike and in-plane stress from silica matrix by the ion hammering. This paper aims at a critical evaluation of this mechanism.

In order to evaluate the transient melting model, two different species of metal NPs, both of which have almost the same diameter ~10 nm but largely different melting points (MP) with each other (420°C and 1890°C for Zn and V, respectively), were irradiated with Xe ions of 200 MeV under the same irradiation conditions. At the fluence of 5×10^{13} ions/cm^2, the distributions of the major and minor axes were evaluated by cross-sectional TEM observation. Both Zn and V NPs showed almost the same degree of the elongation, irrespective of the large MP difference [1]. The validity of the melting model will be discussed in the presentation.

As reported by Benyagoub et al.[2], the ion hammering effect is strongly affected by the radiation-induced compaction of the silica matrix at low fluences where the track coverage ratio $CR = \pi R^2 \Phi < 1$, where R and Φ denote the track radius and the ion fluence, respectively. A silica film of ~ 10 μm thick showed shrinkage at the low fluences ($CR < 1$) and then turned to in-plane dilation with increasing the fluence ($CR > 1$).

The fluence dependence of the elongation of Zn NPs embedded in silica was evaluated particularly at the low fluences, using the optical linear dichroism, i.e., difference between the absorption of light polarized parallel and perpendicular to the elongated axes [3]. The dichroism signal of the irradiated samples showed linear dependence on the fluence down to $CR \sim 0.25$ or less.

The linear fluence dependence also clearly indicated the insensitivity of the NP elongation on the radiation-induced compaction of silica; i.e., the deformation of NPs seems to be induced only by stress from the ion hammering and not by stress from the compaction, while both the processes give comparable but opposite effects on the deformation of a silica film.

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Visualization of heavy ion tracks in calcite by etching techniques

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Carbonate minerals, for example calcite, dolomite or aragonite contain uranium in small amount which leads to damages in the crystal lattice due to the decay of the uranium isotopes. This study aims to visualize these damages and to describe and quantify them. To develop the etching techniques natural calcite crystals were irradiated with 10^6 ^{197}Au ions/cm^2 of 11.1 MeV/u at the UNILAC, GSI Darmstadt. Prior to the experiment the surface of calcite crystals was covered with a hexagonal mask to create irradiated and non-irradiated areas. Experiments showed that reproducible results are achieved with Na-Ethylenediaminetetraacetic acid (EDTA) + 0.5 - 5% Acetic acid in 1:1 proportion for 20 s (± 0.5 s) [1] etching time and an etching temperature of 21 °C (± 1 °C).
Three types of etch pits (Type I, A, B) could be identified. Type I etch pits have a pseudohexagonal shape with a tiny hole in the middle and occur on irradiated surfaces. Width and length of the etch pits increase linear as a function of the etching time. Their areal density match the ion fluence applied. Therefore, Type I etch pits are designated as etch pits of etched ion tracks. The shape of Type A is similar to Type I but without a tiny hole. Type B etch pits differ significantly from Type I, they are more shallow, look like a flat depression on the crystal surface, and have no tiny hole. Minor amount of Type A and B etch pits occur on irradiated and non-irradiated areas. It is proposed that Type A and B etch pits represent etched dislocations.

To differentiate between etched ion tracks and dislocations calcite crystals have been reheated to reveal possible differences in the annealing behavior of ion tracks and dislocations. Non-etched, ion-irradiated calcite samples were heated for 100 h at temperatures between 200 – 500 °C. After heat treatment the samples were etched. The areal density of the etch pits Type I reduces dramatically between 240 and 260 °C from the fluence applied (10^6 ^{197}Au ions/cm^2) to a value of 0.04 * 10^6 cm^{-2}. The only etch pits revealed above 260 °C are of Type A and Type B. For comparison, we exposed non-irradiated calcite crystals to the same annealing processes (100 h, 200–500 °C). The non-irradiated calcite crystal revealed the same areal density (0.04 * 10^6 etch pits/cm^2) at all temperatures including non-reheated samples. In conclusion, ion tracks in calcite anneal between 240 and 260 °C whereas dislocations do not anneal at the applied temperatures which provides a tool to differentiate between etched ion tracks and etched dislocations.

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Electronic Sputtering of CuO Films

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We have studied the electronic sputtering, the electronic and atomic structure modifications of CuO films, under high-energy ion impact, for comparison with the other materials such as Cu_2O [1] and further understanding of the electronic-excitation induced material modifications and atomic-displacement of non-metallic oxides.

CuO films were prepared on MgO-substrates at 700 ºC by using a method in [1]. X-ray diffraction (XRD) shows that the crystal structure of the films is monoclinic with preferential orientation of (111) [2]. The carbon (C)-foil (100 nm) collector method with Rutherford backscattering spectroscopy (RBS) [1] and the stopping powers [3] was applied to analyze Cu sputtered from CuO films.

The sputtering yield of CuO per ion is evaluated to be 173, 120, 80 and 48 for 198 MeV Xe, 99 MeV Xe, 89 MeV Ni and 60 MeV Ar ions, respectively, assuming the stoichiometric sputtering, since the composition remains nearly stoichiometric after the ion impact. Firstly, it is noticed that the sputtering yields are much larger (by a factor of 100-1000) than those of the elastic collisions (Y_C), confirming that the electronic excitations play a dominant role in the sputtering. Here, Y_C is calculated assuming that it is proportional to the nuclear stopping power with the sputtering yield of 0.88 by 100 keV Ne ion impact. Secondly, it appears that the electronic sputtering yields of CuO are larger than those of Cu_2O [1]. The electronic sputtering yield Y of CuO is well fitted by $Y=4.0S_e^{1.08}$, S_e being the electronic stopping power (keV/nm). This is exceptionally close to linear dependence on S_e, in contrast to the super linear dependence for other oxides, e.g., $Y=0.006 S_e^{2.78}$ for Cu_2O. The direct bandgap is determined to be 2.1(±0.1) eV for unirradiated films and no appreciable modification of the bandgap is observed by the 100 MeV Xe ion impact. Disordering and lattice compaction were observed by the ion impact.

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Effects of swift heavy ion irradiation and high temperature annealing on the structure and magnetic propeties of CeO_2

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Recently, we have found that magnetic properties of CeO_2 is changed systematically by heavy swift ion irradiation[1]. In this paper, we report the structure and the magnetic properties of CeO_2 by irradiation and high temperature annealing.

Specimens were CeO_2 bulk pellets which were fabricated by sintering CeO_2 powders at 1673 K. The dimension of the specimens was 6 mm in diameter and 0.3 mm thick. They were irradiated with 200 MeV Xe ions at room temperature by using a high energy heavy ion accelerator at JAEA-Tokai. The irradiation fluencies were $5x10^{12}/cm^2$ to $5x10^{13}/cm^2$. After the irradiation, the magnetization – magnetic field (M-H) curves were measured by means of a superconducting quantum interference device (SQUID) magnetometer. To evaluate the irradiation effect on lattice structure and the chemical state, X-ray diffraction, EXAFS, and XPS measurements were also performed. After these measurements, the irradiated specimens were isochronally annealed in atomosphere at several elevated temperatures from 200C to 1000C.

The M-H curves for 200 MeV Xe ion irradiated CeO_2 clearly show that the increase in magnetization is induced in the specimens by the irradiation. The value of saturation magnetization, Ms, systematically changes as a function of ion-fluence.

The XRD spectra show that the lattice constant of CeO_2 increases with increasing ion-fluence.

After the annealing in atomospere at 1000C, the magnetic state of CeO_2 completely recovered to the non-magnetic state. In the conference, effects of annealing in vacuum will also be discussed.

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Effects of energetic ion irradiation on hardness of Al-Mg-Si and Cu-Ti alloys

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So far, we have found that the hardness of Al-Cu-Mg alloy(JIS2017,Duralumin) increases by energetic heavy ion irradiation at room temperature. Observations by using the three-dimensional atom probe (3DAP) have revealed that nano-meter sized precipitates are homogeneously distributed in the irradiated specimens, which are produced through the irradiation enhanced diffusion of solute atoms. The small precipitates contribute to the increase in hardness. In the conference, we will report the result for other alloys, Al-Mg-Si alloy(JIS6101) and Cu-Ti alloy. They were irradiated with 10 MeV iodine ions and 7.3 MeV iron ions at room temperature and the surface microhardness was measured. Hardness of Al-Mg-Si alloy increases with increasing the ion fluence. In a viewpoint of ion fluence, hardness of Al-Mg-Si alloy for iodine ions irradiation is higher than for iron ion irradiation. But, in a viewpoint of deposit energy density, both are almost the same. This result means that the effect of irradiation on hardness of Al-Mg-Si alloy is dominated by elastically deposited energy. While for Cu-Ti alloy, the hardness once increased by the irradiation with a small fluence, and then it remained constant even with increasing the ion fluence. It suggests that irradiation-induced hardening process for Cu-Ti alloy is quite different from that for Al-Mg-Si alloy. We will also discuss the results of the three-dimensional atom probe and TEM observations, and the electrical resistivity mesurement.

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Morphology and annealing effects of ion tracks in metallic glasses

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Metals are generally not very sensitive to ion track formation due to their high electron mobility. Amorphous metals, also called metallic glasses, are metallic alloys with a disordered non-crystalline atomic structure produced by quenching the liquid state at cooling rates of ~10^6 K/s. While evidence of ion track formation in various metallic glasses has been reported [1, 2, 3], little is known about the track morphology. In amorphous metals average structural properties of ion tracks have been inferred from ion track etching [2] and resistivity measurements [3]. Details of the track structure, however, are difficult to retrieve due to the lack of sufficient contrast inherent with most techniques. Here, we report on the characterization of the morphology of ion tracks produced in Fe-B and Ti-Zr based (amorphous) metallic glasses [3] and their evolution upon annealing using synchrotron based small angle x-ray scattering (SAXS).
We have generated ion tracks using various heavy ion beams with energies ranging from 100 MeV to 2.2 GeV and fluences between 1×10^{10} and 1×10^{12} ions/cm^2. This fluence regime allowed us to study individual ion tracks as well as effects due to increasing track overlap. According to our SAXS results, the tracks can be described by cylindrical objects of constant density with a density difference between the track and the surrounding matrix material of less than 0.1 % [4]. The track radii obtained from our SAXS measurements as a function of the electronic energy loss provide evidence of the "velocity effect" [5]. The annealing kinetics of the ion tracks was studied with simultaneous SAXS and wide angle x-ray scattering in combination with *in situ* isothermal and *ex situ* isochronal annealing experiments. The annealing of the samples leads to a change of the track radii due to the relaxation of the ion track boundaries. Such track recovery occurs while the material still is amorphous and gradually becoming brittle. Furthermore, the formation of ion tracks in these materials slightly enhances the recrystallization process, possibly attributed to different quenching rates during the production of the ribbons and during the track formation process.

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In-situ RBS measurements for the effect of swift heavy ion irradiation on metal-insulator interfaces

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We have studied the atomic mixing at metal-insulator interfaces under 200 MeV heavy ion irradiation by using *in-situ* Rutherford backscattering spectroscopy (*in-situ* RBS).

Through previous studies concerning the effects of swift heavy ion irradiation on materials, it has been proven that the electronic energy deposition by swift heavy ions plays an important role in changes in materials structures and properties.

In metallic materials, the effects have been observed as phase transformation [1], defect production and annealing [2] and so on. For metal-insulator interfaces, the heavy ion irradiation induces atomic mixing [3]. The amount of the mixing increases with increasing the electronic stopping power.

Specimens for the present study were Bi-Al_2O_3 system. Bismuth was evapoirated on single crystalline Al_2O_3 (Sapphire) in a vacuum of 2.5×10^{-5} Torr. The thickness of each evaporated layer was about 50-250 nm. First, the RBS spectrum was mesured for the Bi-Al_2O_3 specimens using 16 MeV carbon ions at JAEA-Tokai high energy ion accelerator. Then, ions were changed quickly from carbon ions to 200 MeV Xe ions. After the irradiation with Xe ions to some fluence, ions were changed again to 16 MeV carbon ions and mesured the RBS spectrum. We repeated the above process several times. Through such an experimental procedure, we could observe the change in RBS spectrum as a function of Xe ion fluence.

The preliminary result is as follows ; the-irradiation with 200 MeV Xe ions to the fluence of 1×10^{14} /cm^2 induced a large amount of mixing at Bi-Al_2O_3 interface. However, the RBS spectra for Bi-Al_2O_3 interface by irradiation to the fluence of 2×10^{14} /cm^2 and the fluence of 3×10^{14} /cm^2 did not change from RBS spectra for the fluence of 1×10^{14} /cm^2 .

In the conference, we will also report the results of x-ray diffraction (XRD) and atomic force microscope (AFM) mesurements as well as the details in the results for *in-situ* RBS mesurements.

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Physical, Chemical and Free Volume Defects Studies in 70 MeV C^{5+} Ion Irradiated PMMA Films

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Swift heavy ion (SHI) irradiation is one of the important physical processes for the modification of polymeric properties. SHI causes changes in physical, chemical, optical and free volume properties of polymers. Poly(methylmethacrylate) (PMMA) is widely used in the lithographic process of the fabrication of microcircuits in electrical and electronic applications and it is one of the polymers most sensitive to the ion beam. PMMA films of 125μm thickness were irradiated by 70 MeV C^{5+} ions from the 15 UD Pelletron Accelerator at Inter University Accelerator Centre (IUAC), New Delhi, India to the fluences of 5×10^{10}, 1×10^{11}, 5×10^{11}, 1×10^{12} and 5×10^{12} ions/cm^2. Physical and chemical properties were studied by X-Ray Diffraction (XRD), UV-Visible absorption spectrometry and Fourier Transform Infrared Spectroscopy (FTIR). The free volume modification was studied by Positron Annihilation lifetime Spectroscopy (PALS) and Doppler Broadening Spectroscopy (DBS). Particle sizes were calculated using the Scherrer formula [1] from the analysis of XRD data which shows that there is 37% increase in grain size at the fluence of 5×10^{11} ions/cm^2. UV–Vis data show the increase of optical absorbance and the shift of absorption edge from the UV towards visible and decrease of band gap with the increase of the fluences. Hole radius (R), free volume (V_f) and fractional free volume (F_v) were calculated by using the Tao-Eldrup Model [2- 3]. There is gradual decrease in the hole radius and free volume up to the fluence of 5×10^{11} ions/cm^2. It could be attributed to the cross linking of polymer chains whereas subsequent irradiation resulted in additional defect generation that aided the free volume growth by their condensation on to the existing free volume defects.

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Radiation effects on yttria-stabilized zirconia

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Water quality in atomic reactors will be measured with electrical corrosion potential sensor (ECP sensor) in order to search the stress corrosion clacks of structural materials on reactors. In an environment where ECP sensors are used, neutron and gamma-ray exist in relatively large numbers. Therefore, it is important to evaluate the irradiation effects on materials which compose main parts of the sensors. One of the main components for ECP sensors is yttria-stabilized zirconia (YSZ). It is well known that in oxides such as YSZ, electrical conductivity is induced by irradiation because of the electron excitation from valence band to conduction band. It may cause a negative effect on the measurement by ECP sensor, operation of which is based on the ionic conductivity. In this study, YSZ samples were irradiated with energetic heavy ions to simulate neutron irradiation on lattice structure. The radiation induced conductivity (RIC) under the gamma-ray irradiation was performed to evaluate the irradiation effect on conductive property. The YSZ samples (8% Y_2O_3 in ZrO_2) indicated the fluorite structure. After irradiation with either 10 MeV I^{3+} ions or 200 MeV Xe^{14+} ions, we performed x-ray diffraction (XRD) and extended x-ray absorption fine structure (EXAFS) measurements to evaluate the ion irradiation effects on lattice structure. Additionally RIC was measured under ^{60}Co gamma-ray irradiation with three-terminal method. The result of XRD measurement shows a large increase in lattice constant by the irradiation. The result of EXAFS measurement shows a peak drop with increasing ion fluences especially for second peaks corresponding to arrangements of second neighbors of Y atoms. While for the RIC measurement, the transient conductivity was triggered only under gamma-ray irradiation. The present result suggests that the fracture at joint surface between metal and YSZ and the effect of electronic conductivity are serious problems for the usage of ECP sensors in reactors.

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Highly Charged Ion Impact Induced Nanodefects in Diamond.

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The morphology of nanoscale defects induced in diamond following impact with highly charged ions (HCI) is studied. Results from interaction of the diamond surface with Bi and Xe ions using charge states between 20+ and 62+ is presented in terms of Atomic Force Microscopy (AFM) analysis (see Figure 1). Kinetic and Potential energy contributions to nanodefect formation are analyzed using empirical data and SRIM Monte Carlo simulations. A direct relation between defect diameter and ion charge state is observed as reported previously for other related materials [1,2]. Numerical modeling using the Coulomb explosion model [3] is used to compare with the experimentally observed defect sizes. An estimate of the empirical charge state limit for nanocrater formation in diamond is presented for the case of Xe and the nature of resultant defects is probed using AFM analysis.

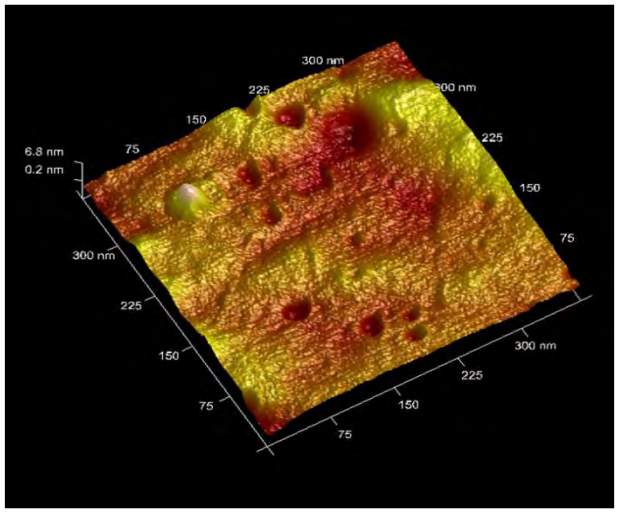

Figure 1. Example of an AFM image showing HCI impact induced nanodefects in Diamond.

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Modelling energy dissipation in swift heavy ion irradiated matter

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The energy dissipation after irradiation of dielectrics with swift heavy ions is studied applying a combination of the Monte Carlo (MC) method and the two-temperature model (TTM). This hybrid scheme was recently introduced in Ref. [1]. The MC calculation provides a kinetic approach to study the initial electron dynamics as the primary excitation and relaxation as well as the creation of secondary electrons [2]. Its results serve as input parameters for the TTM which is applied to calculate the spatial and temporal evolution of the electron and lattice temperatures at later times.

We find three distinct zones of different characteristic electron behavior, see Fig. 1. In the center of the track, the energy is confined by the delayed process of Auger heating [3]. High-energy electrons are excited here, they propagate outwards and create secondary electrons, exhibiting a thermal character. In a second zone these electrons show diffusive behavior, here the TTM is applicable. The high-energy electrons of the first zone may also ballistically reach a third zone.

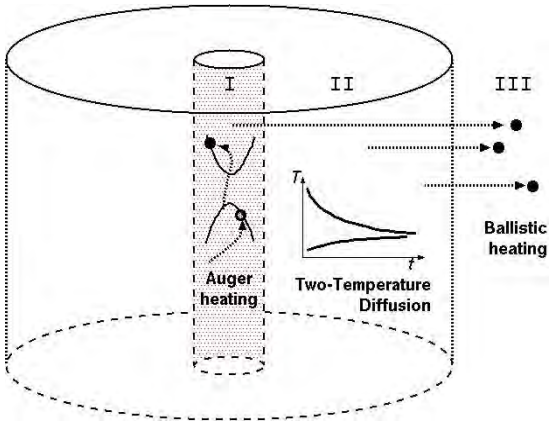

Figure 1. Scheme of three distinct zones of different characteristic electron behavior.

The hybrid model is capable of describing the track creation process in solid dielectrics or semiconductors after swift heavy ion irradiation. It is a universal method which also allows to compute material parameters strongly influencing the results of the TTM describing the thermal spike [4]. Thus, the MC-TTM is capable to calculate track radii and related quantities without fit parameters.

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Distribution of γ-H2AX in Interphase Nuclei of *Arabidopsis* Root Tips

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H2AX is a subtype of histone H2. DNA lesions, especially double strand breaks (DSBs), trigger phosphorylation of this protein at the serine residue placed near the carboxyl terminal.[1] In mammalian cells, phosphorylated H2AX (γ-H2AX) form foci around DSB sites.[2]

In this report, we investigated the distribution of γ-H2AX of *Arabidopsis thaliana* (γ-AtH2AX) in interphase nuclei of *Arabidopsis* root tips irradiated with X-rays or ion-beams by means of immunofluorescence. γ-AtH2AX tended to distribute throughout nuclear volume in early phase (≤60 min) after irradiation of either X-rays or carbon-beams, rather than to localize as foci. In later phase (> 4 hours), some cells revealed prominent γ-AtH2AX foci in their nuclei. KU55933, which preferentially inhibits ATM (ataxia telangiectasia mutated), effectively reduced pan-nuclear phosphorylation of AtH2AX, while it did not effectively inhibit formation of γ-AtH2AX foci. At the same dose, γ-AtH2AX foci generated by carbon-beam irradiation remained in the nuclei for longer time than those generated by X-ray irradiation, suggesting that carbon-beams evoke more irreparable DNA damages than X-rays do.

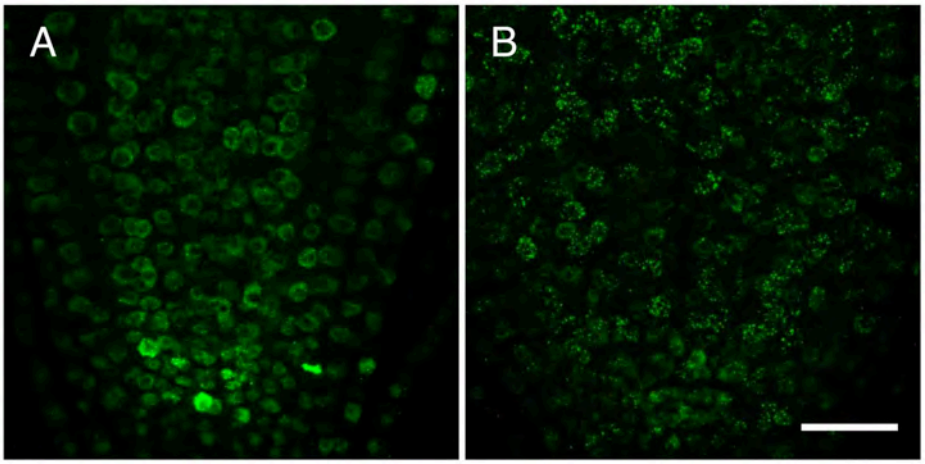

Figure 1. γ-AtH2AX immunofluorescence in Arabidopsis root tips
Green fluorescence indicates γ-AtH2AX signals in a root tip at A; 30 minutes, and B; 6 hours after 80 Gy X-ray irradiation. Scale bar depicts 25 μm.

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High Energy Heavy Ion Irradiation of Polyimide

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Polymers are increasingly attracting interest for the manufacture of flexible lightweight microelectronic devices, with low production cost. Irradiation of polymers with high energy heavy ions produces structural changes that give the polymers enhanced electronic properties [1]. For example, non-overlapping 1-dimensionally conductive ion track arrays can be produced in polyimide by irradiation with iodine ions to a fluence of $<10^{13}$ 55 MeV ions/cm^2, and the electron transport within the track is influenced by the dielectric behaviour of the structurally modified surrounding polymer medium [2]. The processes involved in track formation lead to the release of gas, which can be detected in-situ as the irradiation proceeds. The formation of the tracks and modification of surrounding polymer medium can lead to different rates of evolution for certain species. An understanding of the modification processes can be developed by analysis of the gases, allowing better formulation of polymer matrices and irradiation conditions to produce modified polymers with specific functionalities.

In this work, polymer thin films have been irradiated with 55 MeV iodine ions to a fluence of approximately 4 x 10^{14} ions/cm^2, i.e. including samples from both the overlapping and non-overlapping track regimes. The gases evolved from the film during irradiation were monitored using a quadrupole mass spectrometer for residual gas analysis (RGA). The trends of release for particular species can be fit to show multi-step processes of polymer modification, i.e. gas release from single ion tracks or by the impingement of ions through polymer already modified by ion passage. Ion beam analysis (IBA) is used to measure the composition of films irradiated to different fluences. The IBA measurements provide a quantified measure of the elemental loss from the polymer at different stages of the irradiation. This allows the contribution of various possible molecules for ambiguous masses in the RGA spectra to be determined. It is shown that the RGA results can be correlated with the IBA results, and thus the IBA measurements are used to adjust the gas composition models that are applied to explain the RGA spectra.

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Irradiation Effect of 65 MeV Kr-ions on the Structure and Optical Band-gap of nc-Si:H Film

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As a two-phase mixed material, hydrogenated nano-crystalline silicon (nc-Si:H) film consists of nano-sized silicon crystallites embedded in an amorphous matrix. Nc-Si:H film has been widely applied in solar cells and thin film transistors, and the modifications of nc-Si:H film on the structure and properties have attracted much attention.

In the present work, nc-Si:H films fabricated by using hot-wire chemical vapor deposition were irradiated at room temperature with 65 MeV Kr-ions. The irradiation fluences are 1.0×10^{12}, 1.0×10^{13} and 1.0×10^{14} Kr-ions/cm^2. And then, the X-ray diffraction (XRD), Raman spectroscopy and UV-Vis-NIR spectrophotometer were used to investigate the structure and optical band-gap (E_g) of the irradiated samples. XRD results indicate that the intensities of the diffraction peaks of the nc-Si:H films decrease with the fluence increases. The obtained results of the Raman spectra show that the crystalline fraction (X_c) of the nc-Si:H film decreases while the full width at half maximum (FWHM) of amorphous peak increases with the increasing fluence, as shown in Fig. 1. The UV-Vis-NIR transmission spectra of the irradiated samples show that the absorption edge red-shifts with the fluence increases. Fig. 2 shows that the optical band-gap E_g of the samples irradiated with 65 MeV Kr-ions decreases gradually with the fluence increases. Possible irradiation effects of 65 MeV Kr-ions on the structure and optical band-gap of nc-Si:H film are briefly discussed.

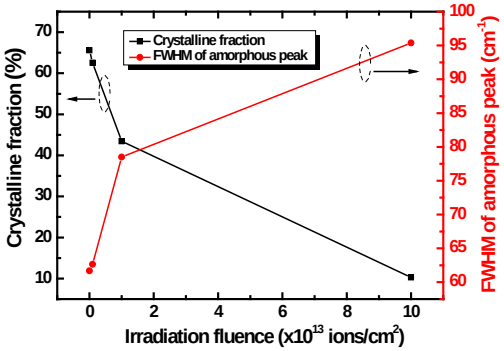

Fig. 1 Crystalline fraction and FWHM of amorphous peak of nc-Si:H film varying with the ion fluence.

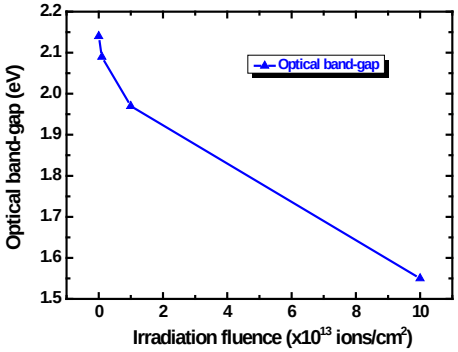

Fig. 2 Dependence of optical band-gap E_g of nc-Si:H film on the ion fluence.

Keywords: Ion irradiation, nc-Si:H film, Structural modification, Optical band-gap

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Swift-heavy ion-sputtered CaF_2 nanoparticles characterized by medium energy ion scattering

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When swift heavy ions penetrate into a target, they deposit energy via electronic excitation processes and induce the ejection of particles from the sample surface, so-called electronic sputtering. For ionic crystals such as LiF and CaF_2, the emission has a jet-like component normal to the target surface superimposed on a broad cosine angular distribution [1]. The jet like emission is probably due to the ejection of nanoparticles (NPs), but the origin of this jet effect is not well understood.

In this work, we characterize the nanoparticles ejected when irradiating CaF_2 crystals with 210-MeV Au ions using Medium Energy Ion Scattering (MEIS). MEIS is a well-established characterization technique to analyze surfaces and thin films. The method was recently extended to allow for the characterization of size and composition of nanoparticles [2]. CaF_2 crystals were irradiated under tilted beam incidence (α=70º, 45º, and 20º with respect to the surface) at the tandem laboratory of Munich. The ejected particles were collected on Si foils positioned at θ=11º, 33º, and 55º on an arc-shaped catcher. Under the same conditions, sputtered particles were collected on TEM grids for high resolution electron microscopy analysis. The resulting TEM and MEIS data agree well with respect to size and size distribution of the nanoparticles. In addition, MEIS shows the presence of atomic Ca on the catcher foils for α= 70º and θ=55º. The amount of atomic Ca vanishes for other emission angles.

In all cases, the NPs can be described by little spheres partially embedded in the substrate. The smaller the NPs are, the more buried they are.. The present results are consistent with the two sputtering components described in [1]: within the jet, mainly NPs are ejected while the sputtering at larger angles originates predominantly from ejected surface atoms.

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Effect of MeV ions on the properties of indium oxide thin films

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Modifications of indium oxides thin films have been investigated using 120 MeV Ag ions. Two different stoichiometric compositions of the film were studied: (i) sub-stoichiometric (as-deposited film) and (ii) stoichiometric (film, which is annealed at 600^{o}C). Sub-stoichiometric indium oxide film shows indium (In) crystallization after irradiation, consisting of primarily crystalline In clusters with a small amount of In_2O_3 phase. Elastic recoil detection analysis (ERDA) and Rutherford back scattering (RBS) measurements showed a change in stoichiometry (an increase in the In:O ratio) after irradiation, thus favouring the formation of indium clusters in sub-stoichiometric films. Moreover, no structural changes occur on irradiating the films with a 60 MeV Si ions, showing the dependence of electronic energy loss on the structural transformations. Topographical changes (structure's shape and size) observed in case of sub-stoichiometric and a spectral analysis suggested the sputtering dominant growth at higher ion fluence. Increase in the conductivity in sub-stoichiometric films after irradiation is attributed to excess of metallic indium (In). In stoichiometric film, the crystal structure is retained with a decrease in the grain size. At lower ion fluence, optical properties (band gap and transparency) remain unaffected. However, at higher ion fluence, an increase in band gap and a reduction in transparency are observed. The creation of defects such as vacancies and interstitials after swift heavy ion (SHI) irradiation is manifested in the emergence of intense photoluminescence (PL) emission in the visible region. Topographical studies show an elongation of surface structures after irradiation and the growth is attributed to the diffusion dominant process. This study gives a scope of SHI to form metal nanoparticles embedded in a dielectric matrix in the sub-stoichiometric films, whereas nanostructure formation can be achieved in the stoichiometric film.

Keywords: Indium oxide, ion irradiation, stoichiometry.

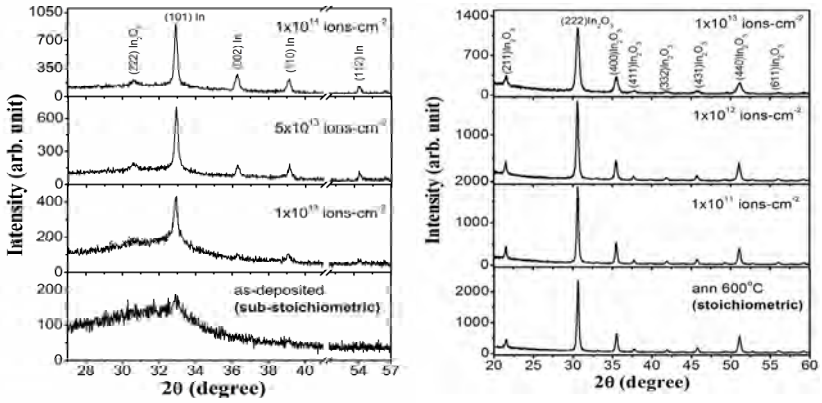

Figure: XRD patterns of sub-stoichiometric and stoichiometric indium oxide thin films irradiated with 120 MeV Ag ions.

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Application of high energy cluster ion impacts to highly-sensitive time-of-flight secondary ion mass spectroscopy

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Secondary ion mass spectrometry, based on the phenomenon that primary ion impacts on a target produce ionized secondary particles originating from the target surface, is one of the most powerful tools for surface analysis. Use of a time-of-flight (TOF) mass spectrometer for mass-analysis of secondary ions is advantageous in efficiently detecting secondary ions at a wider range of mass to charge ratio. Although combination of TOF secondary ion mass spectrometer with primary ion impact ionization can sensitively provide the chemical specific information on the target surface, enhancement of secondary ion yields is required for further surface-sensitive chemical analysis and high-contrast secondary ion imaging. Cluster ion impacts give the unique secondary ion emission phenomenon that the constituent atoms from a primary cluster ion simultaneously impact on a very small region of the target surface and have been reported to provide higher secondary ion yields per incident atom than those for the corresponding monoatomic ion of the same element with the same velocity [1,2]. We have studied the incident cluster energy dependence of emission yields of secondary ions from organic thin films in the energy range up to MeV order and found that the yields increase with increasing incident cluster energy in the energy range studied. This shows that high energy cluster impacts are useful for the highly sensitive surface chemical analysis of organic materials. The possible origin of the incident dependence of the secondary ion yields will be discussed.

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Greater Radiation Chemical Yields for Losses of the Ether and Carbonate Ester Bonds in PADC at the Lower Stopping Powers

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Poly(allyl diglycol carbonate) (PADC) plastics is a well known sensitive etched track detector. Information on the latent track structure in PADC will be helpful for us to find more suited molecular arrangements as novel track detectors with much higher sensitivity. In order to identify the chemical modification along ion tracks in PADC, we have made a series of FT-IR measurements for thin PADC films exposed to proton and heavy ions with energies less than 6 MeV/n [1-3]. In the present study, we have examined the effects of heavy ions with higher energy, including C ions (1.10, 1.25, and 1.39 GeV) and Fe ions (20.8 and 22.8 GeV). Chemical damage parameters, damage density, which is the number of losses of considered functional groups per unit length of tracks, and radiation chemical yields (G values) for each group, are evaluated as a function of the stopping power. The G values for each ion are higher at the lower stopping powers. It is obvious that the G values are greater with increasing ion charge around 300 keV/μm. It has been confirmed that secondary electrons with higher energy should take a significant role of increase the damage density and G values by producing the damage at relatively distant places from the ion trajectories.

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Irradiation Effect of Swift Heavy Ion for $Zr_{50}Cu_{40}Al_{10}$ Bulk Glassy Alloy

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It has been reported that heavy ion irradiation causes softening in some cases of Zr-based bulk metallic glass alloys [1,2]. However, the fundamental mechanisms of such softening have not been clarified yet. In this study, $Zr_{50}Cu_{40}Al_{10}$ bulk glassy alloys were irradiated with heavy ions of 10 MeV I and 5 MeV Al at room temperature. The maximum fluence of each irradiation was 3×10^{14} ions/cm^2. The positron annihilation measurements have performed before and after irradiation to investigate changes in free volume. No crystallization took place in the samples after the irradiation according to X-ray diffraction measurement. The decreasing trend of positron lifetime, which reflected the size of free volume, was observed in both irradiation cases. The relationship between changing value of positron lifetime by the irradiation and total energy loss through the electronic excitation is discussed.

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Fabrication of Nanowires Based on Ethynyl-Functionalized Materials by Single Particle Nano-Fabrication Technique

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The present paper demonstrates the direct formation of 1D-nanostructures based on the cross-linking reactions in the thin films of several kinds of synthetic polymers by irradiation of high energy charged particles; single particle nano-fabrication technique (SPNT).[1-3]

Pentacen is one of the most intensively studied organic materials about the charge transporting properties. To improve the stability and solubilit y, silylethyne substituted pentacens are reported and indicate the excellent electronic performance. These derivatives also provide the solution-based process in fabrication of OFET devices. In this study, direct formation of the pentacene naowires were demonstrated by using trialkylsilyl alkyne substituted pentacen derivatives (Figure 1). The fabrication of nanowires composed of pentacene derivatives with trialkylsilyl alkyne groups; 6,13-bis(triethylsilylethynyl)pentacene (TES-pentacene)[4] and 6,13-bis(triisopropylsilylethynyl)pentacene (TIPS-pentacene) were confirmed by atomic force microscopy (AFM) (Figure 2). These derivatives showed extremely high cross-linking efficiencies which are unlikely values compared with those observed for the other polymeric materials. On the other hand, pentacene and derivative without alkyne moiety didn't produced nano-structures. These results indicate the alkyne moieties enable a fabrication of the 1D-nanostructures based on the pentacene. Unique microprocessing technique for pentacene derivatives was established by this work.

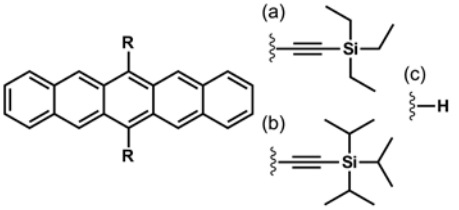

Figure 1. The molecular structures of the pentacene and functional pentacene derivatives investigated in this study: (a) TES-pentacene, (b) TIPS-pentacene , and (c) pentacene.

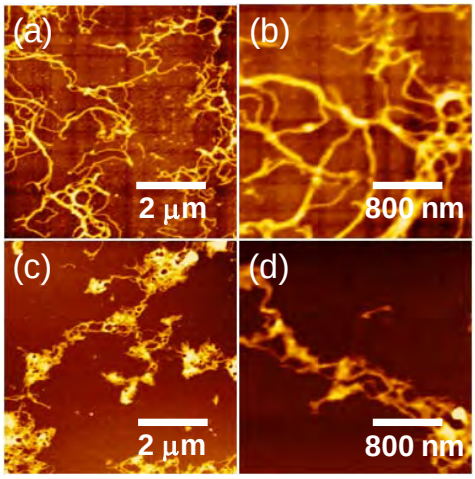

Figure 2. AFM micrographs of the nanowires based on (a and b) TES-pentacene and (c and d) TIPS-pentacene fabricated by irradiation of 490 MeV $^{192}Os^{30+}$ particles at 1.0×10^{9} ions cm^{-2}, respectively. Development was performed by hexane for 1 min.

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WITHDRAWN

Control of radial size of polymer nanowire formed by high energy ion beam irradiation

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Heavy-ion beams are used for high-density energy deposition in polymeric materials, and the effects of such beams differ markedly from those for low-energy ionizing radiation such as γ-ray and electron beams. The inhomogeneous energy deposition along an ion trajectory (ion track) plays a crucial role, allowing for high spatial selectivity in the distribution of radiation dose. The relationships between the deposited energy density and the chemical products in solid polymers have been examined in recent years. Ion irradiation at low fluence without overlapping between ion tracks produces single ion events in the target materials. Single ion bombardment can release active intermediates at high density within a limited area along the single ion track. These active intermediates form a heterogeneous spatial distribution in the ion track due to the variety of chemical reactions involved. Our group has been examining the use of cross-linking reactions in the ion tracks for the direct formation of nanostructures (single particle nanofabrication technique:SPNT) [1-3]. In polystyrene (PS) and polycarbosilane (PCS), the crosslinking reactions along the ion track result in the formation of a cross-linked nanogel (nanowire) in thin films. The non-crosslinked area can be removed by development with toluene, utilizing the change in solubility due to the gelation of PS and PCS. The nanowires formed by ion bombardment can therefore be completely isolated on the substrate as shown in figure 1. The size and number density of nanowires can be precisely controlled by changing the some parameter of both ion beam and polymer. Especially, the radial size of the nanowire was entirely dependent on the energy deposition rate of ion beams. The change of radial sizes of nanowire was quantitatively measured, and we discussed dependence of radial size in terms of deposited energy density and gel formation within an ion track.

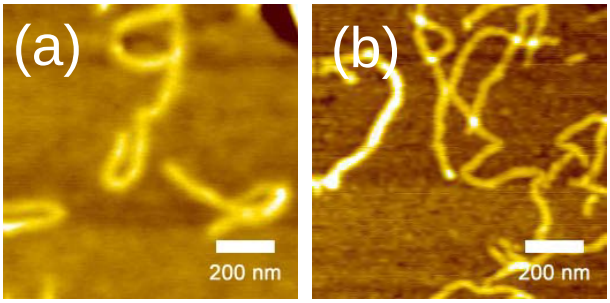

Figure 1. AFM micrographs of nanowires based on PS (a) and PCS (d). The nanowires were formed by 450 MeV Xe ion beam irradiation at 1.1 x 10^9 ions/cm^2.

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Effect of Au ion irradiation on microstructural and chemical changes of SiC/SiC composites

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Silicon carbide (SiC) matrix composites reinforced by SiC fibers are candidate as fuel cladding for generation IV reactor and as structural materials for fusion reactor. The effect of 12 MeV Au ion irradiation on microstructural evolution of three grades of SiC/SiC composites (TS composite (using Tyranno S SiC fibers), TSA3 (using Tyranno SA3 SiC fibers) and HNS (using Hi-Nicalon type S SiC fibers)) has been investigated at room temperature and 800°C up to 0.05 and 1 dpa doses. Analysis of both microstructure and composition of composites were performed by scanning electron microscopy, electron probe microanalysis and Raman spectroscopy. At room temperature and low fluence, Raman spectroscopy results show that irradiation induces a disordered/distorted state into fibers and matrix. With increasing fluence, a total amorphization of these constituents occurs. The increase in the irradiation temperature leads to a damage recovery and partial recrystallization of samples. Image analysis performed from SEM micrographs highlights no significant change in fiber diameter and shape. However, SEM analysis suggests a longitudinal shrinkage of Tyranno S fibers for the composite irradiated at 1dpa at room temperature and 800°C which seems inconsistent with disorder occurrence. Further analysis such as AFM and TEM exams are in progress.

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Analysis of depth redistribution of implanted Fe near SiO_2/Si interface

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We have studied diffusion and clustering process of implanted Fe in SiO_2/Si structure at elevated temperatures. The depth profile of implanted Fe was analyzed by Rutherford backscattering spectroscopy (RBS) and cross-sectional transmission electron microscopy (TEM). In the previous study, we found that the implanted Fe near the SiO_2/Si interface at the substrate temperature of 600°C during the implantation distributed significantly different from the estimation by TRIM simulation.[1] Fig. 1 shows the TEM image observed for the Fe-implanted sample at 600°C with ion dose of 5×10^{15} cm^{-2}. The dark contrasts correspond to the implanted Fe. We can confirm that the blank area where any Fe clusters do not exist in the SiO_2 layer near the interface though Fe was implanted around the interface.

Fig. 1: Cross sectional TEM image around the SiO_2/Si interface region for the Fe-implanted sample at 600°C with 5×10^{15} cm^{-2} dose.

First of all, we have investigated the redistributions of the implanted Fe at room temperature (RT) followed by annealing at 600 and 800°C by RBS analysis. Figure 2 shows RBS spectra for these samples. In particular, it is clearly seen that Fe atoms post-annealed at the 800 °C are preferably gathered at a defenetive depth in the SiO_2 layer. In order to clearify the phenomenon, we have theoretically treated the diffusion process accompanied with aggregation of Fe in SiO_2 by numerically solving Langevin equations.

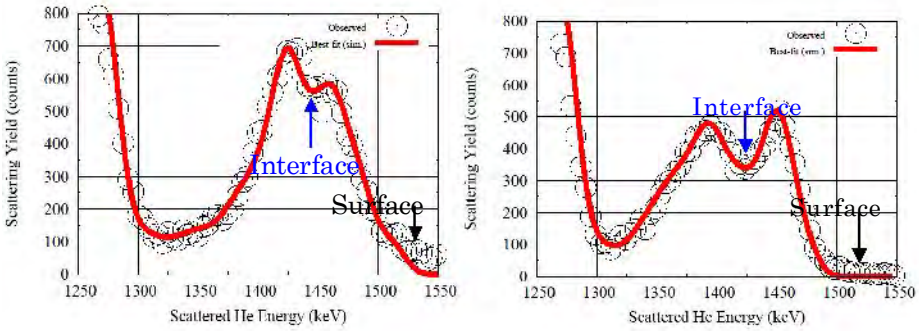

Fig. 2: RBS spectra for the samples as-implanted and post-annealed at 800°C.

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Proton Impact Electron Emission from Biological Molecules

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Ionization of biological molecules such as amino acids and nucleobases is the subject receiving considerable attention in recent atomic collision researches. This is due to the fact that secondary electrons ejected by swift ion bombardment with such molecules including liquid water play important roles in radiation-induced biological effects [1]. In Particular, information about energy and anugular distributions of secondary electrons from these moelcules is of great importance and urgently required in ion radiotherapy to achieve accurate determination of the dose distribution.

In this work, we have measured absolute double $\sigma(\varepsilon, \theta)$ and single $\sigma(\varepsilon)$ differential cross sections of secondary electrons from such molecules bombarded by MeV proton projectiles . Here ε and θ represent the energy and the emission angle of electrons, respectively. The experiment was performed at an accelerator facility of Quantum Science and Engineering Center of Kyoto University. Effusive molecular beam targets of adenine ($C_5H_5N_5$) and uracil ($C_4H_4N_2O_2$) were produced by heating these powders at appropriate temperatures [2]. Data were taken for ε up to 1keV and θ from 15- to 165-degrees with respect to the beam directon.

Experimental cross sections are compared with theoretical values calculated by Champion *et al* [3] and those estimated from simple analytical formulae [4]. It was found that experimental data of both $\sigma(\varepsilon, \theta)$ and single $\sigma(\varepsilon)$ are in excellently good agreement with theoretical cross sections. We also found that total ionization cross sections for our molecules and other various polyatomic molecules reported in literature can be well scaled by universal straght lines as a function of the number of valence electrons of each molecule investigated.

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Study of Radiation Damage Profiles of Thin PEEK and PET Polymers Irradiated with Swift Halogen Ions

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Neutron Depth Profiling (2D and 3D NDP) and Rutherford Backscattering (RBS) nuclear analytical techniques were used for study of damage depth distribution in selected ion-irradiated polymers (poly-aryl-ether-ether ketone PEEK and polyethylene terephthalate PET). Additional information was obtained by electron paramagnetic(spin) resonance (EPR/ESR) and Raman spectroscopy. Similarly as in the previous study [1], the specimens were irradiated with MeV ions (in the present work with the F^+, Cl^+, Br^+ and J^+ halogens) up to the fluence 10^{14} ions/cm^2. The depth profiles of the damaged area in the ion-irradiated polymers were analyzed by profiling of the Li and Hg diffusion markers decorating the distribution of dangling bonds (free radicals). The markers were incorporated into the damage areas by exposing of the foils subsequently after irradiation either to 5 Mol/l water solution of ^{6}LiJ or Hg vapours. The depth distributions of the radiation damage in the inspected specimens were found (for higher fluences) to be fractioned into two zones that followed both electronic and nuclear transfer energy distributions. The NDP and RBS profiling technique were also applied for study of evolution of the damaged profiles induced by thermal processing of the samples. It has been observed that the thermal annealing incited a process of gradual damaged redistribution. This process was dramatically enhanced at elevated temperatures around and above the glassy points.

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Stopping of Relativistic Heavy Ions and its Influence on Angular Distributions of Cherenkov Radiation

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Using theory developed in [1-4] we performed calculations of Cherenkov radiation (ChR) angular distributions from relativistic heavy ions (RHI) taking into account their stopping in a radiator. The results of calculations show that the stopping of RHI in radiator leads to additional broadening of ChR ring and forming of new ChR angular distribution which is different compared with Tamm-Frank distribution. The key parameters which change drastically the ChR angular distribution are: energy, charge and mass of an ion; ChR wave length and corresponding refractive index; stopping power and radiator thickness. The theory developed has been applied to the analysis of earlier experiments 1996-2001 [5-7] devoted to studies of ChR angular distribution from Au RHI beam with energies (0.64 – 0.99 GeV/u) at SIS GSI (Darmstadt).

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Fr-045

Structural and Optical Studies of 100 MeV Au irradiated thin films of tin oxide

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Abstract

Thin films of tin oxide (SnO_2) of 100 nm thickness were grown on silicon <100> and glass matrices by electron beam evaporation deposition technique under high vacuum. Thickness of the films were monitored by piezo-sensor attached to the deposition chamber. Nanocrystallinity is achieved in these thin films by 100 MeV Au using 1 pna current at normal incidence with ion fluencies varying between 1×10^{11} ions/cm^2 and 5×10^{13} ions/cm^2. Swift Heavy Ion beam irradiation was carried by using 15UD Pelletron Accelerator at IUAC, New Delhi. Optical studies of these ion irradiated thin films were done by UV-Vis. spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR). Prominent peak at 610cm^{-1} in FTIR spectrum confirms the O-Sn-O bonding of tin (IV) oxide. Surface topographical studies and grain size calculations are done by atomic force microscopy (AFM) technique using Nanoscope III-A. Crystallinity and phase transformation due to irradiation of as-deposited and irradiated films were studied by glancing angle X-ray diffraction (GAXRD) technique using Brucker–D8 advance model. GAXRD results show improvement in crystallinity and phase transformation due to swift heavy ion irradiation. Grain size distribution is verified by AFM and GAXRD results. Swift Heavy Ion induced modification in thin films of SnO_2 were confirmed by the presence of prominent peaks at 2θ values of 30.65^0, 32.045^0, 43.94^0, 44.96^0, 52.36^0 in GAXRD spectrum. Results will be discussed in detail during the presentation.

Key words: Swift Heavy Ion, UV/Vis., GAXRD, AFM, FTIR.

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A Multi-Pattern Gas Detector for Beam Monitoring in Proton Therapy

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Charged particle therapy provides a three-dimensional dose distribution optimized to match the maximum dose distribution to the tumor shape. Although it shows therapeutic advantages over conventional radiotherapy using an X-ray, the beam control requires accurate real-time information about profiles of the clinical beam from beam monitors to avoid under- or over-dosage. Recently, a gas electron multiplier (GEM) technique has been developed[1] and used in various fields as a new type of a gas detector system. The GEM has advantages over a multi-wire proportional chamber such as the excellent special resolution and higher counting rate, and can be expected to meet severe requirements for beam monitoring in charged-particle therapy. We developed a multi-pattern gas detector (MPGD) based on GEM of a proton irradiation system for proton therapy experiments using small animals at Cyclotron and Radioisotope Center, (CYRIC) Tohoku University (Figure 1). In order to evaluate characteristics of the MPDG, beam tests were performed using an 80-MeV proton beam from the AVF cyclotron at CYRIC. The experimental results showed that the MPDG system can be used not only as a two-dimensional lateral dose distribution monitor but also as a dose monitor to obtain real-time information about beam parameters in the pencil beam scanning.

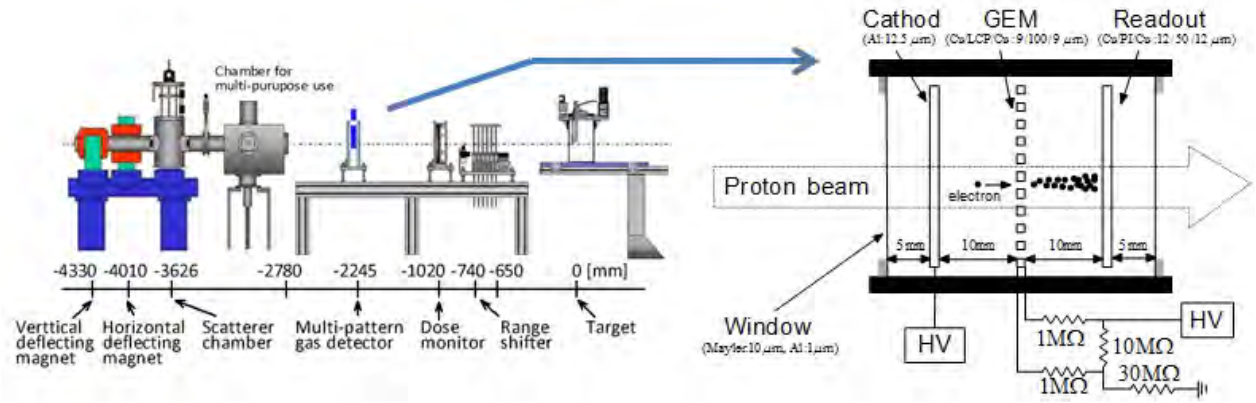

Figure 1. Mult-pattern gas detector using GEM and proton irradiation system at CYRIC, Tohoku University.

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TEM analysis of ion tracks in $MgAl_2O_4$

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High-density electronic excitation induced by swift heavy ions is known to form non-amorphous ion tracks in some ionic oxides. We have reported the size and the structure of ion tracks in $MgAl_2O_4$, which has potential applications for inert matrix of advanced nuclear fuels and transmutation targets, by using transmission electron microscopy (TEM) [1, 2]. The core region of ion tracks in $MgAl_2O_4$ was found to retain crystallinity up to the electronic stopping power of 35 keV/nm. The TEM images of non-amorphous ion tracks show various contrast features depending on observation conditions. In the present study, we discuss TEM image contrast of ion tracks in $MgAl_2O_4$ with different TEM techniques and observation conditions to characterize atomic structure of the ion tracks.

Figure 1 shows bright-filed images of inclined views of ion tracks in an identical region of $MgAl_2O_4$ irradiated with 340 MeV Au ions. The ion track contrast strongly depends on the extinction distance. This suggests that ion tracks are observed as structure factor contrast and strain contrast. Strong strain contrast appears heterogeneously between ion tracks rather than along individual ion tracks. Atomistic observations by high resolution TEM imaging confirmed that some regions between ion tracks were structurally disordered. A combination of bight-field imaging with defocus conditions and HAADF STEM method detected the reduction of atomic density at the core region of ion tracks, suggesting a high density of vacancies was formed along ion tracks.

In conclusion, analysis with different TEM techniques revealed that a high density electronic excitation induces the reduction of atomic density at the core region of ion tracks and cause strong lattice strain between the ion tracks.

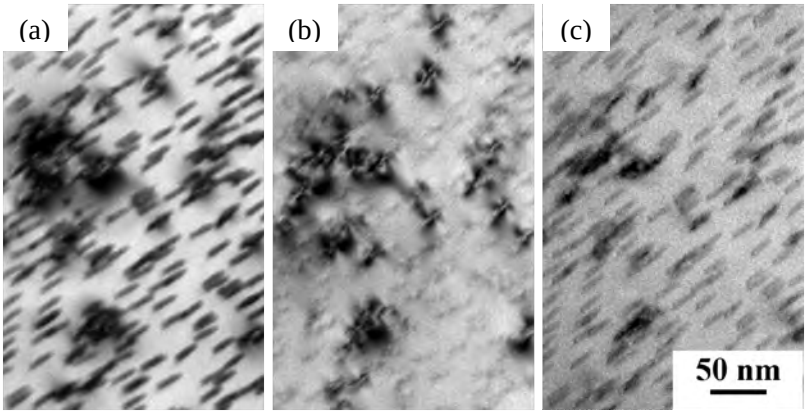

Figure 1. BF images of an identical region showing inclined ion tracks in $MgAl_2O_4$ irradiated with 340 MeV Au ions to a fluence of $5x10^{15}$ ions/m^2. Diffraction conditions are (a) **g**=220, (b) **g**=440, and (c) **g**=880.

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Branch-Structure Forming by MeV Cluster Ion Beam Irradiation

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Unique structural modifications were observed in cluster ion beam irradiations for bulk metals [1]. The characteristics of the modifications differ strongly compared to monatomic projectile at the same velocity. Behaviors of the injected cluster ions were interpreted to fragmentize to the constituents of the cluster ion during the penetration or at the several layers from the surface, cased by Coulomb explosion [2]. However, behaviors at just fragmentizing have not been revealed clearly due to inexistence method of directly detection or visualization. On the other hand, the direct formation technique of 1-D polymer nanostructures has been developed by utilizing of induced cross-linking reactions along single track of a heavy ion, Single Particle Nanofabrication Technique (SPNT) [3]. In cluster ion beam irradiation, sufficient energy deposition to form the nanostructure is expected. In this study, the visualization of the fragmented track was tried by the SPNT with cluster ion beam. The ion beam irradiations were performed at TC beam-line connected to a tandem accelerator at Takasaki Ion Accelerators for Advanced Radiation Application facility (TIARA), of JAEA/Takasaki. The ion species were selected to be $^{12}C_8^+$ and $^{96}Mo^+$. The energy of both ions was adjusted to be 2.4 MeV. In the 2.4 MeV $^{96}Mo^+$ beam irradiation, the particle velocity and particle mass are the same to those of the 2.4 MeV $^{12}C_8^+$ beam. As the results for SU-8 epoxy resin which is high sensitivity for the ion beam irradiation, the branch structures forming were observed in the case of only the $^{12}C_8^+$ beam irradiation, supposing a reflection of the behavior at the fragmentizations.

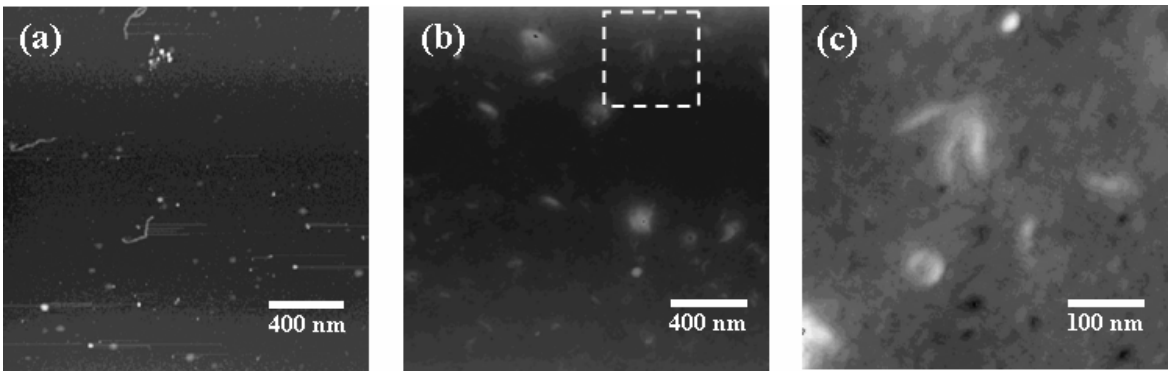

Figure 1. AFM images of epoxy nanostructures formed by the SPNT with 2.4 MeV $^{96}Mo^{3+}$ (a) and 2.4 MeV $^{12}C_8^+$ (b). (c) is magnified image of the area surrounded by dashed square in (b).

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Studies of Swift Heavy Ion Radiography at IMP-Lanzhou*

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Radiography with high energy proton or heavy ion beams is a promising method in diagnostics of spatial and density distribution of a dense matter with good time resolution. Comparing to the conventional hard X-ray radiography, high energy ion radiography has the following advantages: longer penetrating depth, better contrast and higher dynamic range, higher efficiency, sensitive to both density and material composition and so on. These advantages especial cope with the needs in the investigation of high energy density matter driven by intense heavy ion beams, as will be one of the very important topics in future at Institute of Modern Physics (IMP), Chinese Academy of Science (CAS)[1-2].

In this conference we would like to present the recent experiment results on energy loss radiography of statics objects, where in the experiment about 10^9 carbon ions with energy of 240MeV/u were extracted from CSR (the Cooling Storage Ring at IMP) in ~600ns. It is found that, after some mathematic treatment of the primary radiographs, very fine inner structures of the objects can be achieved. The advantages of heavy ions over proton in this method of radiography will be discussed. Status and perspectives of heavy ion applications and sciences at IMP will be introduced as well [3-5].

This works is supported by the “973” program (the National Program on Key Basic Research Project, No. 2010CB832902) and NSFC (the National Natural Science Foundation of China No. 11075192, 11075125).

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Status and perspectives of heavy ion applications and scientific researches at IMP-Lanzhou *

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Current status and perspectives of heavy ion application and scientific researches at Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS) are presented. As the heavy ion research centers in China, the National Laboratory of Heavy Ion Research Facility in Lanzhou (NL-HIRFL) was established at IMP in 1991 and has been open to the scientists at home and abroad since then. The research activities at IMP cover not only the fields of basic research such as nuclear physics, atomic physics, plasma physics and astrophysics, but also the fields in applications such as heavy ion tumor therapy, mutation breeding, material modifications, nano-technology, single event effects in microelectronics and so on [1-4]. Beside the performances of the Heavy Ion Research Facility in Lanzhou, the proposed project, HIAF (High Intensity heavy-ion Accelerator Facility), as the 12th 5 year plan of China, will be introduced as well [3-5].

The works are partially supported by the “973” program (the National Program on Key Basic Research Project, No. 2010CB832902).

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Effects of irradiated biodegradable polymer in endothelial cell monolayer formation

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Ion beam irradiation of polymers with heavy ions beams generates irreversible structural and chemical changes in the molecular structure, which increase the bio and citocompatibility [1]. The purpose of the present work was to modify the chemically inert Poly-L-lactide acid (PLLA) surface with swift heavy ions, and used the Bovine Aortic Endothelial Cells (BAEC) as a model anchorage-dependent cell for monolayer formation test. We evaluated cell viability, proliferation and the morphological and related structural responses of BAEC on different irradiated supports. Thin films of PLLA samples were irradiated with sulfur (S) at energies of 75 MeV and gold (Au) at 18 MeV ion-beams; provided by the Tandar (Buenos Aires, Argentina) and Tandetron (Porto Alegre, Brazil) accelerators, respectively. The monolayer growth of BAEC´s cells onto unirradiated and irradiated surfaces has been studied by in vitro techniques in static culture. Cell morphology was observed using phase contrast microscopy and cytoskeleton proteins with fluorescence microscopy. The results indicate that mitochondrial activity increase up to 4 times at 96 hours of culture with respect to the pristine one. In addition, the confluent cells showed cobblestone like morphology and growth in a monolayer, which is typical of the endothelial lineage. On the other hand, we observed in the unirradiated PLLA a decrease in proliferation, as a result a cell death (necrosis/apoptosis). Cell metabolism and morphology can be regulated by the irradiation conditions and the experiment results suggest a set of optimum parameters. Concluding, a mechanism for cell spreading can be visualized in terms of ion hits with varying degrees of overlap, which in turn modulates cytoskeleton reorganization and focal adhesion structure.

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LET-dependent effects of heavy-ion irradiation on mutation induction in *Arabidopsis thaliana*

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Heavy-ion irradiation has been accepted as an effecient technology for mutation breeding. It is revealed that heavy-ion irradiation induce a braod spectrum of mutation phenotypes even in at low irradiation dose and short irradation time. A noted physical characteristic of a heavy-ion beam is that it has higher LETs than other conventionally used radiations X-rays or γ -rays. It is well known that high-LET radiation shows stronger biological effects than low-LET radiation. However, the effect of the LET values on the nature of mutated DNA has not been characterized.

In this study, the effect of the LET value on the structure of mutated DNA was investigated. We used a wildely used model plant *Arabidopsis thaliana* (L.) whose entire genome has been sequenced. *A. thaliana* also has advantages for isolating mutants; it allows us to perform large scale screening, because it is a small plant with a short life cycle (two to three months). The size of *A. thaliana* seeds is suitable to control the LET value in heavy-ion irradiation.

Dry seeds of *A. thaliana* were irradiated with $^{12}C^{6+}$ (22.5, 30.0, or 290 keV/μm) and $^{40}Ar^{17+}$ ions (290 keV/μm) using E5 beam line in the RIKEN RI-beam factory (RIBF). For the detection of mutations, *elongated hypocotyl* (*hy*) and *globrous* (*gl*) mutants were screened in M_2 generation. The *hy* mutant has an elongated hypocotyl when grown continuously under weak light. The *gl* mutant is characterized as having no or reduced trichomes on the leaves. Other well-characterized morphological mutants were also identified: *amp1*, *bin2*, *egy1*, *pid1*, and *var2* [1][2]. Candidate genes responsible for each mutant were sequenced. Of the identified 49 mutations, 40 mutations were deletions [1][2]. Among them, the proportion of small deletions ($\leqq$100 bp) was about 94% for irradiation with LETs of 22.5 or 30.0 keV/μm. On the other hand, the proportion of small deletions was only 42% after irradiated with LET of 290 keV/μm; instead, the proportion of the large deletions increased. These results indicate that the size of deletions induced by heavy-ion irradiation was affected by the value of LET. Now, we can select the value of LET depending on the experimental purpose or target genes. LET of 22.5 or 30.0 keV/μm is suitable for inducing single gene mutations, whereas LET of 290 keV/μm is useful for disrupting tandemly arrayed multiple genes. Mutagenesis has become more and more important in modern genetic studies, enabling the discovery of genes that control important traits. Heavy-ion irradiation with appropriate LET will be an effective tool for mutagenesis.

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Surface Amorphization in Al_2O_3 Induced by Swift Heavy Ion Irradiation

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Aluminum oxide is expected as functional materials in a field of nuclear energy e.g. insulating materials, windows used for plasma diagnosis in a fusion reactor and/or inert matrix materials of geological disposal of high level radioactive waste. Recently, amorphization in ceramics such as Al_2O_3, which affects the physical and mechanical properties, is attracted as a phenomenon induced by swift heavy ion irradiations with high-density electronic energy depositions (S_e) [1]. In this study, detailed mechanism of the amorphization was discussed. Single crystalline Al_2O_3 specimens were irradiated with several energies of Xe ions at ambient temperature, by using the Tandem Accelerator of JAEA. The irradiation energy was from 70 to 160 MeV. The fluences were in the range of from 1.0 x 10^{13} to 1.0 x 10^{15} ions/cm^2. After irradiations, x-ray diffractometry (XRD) measurements and cross sectional transmission electron microscope (TEM) observations were conducted. The TEM observations demonstrated that amorphization was induced in surface region in single crystalline Al_2O_3 irradiated by swift heavy ions above the fluence expected from the results of XRD. Obvious boundary was observed around 800 nm depth in the cross sectional TEM images as shown in Fig. 1. The crystal structure of surface region above the boundary was identified to be amorphous and deeper region to be single crystal by electron diffraction patterns. Distinct ion tracks, induced by passing of high energy particles, were vertically observed in depth of single crystalline region. This result indicates that amorphization could be caused by overlapping of ion tracks. The amorhization depth of 800 nm was rather short from the case of polycrystalline aluminum oxide shown in previous study [2], in spite of almost same S_e. These results imply that degree of amorhization induced by high energy ion irradiation depends on not only irradiation conditions but also crystal structure.

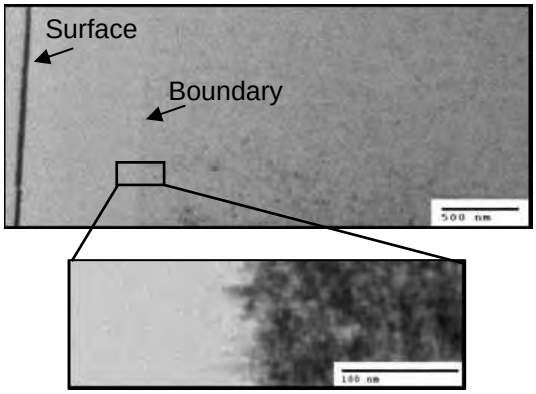

Fig.1 Cross sectional TEM images of single crystalline Al_2O_3 specimen irradiated by 160 MeV Xe ions. Total fluence was 3.5 × 10^{14} ions/cm^2.

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Charging and de-charging of ion irradiated polymers

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Interaction of ions with solids leads to secondary electron emission and charging-up of insulators. The slowing down of fast electrons emitted from polymers (Mylar, polypropylene) irradiated with swift ion beams (C, O, Kr, Ag, Xe; 20-64 MeV/u) was measured by the time-of-flight (TOF) method at LNS/Catania and at GANIL/Caen [1-3]. The charge build-up, deduced from convoy- [1,3] and binary encounter [2,3] electron peak shifts, leads to target material dependent potentials (6.0 kV for Mylar, 2.8 kV for PP) which in turn slow down the fast electrons.. The number of projectiles needed for charging up (charging-up time constant) is inversely proportional to the electronic energy loss [2,3].

After a certain time, a sudden de-charging occurs [1,3]. For low beam currents, charging-up time, energy shift corresponding to maximum charge build-up, and time of de-charging are reproducible and regular. For high beam currents, the time intervals become irregular and chaotic. A surprising finding is that sandwich targets with gold layers on both surfaces of polymer foils behave in the same way as pure insulators, whereas a single gold layer suppresses the charging and de-charging phenomenon. The puzzling question whether the observed charging-up is a surface- or a bulk (track) phenomenon or if both processes contribute, remains open.

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Phys. Rev. A83 (2011) 064901.

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Study on ferromagnetic ordering of FeRh thin films induced by energetic heavy ion irradiation by means of X-ray Magnetic Circular Dichroism

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Equiatomic intermetallic compounds of FeRh have several potential technological advantages for devices, such as thermally assisted magnetic recording media, mainly due to their first order anti-ferromagnetic (AF) - ferromagnetic (FM) phase transition. In our previous studies, we reported that ion beam irradiation induced the FM state in Fe-50at.%Rh bulk and film samples even at low temperatures where they were originally AF state. In addition, we also revealed that the change in magnetizations was dominated by the density of energy deposited through elastic collisions between ions and the samples.[1] In the present studies, we have tried to evaluate the nature of the irradiation induced magnetization in the FeRh thin films by means of soft X-ray magnetic circular dichroism (XMCD) with synchrotron radiation.

FeRh thin films about 80 nm thick were fabricated by using ion beam sputtering of $Fe_{50}Rh_{50}$ target on MgO(100) substrates at 700°C, and were post-annealed at 800°C for 4 hours in vacuum. Irradiation with 10 MeV Iodine ions were performed at room temperature up to the fluence of 4×10^{14}cm^{-2} at Japan Atomic Energy Agency, Takasaki. Magnetic properties of the samples were evaluated by XMCD at SPring-8 BL25SU as well as by a SQUID magneto meter.

According to the structural characterization by X-ray diffraction, the FeRh phase with B2-type ordered crystal structure is successfully synthesized in the annealed samples. As for the magnetic property of the sample before irradiation, the XMCD signal at the photon energy of the Fe $L_{2,3}$-edge was very tiny, suggesting that the sample is almost AF. After 10MeV I irradiation with the ion fluence up to 2×10^{13} cm^{-2}, the XMCD spectra become significant, which means that the Fe atoms are strongly spin polarized. In contrast, the excess irradiation over 4×10^{14} cm^{-2} decreased the XMCD signal again. These behaviors are almost identical as those for the results obtained from the SQUID measurements. We will quantitatively discuss the present result in detail, and will communicate the analysis using orbital and spin sum rules in XMCD.

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Computer Simulation of High-Energy-Beam Irradiation of Ceria

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The structural relaxation caused by the high-energy-beam irradiation of single-crystalline ceria (CeO_2) was simulated by the molecular dynamics method and compared to the results of UO_2. As the initial condition, high thermal energy was supplied to the individual atoms within a cylindrical region of nanometer-order radius located in the center of the specimen. The potential proposed by Inaba et. al.[1] was utilized to calculate interaction between atoms. The supplied thermal energy was first spent to change the crystal structure into an amorphous one within a short period of about 0.3ps, then it dissipated in the specimen. The amorphous track radius R_a was determined as a function of the energy density of the thermalized region. As shown in Fig.1, it was found that the CeO_2 is more stable than UO_2 against high thermal energy caused by high-energy-beam irradiation.

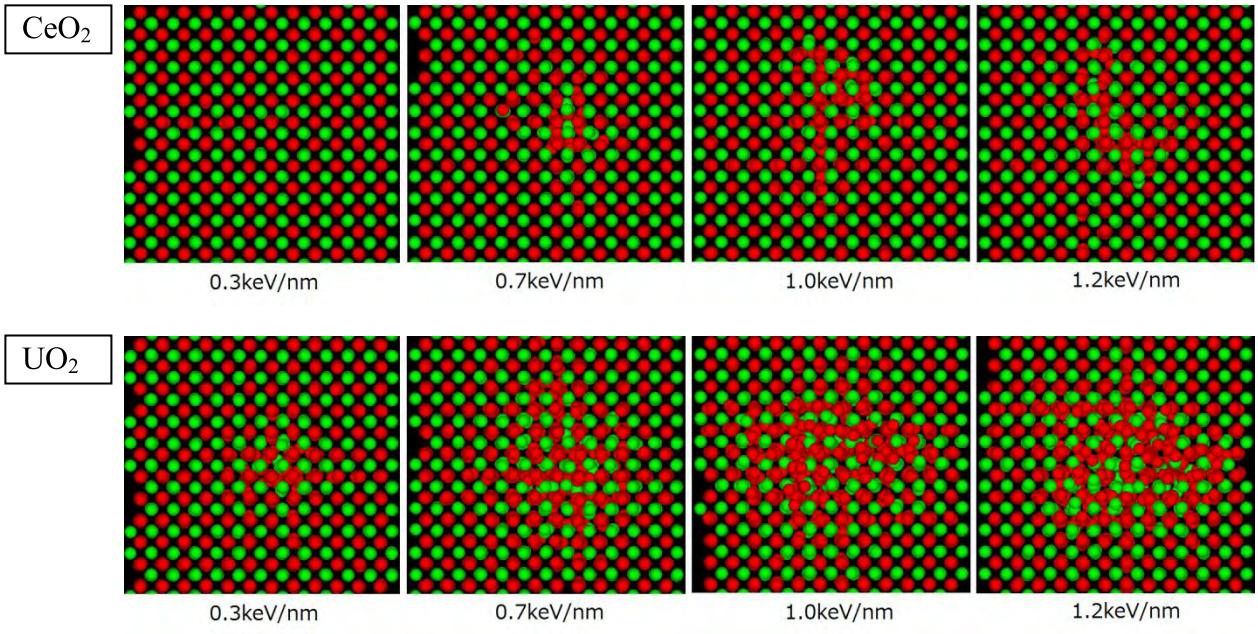

Figure 1. The final structure of CeO2(upper) and UO2(lower) under the effective stopping power

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Effects of energetic ion irradiation on magnetic properties of Fe-Ni Invar alloys

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The Fe-Ni alloys with Ni concentration ragne around 35 at% shows anomalous magnetic properties so called Invar effect [1]. The magnetic properties of Fe-Ni Invar alloys is very sensitive to not only concentration, lattice volume, but also energinic ion irradiations. Therefore ion iradiation technique would be considered as the useful tool to modify the magnetic properties of the Fe-Ni Invar alloys. We have been investigated the effects of enerigetic ion irradiation at room temperature on the magnetic properties of FCC Fe-Ni alloys with concentration range around 35 at% Ni.

The magnetic properites of FCC Fe-Ni alloys varies depending on the irradiation conditions such as the kind of ion, ion energy and fluence. In particularly, the ion fluence shows remarkable effects on the magnetic properties of FCC Fe-Ni alloys. Considering from the AC susceptiblity, Curie temperatures of the FCC Fe-Ni alloys increase with an increase in the ion fluence; however the increments of the Curie temperatures by ion irradiations saturate around 80 K regardless of ion kind and energy. Further the magnetization is increased by the ion irradiation as shown in Figure l. The ion irradiation effects on the magnetism of Fe-Ni Invar alloy is maintained the temperature below 573 K.

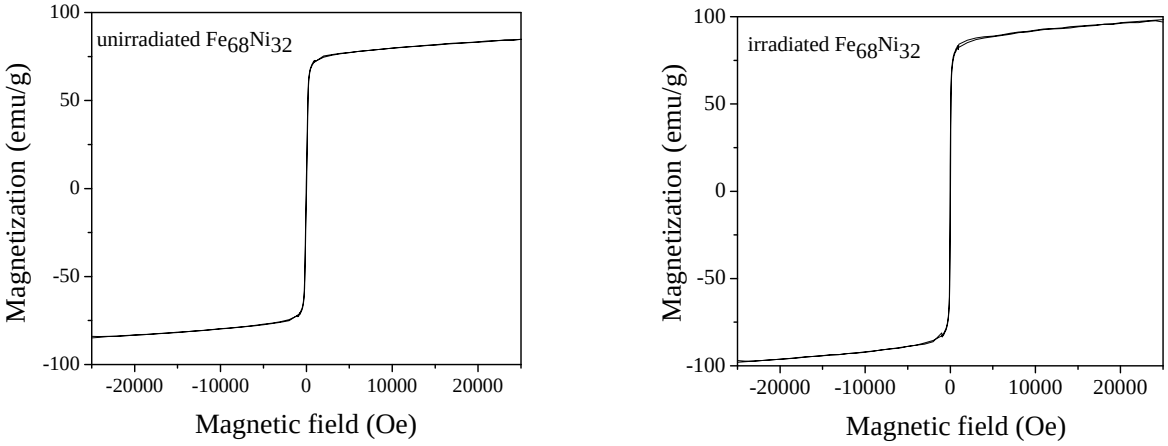

Figure 1. Magnetization –field loop of unirradiated and 7.8 MeV Fe ion irradiated $Fe_{68}Ni_{32}$ alloy.

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Defect formation and accumulation in CeO_2 irradiated with swift heavy ions

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Oxide ceramics with fluorite structure have successful achievements and potential applications in nuclear industries such as for nuclear fuel and host of inert matrix fuel. Understandings of radiation-induced defects formation and accumulation caused by high density electronic excitation is one of the essentials to clarify the radiation damage process by fission fragments. In the present study, microstructure evolution in CeO_2 irradiated with swift heavy ions was investigated by using transmission electron microscopy techniques as a simulation study of the radiation damage of fission fragments in fluorite structure oxides.

Polycrystalline sintered CeO_2 specimens were irradiated with 210 MeV Xe ions at an ambient temperature in a Tandem accelerator at JAEA-Tokai to a fluence ranging from $1x10^{15}$ to $1.5x10^{19}$ ions/m^2. Plan view observations of ion tracks with bright-field imaging revealed that the density of ion tracks proportionally increases with fluence to evolve a saturation at fluence higher than around $1x10^{16}$ ions/m^2. The influence region to induce recovery of pre-existing ion tracks caused by an incident ion was evaluated to be a cylindrical region with a diameter of 17 nm.

Cross section observations along the direction of incident ions at a fluence of $1x10^{16}$ ions/m^2 revealed the formation of both ion tracks and dislocation loops. Dislocation loops were observed up to a depth of 7.5 μm and their size was larger at the shallower depth of incident ions. This suggests that the nucleation and growth of both ion tracks and dislocation loops were caused by the high density electronic excitation. At a higher fluence of $1.5x10^{19}$ ions/m^2 and $1x10^{20}$ ions/m^2, at which radiation damage of high density electronic excitation was repeated for $3.5x10^3$ and $2.3x10^4$ times respectively, microstructure including ion tracks, dislocation loops and line dislocations was developed depending on the depth of incident ions. At $1x10^{20}$ ions/m^2, the nucleation of small size grains with a low tilt angle to the matrix was formed. Further, small pores were found to change their shape to be a round space and the density pores was decreased. These results clearly shows an important role of high density of electronic excitation for the development of dislocation structure and grain nucleation in fluorite structure oxides.

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Effects of Gd_2O_3 doping and swift heavy ion irradiation on CeO_2 bulk pellets and thin films

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To control the initial reactivity of UO_2 fuel of the present light-water reactors, Gd_2O_3, which has high neutron-absorption cross section, has been doped into UO_2. As the Gd_2O_3-doped UO_2 fuels are exposed to the irradiation with high energy (~100 MeV) fission products (FPs) during burning, it is important to investigate the effects of Gd_2O_3 doping and the irradiation with FPs on UO_2. During recent years, CeO_2 has been used as a simulation material for UO_2 because it has the same fluorite structure as that of UO_2 and some properties which are similar to UO_2 [1,2]. In our previous paper[3], we have reported the result of EXAFS measurements near Ce-L3 edge ; the local O and Ce atom arrangements around Ce atoms become more disorderd with inceasing the amount of Gd_2O_3 dopants or the fluence of 200MeV Xe irradiation. Our recent EXAFS results, however, show that the effects of Gd_2O_3 doping or 200MeV Xe irradiation on EXAFS spectra near Gd-L3 edge are different from those around Ce atoms. This difference may be due to the existence of oxygen vacancies near Gd atoms. To discuss the irradiation effects in more detail, irrdaiation experiments using lower energy (several MeV) and higher energy (several GeV) heavy ions were are also performed. In the symposium, we will discuss the effects of doping or irradiation on thin films as well as bulk peletts.

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Flower Color Mutations in Chrysanthemum Induced by Heavy Ion Beam

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Chrysanthemum is one of the important cut flowers in Hyogo Prefecture. Chrysanthemum cut flowers are sold in the market as bundles consisting of flowers with 3 colors; deep pink, white, and yellow. Mutation breeding occasionally has been used to improve cultivation characteristics of original cultivars with minimum changes. We attempted to use heavy-ion beam irradiation as a mutation breeding technique to change only one or two characteristics, such as flower color and flower shape.

We irradiated cuttings of 53 cultivars of chrysanthemums with C-ion beam (Energy, 135 MeV /nucleon; LET 23 keV/∝m), Ne-ion beam (135 MeV/nucleon; 23 keV/∝m) or Ar-ion beam (95 MeV/nucleon; 240 keV/∝m). The doses of C-ion beam were 2, 4, 6 and 8 Gy. The doses of Ne-ion and Ar-ion beam were 2 and 4 Gy. The irradiation doses of C-ion beam were determined on the basis of a previous study [1]. After irradiation, the cuttings were planted cell-trays containing soil. One month later, these cuttings were transplanted to an experimental field or a green house. Plants were grown without pinching. Other conditions were standard of Chrysanthemum cultivation. At the time of full bloom, we observed the flowers.

Severe growth inhibition was observed after 8 Gy irradiation of C-ion beam. Flowering of these plants were 2 weeks or more later than that of non-irradiated plants. Same effects were observed in plants irradiated with Ne-ion and Ar-ion beams. Moderate growth inhibition was observed in plants irradiated with 6 Gy C-ion beam. Flowering of these plants delayed about a week. We isolated 58 mutants from 29 cultivars. 45 of mutants were flower color mutants. Others were leaf shape or leaf color or flower shape mutants. Mutation frequency diffed according to cultivars. The optimum dose of C-ion irradiation on cuttings for mutation induction was estimated to be between 4 and 6 Gy in chrysanthemums. We isolated flower color mutants of yellow, cream, and pale pink from 7 cultivars. Original flower color of these cultivars were white. The cultivars with yellow flower showed no mutation of flower color. There were two directions of flower color mutation in the cultivars with deep pink flower. One was mutation to white, and the other was mutation to dark red or reddish brown or orange. There was no cultivar that showed mutation in both directions.

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Simultaneous Measurements of Lattice Constant Change and Length Expansion of Al Induced by Swift Heavy Ion Irradiation

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A swift heavy ion irradiation is known to cause a large number of lattice defects in a solid resulting from atomic displacement or heating via electronic excitation processes. Such radiation damaging effects induce deformation of the solid. The irradiation-induced deformation is probably due to dynamical processes of defect reactions, such as lattice diffusion, vacancy-interstitial recombination and defect agglomerates. To understand the dynamic phenomena, it is necessary to perform real time observation of radiation-induced defects during irradiation.

In this work, a new method has been developed for in-situ study of radiatin damaging effects in materials. The apparatus consists of an X-ray diffractmeter combined with a 2-dementional laser displacement meter, enabling to observe lattice constant of materilas during ion-beam irradiation. The purpose of this study is to reveal a contribution of radiation defects to the irradiation-induced deformation. We performed simultaneous measurements of lattice parameter change and length expansion during ion irradiation. Figure 1 shows a schematic diagram of the experimental setup. Target samples of well-annealed Al foils were irradiated with a 6.4 MeV Si beam. We present details of our developed apparatus and show some experimental data for the relationship between lattice constant change and length expansion as a function of the incident beam flux.

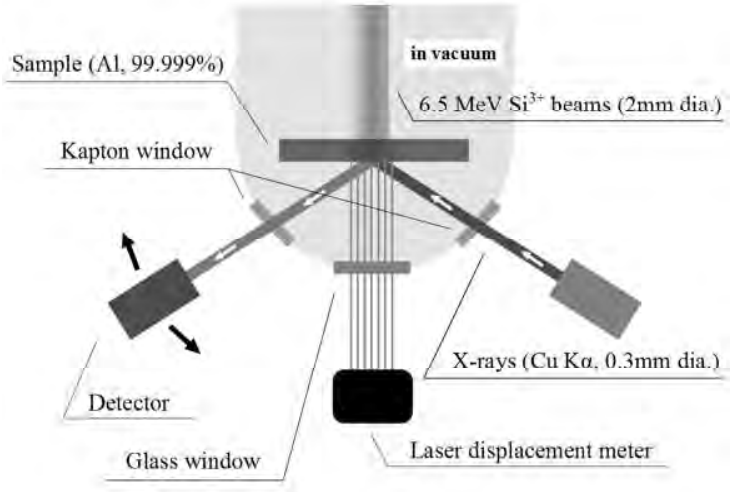

Figure 1. Schematic of the experimental setup

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Direct Measurements of Multiple Ionization of Isolated Polyatomic Molecules Induced by Fast Ion Collisions

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Recently, polyatomic molecules such as biological molecules and clusters in gas phase have gained increasing attention as new targets in both experimental and theoretical atomic collision studies. Multiple ionization is one of the fundamental issues in the collision processes. Distributions of multiple ionization probabilities were conventionally obtained from charge states of recoil ions or fragment ions generated in the collisions. However, for polyatomic molecular targets, it is difficult to detect all the fragment ions produced in a single collision event because of insufficient detection efficiency. This prevents obtaining accurate information on degrees of multiple ionization of polyatomic molecules. In this work, we overcome this difficulty by measuring directly the number of emitted electrons with a semiconductor detector (SSD) in coincidence with time-of-flight (TOF) measurements of fragment ions [1,2].

The experiment was carried out at 1.7-MV tandem accelerator facility of the Quantum Science and Engineering Center, Kyoto University. A well collimated beam of 580-keV C^+ ions was incident on polyatomic gas targets (such as C_2H_6 and CH_2FCF_3). Electrons emitted in collisions were detected by a SSD applied at a potential of +25 kV. The number distribution of electrons was deduced from energy spectra measured by the SSD. Thus, this provides degrees of multiple ionization directly. At the same time, fragment ions were extracted to the opposite direction of the electrons and detected by a microchannel plate (MCP) detector in conjunction with a position-sensitive delay-line detector (DLD). From coincidence measurements between the number of emitted electrons and time-of-flight measurements of the product ions, we obtained correlation between multifragmentation processes and the charge state of prefragment parent ions for each event.

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Hydrogen Trapping in ^{3}He-Irradiated Fe

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In a DT fusion reactor, components around core plasma are heavily damaged by fast neutrons and radiation damages will act as traps for hydrogen isotopes such as deuterium and tritium. For the safety of radiological protection, quantitative information about the trap is required. In the present work, deuterium trapping in ion-irradiated iron, the most basic element of structural materials, is investigated by use of a nuclear reaction analysis (NRA).

One side of a sample disk of iron with a thickness of 2.0 mm and purity of 99.99% was exposed to a deuterium rf plasma to charge deuterium into the sample. The same side was irradiated with 0.8-MeV ^{3}He ion at 45 degrees to the surface and deuterium depth profiles near the surface were observed by the NRA with a 1.7-MeV ^{3}He beam. During the irradiation and the NRA, the sample was continuously exposed to the plasma and deuterium permeation through the sample was monitored.

Before irradiation, the deuterium concentration just beneath the surface was 2.9×10^{23} m^{-3} at 453 K, estimated from the permeation flux. After ^{3}He irradiation of 1.7×10^{17} m^{-2}, the deuterium concentration increased by 3 orders of magnitude. The shape of the deuterium depth profile was very similar to a profile of atomic displacement. These indicated that a large amount of the hydrogen isotope trap was produced by the irradiation.

From analysis of temperature dependence of the deuterium concentration, it was found that a potential of the trap was 0.36 eV and the trap was annihilated around 500 K. The number of the trap was nearly proportional to the displacement. The proportional constant was 0.009. This value could greatly affect the tritium retention in the fusion components at low temperatures where the trap was not annihilated.

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Preparation of Tungsten Carbide Nanoparticles by Ion Implantation and Electrochemical Etching

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Tungsten carbide (WC) has been expected as an alternative to noble metal catalysts because of its platinum-like electronic state [1]. This study deals with WC nanoparticles prepared by W^+ implantation to glassy carbon (GC) since they are likely to have the coupled effect of nanometer size confinement and radiation defects remaining in the surrounding medium. The subsequent electrochemical etching removed the outer GC-rich surface layer and made more of the implanted atoms exposed. This would allow us to access the functionalities of the formed WC nanoparticles.

We implanted 100 keV W^+ in unpolished GC substrates at nominal fluences up to 1.7×10^{17} ions/cm^2. The implanted samples were electrochemically anodized in a 0.1 M NaOH aqueous solution to etch the surface layer [2]. The analyses were performed by X-ray photoelectron spectroscopy (XPS), Rutherford backscattering spectrometry (RBS), and transmission electron microscopy (TEM).

The time for the etching was determined from the etch rate for a polished GC substrate, i.e., 80 nm/min. XPS W 4f spectra indicated the formation of carbides as reported previously [3]. Figure 1 compares W depth profiles before and after the electrochemical etching, which were determined from XPS peak intensities during the course of Ar^+ sputtering. The etching clearly increased the W concentration on the surface. According to the RBS results, half of the implanted W atoms were retained in the substrate, while the rest should escape to the etching solution. The cross-sectional TEM image revealed a uniform distribution of WC particles with a diameter of less than 10 nm just near the surface region.

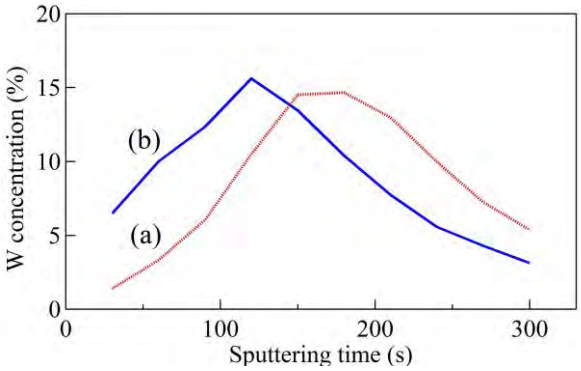

Figure 1 Tungsten concentration as a function of Ar^+ sputtering time (a) before and (b) after the electrochemical etching.

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Damage Structures and Hardness Changes in Austenitic Stainless Steels and their Model Alloys Irradiated with Ni Ions

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Austenitic stainless steels have been important nuclear materials. They can experience, however, dimensional changes at very high doses due to irradiation induced swelling. Before the start of steady state swelling, there exists an incubation stage, where no voids are generated. Understanding the incubation period is important because it determines the service lifetime of stainless steel components under irradiation in nuclear systems. Theoretical and experimental analyses of the incubation period and microstructural evolution during the period have been performed [for example 1,2]. It is known that the defect evolution during the incubation period strongly depends on alloying elements [3].

As most experimental studies for void formation have been performed using transmission electron microscopy (TEM), the point defects and their clusters smaller than the resolution limit of TEM were impossible to detect. Positron annihilation spectroscopy makes it possible to detect small defects whose sizes are below the resolution limit of TEM. The authors have studied defect structures during the incubation period after electron and neutron irradiation using positron annihilation lifetime measurements [4,5]. After electron irradiation of 4×10^{-3} dpa at 100 K and measurement at room temperature, only single vacancies and voids of 2 - 3 vacancies existed in commercial alloys and in model alloys. At the higher temperature of 563 K, the lifetimes of precipitates and/or large stacking fault tetrahedra were detected in Ti added modified SUS316SS after neutron irradiation below 0.02 dpa. After increasing the dose to 5 dpa, however, the growth of micro-voids was detected.

In this study commercial austenitic stainless steels (SUS316 SS, SUS316L SS, SUS304, Ti added, modified SUS316SS) and their model alloys (Fe-16.13Cr-16.96Ni, Fe-15.39Cr-15.92Ni-2.68Mo-1.89Mn, Fe-15.27Cr-15.8N-2.66Mo-1.88Mn-0.53Si, Fe-15.27Cr-15.8N-2.66Mo-1.88Mn-0.53Si-0.24Ti) were irradiated by Ni ions (6 MeV) with an accelerator of QSEC, Kyoto University to a dose of 6.8 dpa (peak position) at room temperature and 573 K. After irradiation, damage structures were studied by using positron annihilation lifetime spectroscopy. There were a large difference between room temperature irradiation and 573 K irradiation. At room temperature, lifeteimes decrease with increasing alloying elements. Effects of alloying elements in steels were not clear at 573 K irradiation. Hardness tests were also performed by micro-hardness tester and effects of alloying elements were detected.

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Formation of Bioorganic Compounds from Possible Interstellar Media by Swift Heavy Ion Irradiation

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A wide variety of organic compounds have been found in extraterrestrial bodies such as carbonaceous chondrites and comets. It was suggested that these organic compounds were originally formed in interstellar dust particles (ISDs) in molecular clouds, and that the organic compounds formed in ISDs were brought in small solar system bodies. We examined possible formation and alteration of organic compounds in interstellar and interplanetary environments by cosmic radiation.

Water, methanol and ammonia are major compounds found in interstellar media. Thus we irradiated a frozen (77 K) or liquid mixture of them with heavy ions from HIMAC accelerator at National Institute of Radiological Studies, Japan. Ions used were helium (150 MeV/u), carbon (290 MeV/u), neon (400 MeV/u), argon (500 MeV/u) or iron (500 MeV/u). After irradiation, the resulting products were acid-hydrolyzed, and amino acids in them were determined by HPLC and/or GC/MS. Unhydrolyzed products were characterized with various methods including pyrolysis-GC/MS and XANES.

A variety of amino acids were detected in all the hydrolyzed irradiation products. Glycine was predominant, followed by racemic mixture of alanine. G-value of glycine by carbon ion irradiation was 0.014 (liquid) and 0.007 (frozen), respectively. Neon ion gave larger G-value of glycine than carbon, while helium, argon and iron gave smaller values. Unhydrolyzed products were mixture of complex hydrophilic organic compounds with molecular weight of *ca*. 2000. It was suggested that complex amino acid precursors with high molecular weight could be formed in ice mantles of interstellar dusts in dense clouds by the action of cosmic radiation.

Stability of amino acids, their precursors and nucleic acid bases against heavy ions and soft X-rays irradiation was investigated. Amino acids (glycine, isovaline), amino acid precursors (hydantoins) and complex precursors of amino acids (proton irradiation products from a mixture of carbon monoxide, ammonia and water) were irradiated with carbon ions (290 MeV/u) from HIMAC. Soft X-rays irradiation was performed by using BL-6 of NewSUBARU synchrotron facility (Univ. Hyogo).

Amino acids and their precursors were stable against heavy ion irradiation (16 kGy) if they are irradiated in dry conditions. Purines bases are more stable than pyridine bases against heavy ions irradiation, while both were more stable than amino acids. However, amino acids, their precursors and nucleic acid bases were easily decomposed by soft X-rays irradiation even in dried state, and hydrophobic products were formed. Thus, in interplanetary space, high-energy photons are more responsible than high-energy particles for their stability. Stability of organic compounds in actual space environments will be tested as a part of *the Tanpopo Mission* [1].

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Microscopic Evaluation of the Absolute Fluence Distribution of a Large-Area Uniform Ion Beam Using the Track-Etching Technique

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The uniform-beam formation/irradiation system with multipole magnets has been developed at Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) of Japan Atomic Energy Agency (JAEA) [1]. For the evaluation of the beam uniformity, the relative intensity distribution is obtained from the optical density of a radiochromic film (Gafchromic film). However, the absolute fluence distribution is unknown since it cannot be estimated easily and precisely from the Gafchromic film. The actual fluence and its distribution would be crucial to beam applications in materials and biological research. In this study, we microscopically evaluated the particle fluence distribution using the track-etching technique, which involves irradiating a polymer with energetic heavy ions and etching the resultant tracks chemically.

Polyethylene terephthalate (PET) films (25 μm in thickness) and Gafchromic films were irradiated in air with uniform and purposely-perturbed non-uniform beams of 520 MeV Ar from the AVF cyclotron in TIARA. The irradiated area was 51 mm × 50 mm and the average fluence was 1.1×10^8 ions/cm^2. The PET samples were etched in an alkaline solution and divided into 64 segments. The number of track-etched pores in the center (12 μm × 17 μm) of each segment was counted with a scanning electron microscope. The relative standard deviation (RSD) was calculated as a measure of the beam uniformity.

The microscopic fluence distribution of the uniform beam on the PET flim is shown in Fig. 1. The RSD value was 12 %, which agreed well with that determined by the Gafchromic film. Thus, our evaluation of the microscopic fluence distribution could be validated in a statistical sense. The RSD of the non-uniform beam became as large as 22%. It was, therefore, confirmed that the uniform intensity distribution was realized in our uniform-beam formation system microscopically.

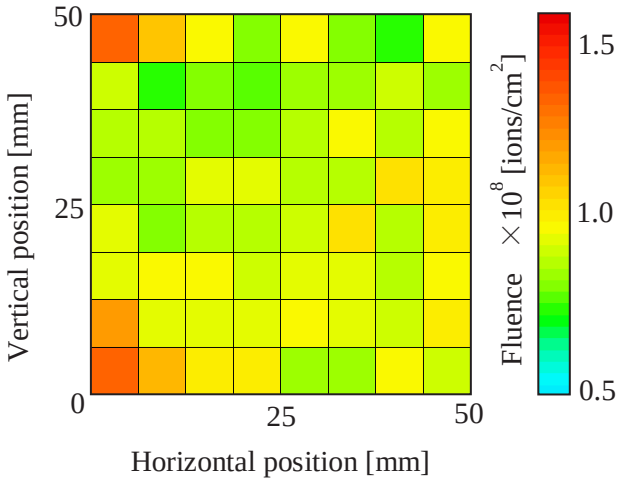

Figure 1 Microscopic fluence distribution of the PET film irradiated with the uniform beam.

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Aluminum Coating on Polymer Surface to Reduce Radiation Damage during Ion Beam Analysis with Heavy Ions

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Ion beam analysis (IBA) for covalent macromolecule, such as plastics and other organic materials, electronic excitations and ionization induced by MeV ion beams sometimes cause degradation of targets. Especially for polymeric targets, light elements such as hydrogen (H), carbon (C) and oxygen (O) are likely to be released from the material surface, resulting in serious compositional changes during IBA. In order to achieve precise measurement of IBA for organic materials, a technique to lower the compositional changes caused by MeV ion beam irradiation is needed. In our previous study [1,2], we showed that thin aluminum (Al) coating on a polymer foil was an effective way to reduce light elements losses from the foil during MeV proton irradiation. In the present work, we examine the effect of Al coating on elemental losses from a polymer foil during IBA with MeV He or O ions. As shown in Figure 1, the hydrogen forward scattering (HFS) yield for the Al coated polyimide (Al / PI) was found to be somewhat larger that that for the uncoated PI, indicating that Al coating hinders a hydrogen loss from the Al / PI foil. Ion beam induced luminescence (IBIL) as well as HFS results using MeV He or O ions for some polymers will be presented to discuss the effect of Al coating.

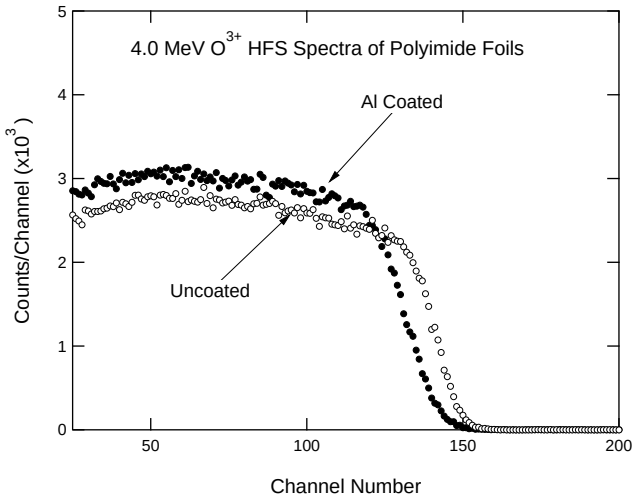

Figure 1. Hydrogen forward scattering (HFS) spectra taken with 4.0 MeV O^{3+} ions for polyimide foils with (filled circles) and without (open circles) Al coating.

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Direct Ion-Irradiation of Liquid Targets in Vacuum Using Capillary Microprobe

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Since charged particle therapy has been recognized as a powerful method for cancer treatment, several studies have recently been performed on studies of collision interactions of swift ions with liquid materials [1,2]. In this work, we developed a new experimental method for charged-particle irradiation of a liquid targets in vacuum by using apparatus combined the capillary-microprobe method and liquid jet technique. Using the method, the spatial shape of liquid water jet was investigated.

The experiment was carried out using a 2.0 MV tandem Pelletron accelerator at QSEC of Kyoto University. Figure 1 shows a schematic of the experimental setup. The apparatus consists of capillary-microbeam system, liquid jet target system and detection system. A well-collimated ion beam was incident on a single tapered glass capillary mounted on a two-axis goniometer. The goniometer was positioned at two-axis piezo-driven stage. A liquid jet target was crossed perpendicularly with an incident beam. By moving the stage along the Z-axis, it enables to approach the tip of the capillary to the liquid target. In the present work, the diameter of liquid water jets was determined by measuring energy loss spectra of ions passing through the jet targets.

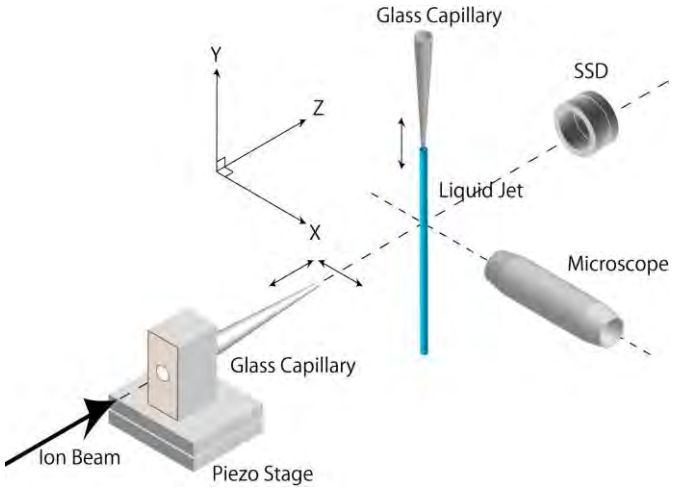

Figure 1. Schematic of the experimental setup

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Oxide nanoparticles in the ODS alloys irradiated with high energy Xe and Bi ions

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High level of ionization energy loss may stimulate significant structural changes in nano-oxides under irradiation of the ODS materials with heavy ions of fission fragment energies [1,2]. Since the sensitivity of nanoparticles in the ODS alloys was found to be dependent on many parameters, like the nature of oxides, ion fluence, irradiation temperature, this stimulates further research with involving of new materials and variation of irradiation parameters. In the present work we discuss the results of microstructural examinations of Fe-16Cr-3W ferritic steel reinforced with yttrium oxides and KP4 Fe-15Cr-4Al-2W-0.35Y2O3 ODS alloy irradiated with 167 MeV Xe and 700 MeV Bi ions. It was found that Bi ion irradiation at fluences more than 10^{13} cm^{-2} (ion track overlapping regime) leads to complete amorphization of oxide particles in Cr16 samples, while central regions of a large (~ 20 nm) particles and small oxides (~ 5 nm) in KP4 steel remain crystalline. The Xe ion irradiation effect consists in polycrystallization of single crystalline oxide particles as shown in Fig. 1. The size of polycrystals decreases with ion fluence increase. No dissolution of nanoparticles has been revealed in all studied samples.

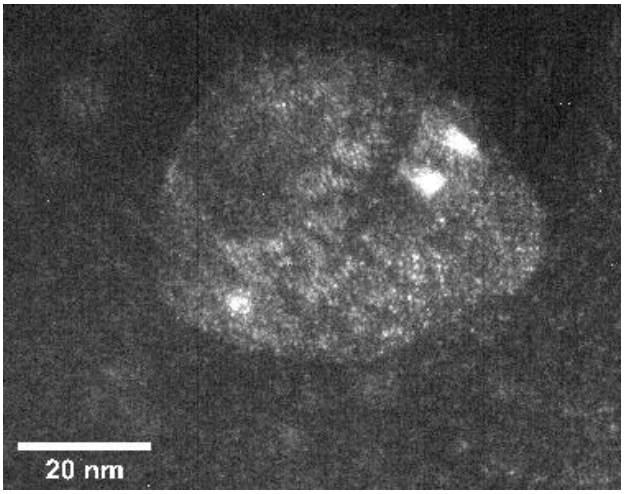

Figure 1. Dark-field TEM image of oxide nanoparticle in KP4 alloy irradiated with 1.5×10^{15} cm^{-2} Xe ions

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Applied-Voltage Dependence on Conductometric Track Etching of Poly(vinylidene fluoride) Films

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Our efforts have been focused on ion-track etched membranes of poly(vinylidene fluoride) (PVDF). We have used conductometric analysis to monitor the chemical development of tracks in PVDF. The previous results demonstrated that much milder etching conditions without any oxidant additives in the alkaline etching solution led to the negligibly-slow bulk etching, thereby enabling us to examine precisely pore growth during the etching of the damage zone [1,2]. This study deals with the effect of the transmembrane potential applied during the conductometry in order to offer a higher degree of freedom to control the pore size.

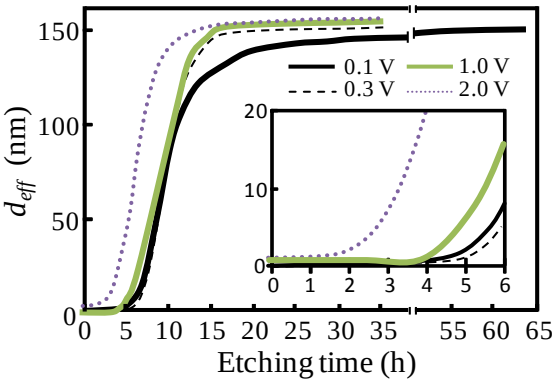

Figure 1. Plot of the d_{eff} value as a function of etching time. Inset: an initial stage of etching for comparing the breakthrough time.

A PVDF film with the thickness of 25 μm was irradiated with 450 MeV ^{129}Xe ions at a fixed fluence of 3×10^7 ions/cm^2. The chemical etching was then performed in a 9 mol dm^{-3} KOH aqueous solution at 80°C in a conductometric cell. A 1 kHz AC voltage ranging from 0.1 to 2.0 V was applied between the Pt electrodes of the cell. Assuming cylindrical pores, we calculated the effective pore diameter, d_{eff}, at any given time from the measured conductance.

Figure 1 shows a curve of the d_{eff} value versus etching time. As shown in an inset, the breakthrough time became approximately 2.5 times shorter when the applied voltage increased from 0.1 to 2.0 V. This means that a so-called track-etch rate increased at the same rate as the breakthrough time. Another difference between the curves was seen near the end of the track etching, in other words, just before reaching the final plateau d_{eff} value. Although the final d_{eff} was 150 nm for all the curves, the time for reaching it seemed to depend largely on the applied voltages. This was the shortest (ca. 17 h) at 2.0 V while it became slightly longer at 1.0 and 0.3 V; ultimately, the application of 0.1 V gave by far the longest time up to 64 h. We can say, therefore, that higher voltage application during the conductometry would accelerate the etching in the tracks. The electrophoretic migration of dissolved products occurring out of each pore might be one of the reasons for this enhanced pore evolution and growth.

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Measurements of hardness and free volume change of eutectic and hypoeutectic ZrCuAl bulk glassy alloys after heavy ion irradiation

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It is thought that mechanical properties, such as viscosity, ductility and hardness of bulk metallic glasses have relation with free volume [1-3]. Some groups reported hardness change of bulk glassy alloys by heavy ion and electron irradiations [4-6]. We examined mechanical property and local structure, especially around the free volume, change of eutectic ($Zr_{50}Cu_{40}Al_{10}$) and hypoeutectic ($Zr_{60}Cu_{30}Al_{10}$) bulk glassy alloys by heavy ion irradiation by using micro Vickers hardness, XRD (X-ray diffraction), EXAFS (extended X-ray absorption fine structure) and positron annihilation measurements. Radiation induced softening with no alloy composition dependence after 100, 200 MeV Xe and 5 MeV Al-ion irradiations was observed. Nevertheless, positron annihilation lifetime decreases only in case for $Zr_{50}Cu_{40}Al_{10}$ eutectic alloy after the irradiation.

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Development of One-Accelerator-Dual-Beam System for *in-situ* Observation of Swift Heavy Ion Irradiation Effects on Materials

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We are developing the dual beam system which accelerates two kinds of ion beams simultaneously and successively from one accelerator. The acceleration of dual beam is performed at the 20MV electrostatic tandem accelerator which mounts an ECR ion source in the high-voltage terminal as shown in Fig.1 [1,2]. The multi-charged ions of two or more elements are generated simultaneously from the ECR ion source, so dual beam irradiation is achieved by accelerating the ion with the same charge to mass ratio (for example, $^{132}Xe^{11+}$ and $^{12}C^{+}$). It can make the real time beam analysis possible such as RBS, while a target is irradiated with swift heavy ions.

For the quick change of the accelerating ion beam, the automatic setting program of the optical parameter of accelerator has been developed. The switchover time of an ion beam is possible within a few minutes if the acceleration voltage is almost the same.

This development has been applied to the study on the ion beam mixing caused by the swift heavy ion induced high density electronic excitation [3].

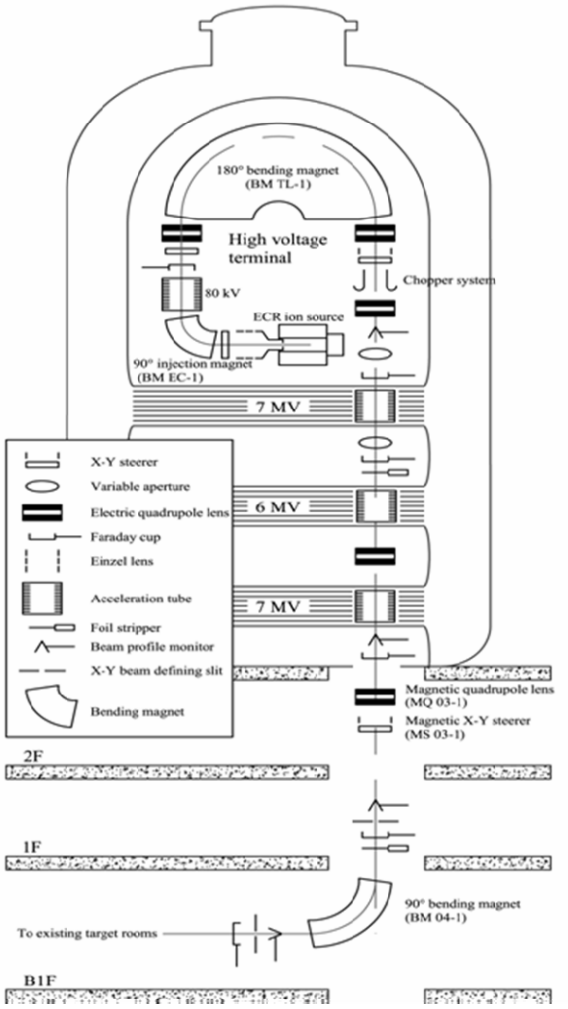

Figure 1. JAEA-Tokai 20MV tandem accelerator. In-terminal ECR ion source is used for single-end acceleration mode.

References

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Characteristics of Fast Ions from Laser-Induced Plasma and their Applicability to Shallow Junction Doping

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In the development of complementary metal-oxide semiconductor (CMOS) fabrication process, low-energy and high-current p-type dopant delivery for the formation of ultra shallow junction (USJ) has been one of the more challenging issues. In this contribution, we propose using massive B⁺ ions produced from laser-induced plasma on a B solid target. Figure 1 shows the experimental setup. The energy distribution of ions is heavily dependent on the laser density which can be adjusted by moving the lens position in front of the laser entrance window. There are some advantages compared with conventional ion implantation. There is no need to decelerate ions of typically a few tens of keV, so that no energy contamination occurs. As the ions are produced directly from a solid target, we do not need to handle harmful semiconductor gases. This work was supported by Grants-in-Aid for Scientific Research (22656023).

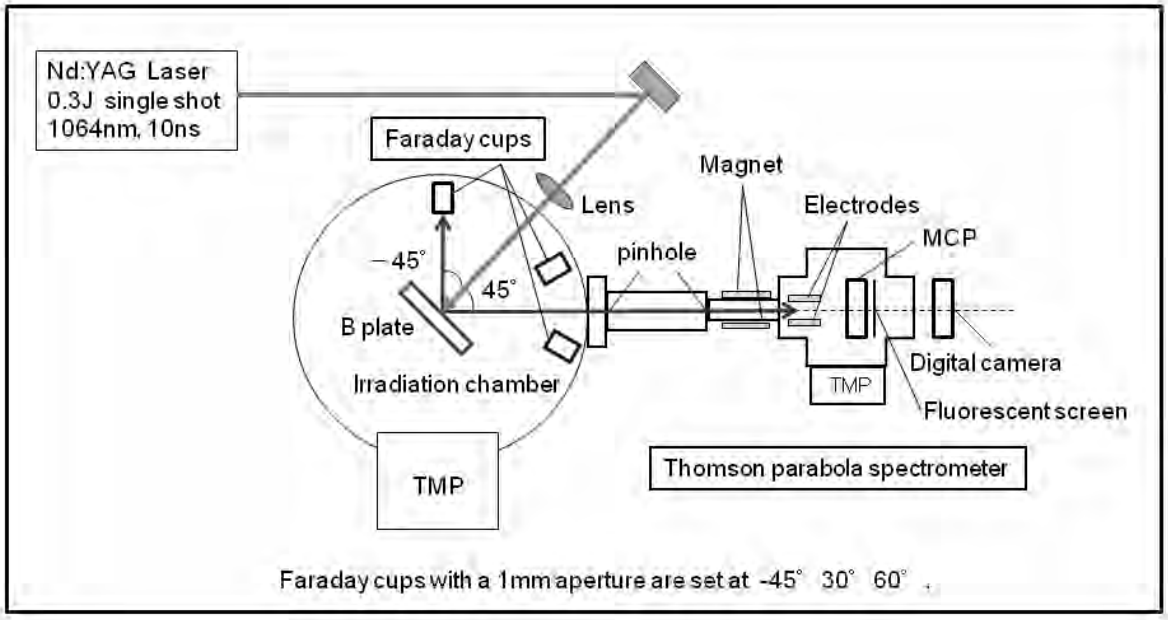

Figure 1. Experimental setup

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Influence of anisotropically splayed columnar defects on angular dependece of critical current density in YBCO thin films

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Columnar defects (CDs) produced by heavy-ion irradiations into high-T_c superconductors such as $YBa_2Cu_3O_y$ (YBCO) are most effective to immobilize flux lines, leading to the enhancement of critical current density J_c. In addition, dispersion (splay) in the CD directions around *c*-axis of can further improve the J_c. In this study, YBCO thin films were irradiated using the 200 MeV Xe ions at two angles $\pm\ \theta_i$ relative to the *c*-axis in two geometries where the Lorentz force is parallel or perpendicular to the splay plane, for the purpose of investigating the influence of the direction of splay plane on the flux pinning properties. A weaker magnetic field dependence of J_c for the Lorentz force perpendicular to the splay plane than that for the Lorentz force parallel to the splay plane was observed below the matching field B_ϕ. For the Lorentz force perpendicular to the splay plane, the J_c tends to be higher below B_ϕ, whereas the *n*-values extracted from linear fits to empirical relation $E \sim J^n$ in the range of $10^{-4} \sim 10^{-3}$ V/m rapidly decrease with increasing magnetic field, especially in case of $\theta_i = 45°$ (see Figure 1). Such inverse correlation between J_c and *n*-values would originated from the expansion of the double kink of flux lines under the quasi-2D pinning centers consisting of splayed columnar defects perpendiculat to the Lorentz force.

*This work was performed under the Common-Use Facility Program of JAEA.

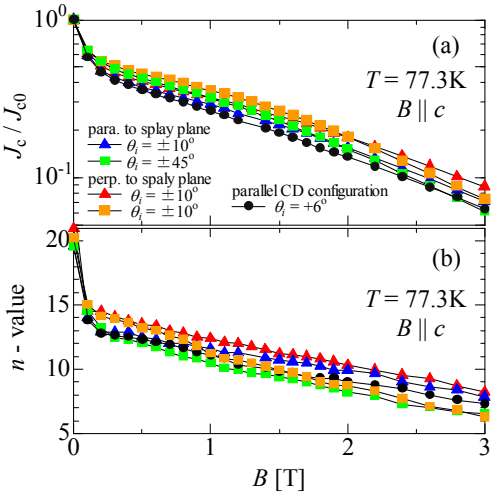

Figure 1. Magnetic field dependence of critical current denisty and *n*-values.

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90 MeV O^{7+} ion irradiation induced modifications in morphology, conformation and charge transport properties of polyaniline nanofiber reinforced nanocomposites

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Polyaniline-nanofiber-reinforced PVA nanocomposites have been synthesized using in-situ rapid mixing polymerization technique and irradiated with 90 MeV O^{7+} ions. It has been observed that upon swift heavy ion (SHI) irradiation the porosity of the nanocomposites decreases and the surface becomes dense and smooth. The irradiation induces enhancement in crystallinity in these nanocomposites. This might be due to cross-linking of PAni nanofibers within the PVA matrix as observed from the X-ray diffraction analysis. FTIR results show that there is no change in the basic polymer structure upon SHI irradiation, although some specific bands such as the C-C stretching band intensifies and the intensity of the band associated with the C-C twisting vibration decreases. This indicates that the polymer undergoes cross-linking upon SHI irradiation since twisting vibrations are generally not observed in cross-linked polymers [1]. The analysis for the evolution of the C=C stretching vibrations corresponding to the benzenoid and the quinoid structures indicates that a partial deformation from the quinoid to the benzenoid structure is induced by SHI irradiation. UV-Visible studies indicate that the density of states in the polaron band, lying deep inside the band-gap of the nanocomposites, increases upon SHI irradiation. The ac conductivity results indicate that although there is an increase in the dc conductivity, the charge transport mechanism follows the correlated barrier hopping (CBH) model. Positron annihilation lifetime spectroscopy (PALS) results reveal that there is a sharp decrease in the shortest and the intermediate lifetime components after irradiation that has been attributed to the perturbation caused by irradiation in the intermolecular forces in the vicinity of the ion track. This perturbation may lead to the formation of local negatively charged regions that localize positrons [2]. The decrease in the positron lifetimes upon SHI irradiation suggests an increase in the π-electron density in the nanocomposites leading to an enhancement in conductivity of the nanocomposites.

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Charge State Distribution of 1 MeV/u Tungsten Ions after Penetration of Carbon Foils

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In recent progressive development over a wide range of science and technology, detailed studies of atomic charge-changing collision processes involving “very” heavy particles are urgently required. Tungsten is one of such elements, particularly in the field of thermo-nuclear fusion research, being proposed as plasma-facing materials in the next experimental fusion reactor. On the contrary to its desirable features, studies of atomic charge-changing collision processes for ions of tungsten are still very limited [1,2]. We present charge state distribution of 184 MeV (1.0 MeV/u) W ions after penetrating C-foils, where strong density effects are expected, measured using the same apparatus for a presentation in the joint ICACS–25 [3] as a preliminary result for our plan for both gas and solid target collisions involving very heavy ions of tungsten.

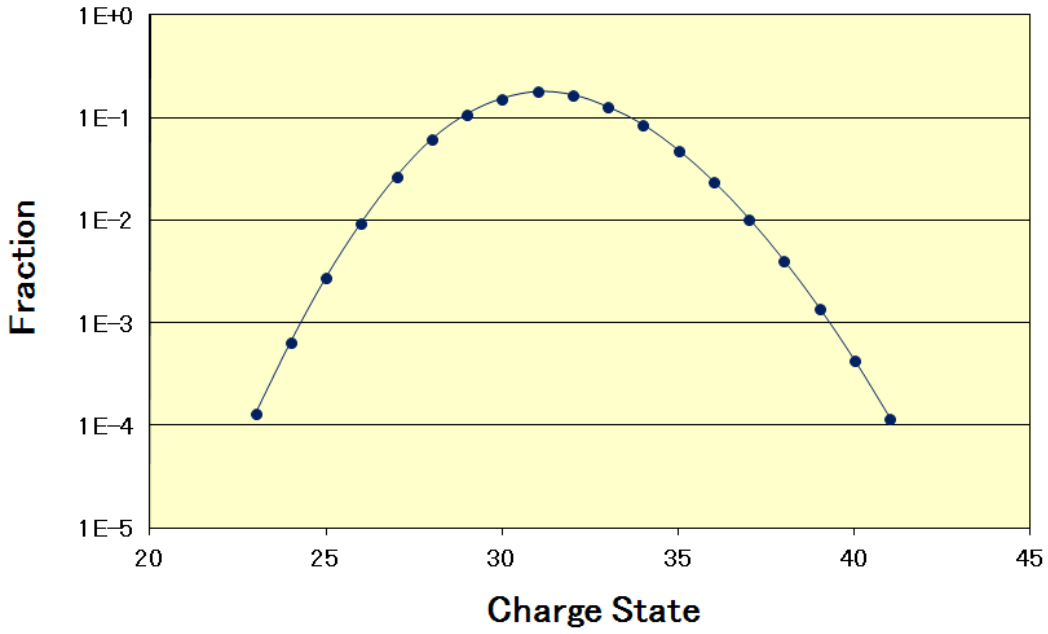

Figure 1. Charge state distribution for 1.0 MeV/u W^{30+} ion after penetrating a 9.9 μg/cm^2 C-foil.

References

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Microstructure evolution of UO_2 under irradiation with high energy fission products

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In order to understand the formation mechanism of microstructure evolution of high burnup LWR fuels such as high burnup structure (HBS), accumulation processes of radiation damages under overlapping of ion tracks, that is formed by high density electronic energy deposition of high energy fission products, should be clarified[1,2]. The objectives of the present study are to understand the diameter of ion tracks in UO_2 at room temperature, and the microstructure evolution in UO_2 under irradiation with high energy fission products.

Natural UO_2 disc samples whose density was around 96.7% were used in this study. Ion irradiation examinations have been done at JAEA-Tokai Tandem accelerator facility, which installed an ECR ion source. Microstructure evolutions were observed by use of a 300kV FE-TEM and a FE-SEM at CRIEPI. Cross sectional TEM samples are fabricated by FIB methods.

The diameter of ion tracks in UO_2 under irradiation with 100-210 MeV Xe^{+15-29}, 100 MeV Zr^{+15}, and 150-320 MeV Au^{+29} ions at room temperature were observed. Because the diameter of ion tracks under irradiation with 100 MeV Xe^{+25} and Zr^{+15} are 2.0 and 1.8 nm respectively, it suggests that the diameter of ion tracks by high energy fission products (70-100 MeV) will be ~ 2 nm.

For understanding the microstructure evolution in UO_2, 210 MeV Xe^{+16} ions irradiation up to a fluence of 2.7 x 10^{16} ions/cm^2 were done. Irradiation surface observations by SEM clarify that the areal density of pores on the surfaces tend to increase up to 5x10^{14} ions/cm^2 (overlapping num. of tracks: ~10^2), and decrease as increasing a fluence over 5x10^{14} ions/cm^2. The size of pores tends to increase up to 5x10^{15} ions/cm^2 (overlapping num. of tracks: ~10^3), and decrease as increasing a fluence over 5x10^{15} ions/cm^2. Inner morphology of UO_2 by TEM observations show that the elliptical changes of fabricated pores and the formation of dislocations are started at a fluence of 5x10^{14} ions/cm^2, and the grain sub-divisions are observed and the dislocation density does not tend to increase over 1 x 10^{16} ions/cm^2 (overlapping num. of tracks: ~ 2x10^3). These drastic changes in UO_2 indicate that the overlapping of ion tracks will cause the point defects, enhance the diffusion of point defects and dislocations, and form the sub-grains at relatively low temperature.

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Defect structure of CeO_2 by high-energy heavy ion irradiation

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The observation of beam track for high-energy heavy ions produced in the CeO_2 films was made with an electron microscope in order to clarify the governing factors and mechanisms for beam track formation. CeO_2 film was irradiated with 200 MeV $Au^{14+,}$ 290 MeV $Au^{27+}$and 340 MeV Au^{25+} ions with a fluence of 1.0 x 10^{11} ions/cm^2 at room temperature, using a Tandem accelerator in JAEA. Fig. 1 shows TEM image of CeO_2 irradiated with 200 MeV Au^{14+} ions to a fluence of 1 x 10^{11} ions/cm^2. Beam tracks are seen with a rectangular shape of ~5 nm in size. Lattice fringes are clearly seen inside the beam tracks, which indicate that fluorite structure is not amorphized by individual beam tracks. It is also note that multiple low angle grain boundaries (white arrow) are formed near the beam track. It is considered that low angle grain boundary was produced for high electronic excitation, and it seems to be induced atomic disorder [1]. Beam track can be produced in due to atomic disorder coming from the energy dissipated in electron energy loss. The relationship between low angle grain boundary and atomic disorder will be discussed through HRTEM.

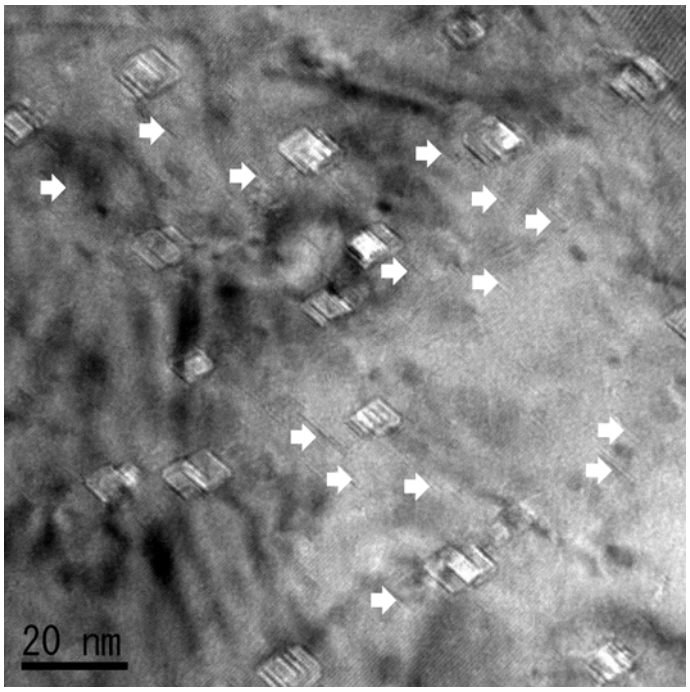

Figure 1. TEM micrograph of a plan view of the columnar defects in CeO_2 films with 200 MeV Au^{14+} ions with a fluence 1 x 10^{11} ions/cm^2.

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Absolute detection efficiency of a high sensitivity microchannel plate

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The detection efficiency of a microchannel plate (MCP) is limited by the open-area-ratio (OAR) because particles are poorly detected if those are not injected into the channel of the MCP. The OAR of a commercial MCP is typically 50~60%. It directly affects multiple-coincidence experiments. In the case of the triple coincidence, the detection efficiency decreases to about 15%. In order to increase the detection efficiency of an MCP, we have fabricated the tapered MCP (T-MCP) which is processed that the entrances of the channels are extended in a tapered shape so that the effective OAR is increased.

We have examined the absolute ion-detection efficiency in single-ion counting mode. The detection efficiency of the chevron-type assembly consist of T-MCP (Hamamatsu Photonics F1217, outside diameter: 49.9 mm, channel diameter: 12 μm, thickness: 0.48 mm, bias angle: 8 degree, OAR: 90%) at the first stage and normal MCP (Hamamatsu Photonics F1217, the same in form except OAR, OAR: 62%) at the second stage has been compared with that of the chevron-type assembly with normal MCPs. The experiment has been carried out with Ne^{q+} and Xe^{q+} (q = 1-3) ions produced with an electron impact ionization in the energy range from 0.5 to 13.5 keV. Details of the experiment setup have been described in ref [1].

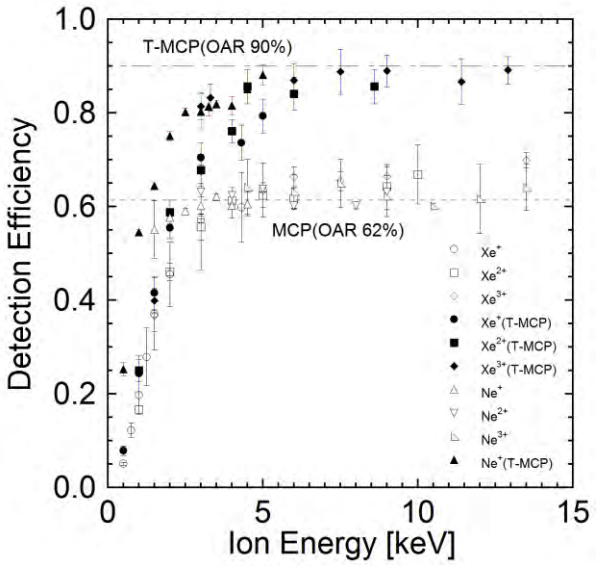

Figure 1. Absolute detection efficiencies of the MCP and the T-MCP. Dashed line and dashed-dotted line are OAR of MCP (62%) and T-MCP (90%), respectively.

Figure 1 shows the absolute detection efficiencies for Ne^{q+} and Xe^{q+} (q = 1-3) as a function of the incident ion energy. In lower energy range, the detection efficiencies increase with an increase in the ion energy. In higher energy range, the detection efficiencies of MCP and T-MCP approach constant values which are 65 and 88%, respectively. The detection efficiencies of T-MCP are close to the effective OAR at higher ion energy and are greater than that of MCP in the energy range between 0.5 and 13.5 keV. The taper processing of an MCP is validated to increase the detection efficiency of an ion.

Reference

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Phase Transformation of $ZnMoO_4$ to ZnO by 100 MeV Ag Irradiation

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Present experiment shows that $ZnMoO_4$ remains in stable phase under thermal annealing up to 1000^{o}C, whereas it looses Mo and transforms to ZnO under transient thermal spike induced by 100MeV Ag irradiation. The transformation is evidenced by X-ray diffraction, Raman spectroscopy, X-ray Photo electron spectroscopy and Rutherford backscattering spectroscopy. Thin films of Mo doped ZnO were synthesized by thermal evaporation and subsequent annealing in oxygen ambient at 600^{o}C for 4h. XRD results show that as the irradiation fluence increases, the peak related to $ZnMoO_4$ decreases and all the peaks eventually disappears at highest fluence. The remaining peaks related to ZnO indicates that polycrystalline $ZnMoO_4$ film has transformed to polycrystalline ZnO thin film. The Raman lines related to $ZnMoO_4$ are observed to have disappeared with increasing irradiation fluence. XPS results show the modification in bonding after the ion irradiation and RBS reveals insignificant presence of the Mo after this transformation but restricted to upto 100 nm from the sample surface. This indicates that transformed ZnO layer on the top acted as barrier for the Mo atoms to further out-diffuse. Cross-sectional TEM result shows the formation of ion track of 12-16 nm in irradiated samples, which confirms the transformation to complete after irradiation fluence between $1x10^{12}$ to $3x10^{12}$ ions/cm^2. These results demonstrate that ion beam methods provide the means to control phase splitting of $ZnMoO_4$ to ZnO and MoO within nanometric dimension along the ion track. The susequent vaporization of MoO leads to two component material in intermediate fluence and total transformation to ZnO after a critical fluence. Results are explained in the framework of ion beam induced thermal spike formalism.

Optical Waveguide Formation in $LiTaO_3$ Single Crystal after Swift Heavy Ion Irradiation

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Lithium tantalite ($LiTaO_3$) single crystal is of intriguing electro-optical, acousto-optical, and nonlinear optical responses that makes it a key material for fabrication of integrated optical devices. Recently, swift heavy ion irradiation has emerged as a powerful method to modulate the refractive index of optical materials and to form waveguides. In such processes, high-energy (energies larger than 1 MeV/amu) heavy ions are incident into the optical materials to modify the near-surface properties of the substrates. In the present work, we paid more attention on the modification of nonlinear optical responses of $LiTaO_3$ after energetic ion irradiation, especially the formation of waveguide.

In experiments, optically polished z-cut $LiTaO_3$ single crystal wafers with the size of $10\times10\times1mm^3$ were implanted at room temperature by 30.0, 375 and 1980 MeV Kr ions, respectively. The different fluence ranges from 1×10^{11} to 1×10^{13} Kr/cm^2. The modal profile of the waveguide was measured at wavelength of 632.8 nm through a conventional end-face coupling system, using a He-Ne laser. The obtained profile (near-field intensity distribution of the light from the exit face of the waveguide) showed that planar waveguides were formed in $LiTaO_3$ crystals by using 375 and 1980 MeV Kr ions. The reflectivity calculation method was used to reconstruct the refractive index profile in the waveguide. The end-face Raman spectra showed that only at the end of ion track the lattice structure changed significantly in the wide guide layer, which may indicate that barrier-confined waveguides were formed in $LiTaO_3$ samples. The mechanism of waveguide formation in $LiTaO_3$ single crystal after ion irradiation was discussed briefly.

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Development of MeV SIMS setup at RBI's Heavy ion microbeam facility in Zagreb

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Heavy ion microbeam facility at Laboratory for Ion Beam Interactions of "Ruđer Bošković" Instiute, Zagreb, has recently been upgraded with TOF MeV SIMS setup, thus enabling molecular imaging of organic samples using focused swift heavy ion beams. TOF telescope for MeV SIMS setup has been designed and made at Kyoto University, Japan. Design of TOF MeV SIMS setup is shown, including upgrades of the Heavy ion microbeam facility necessary for MeV SIMS experiments. The negative secondary ion molecular spectra (using continuous ion beam and electrons for start signal), as well as positive secondary ion molecular spectra (using beam bunching) are given. Using of post-accelerator foil stripper for production of highly-charged ions and their application in MeV SIMS is discussed.

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Ion-Track Membranes of Fluoropolymers: Toward Controlling the Pore Size and Shape

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Ion-track membranes of poly(vinylidene fluoride) (PVDF), a type of fluoropolymer, could find wide applications due to its superior chemical and mechanical properties. In order to produce track-etched pores in PVDF films, a highly-concentrated alkaline solution with a strong oxidizing agent (e.g., $KMnO_4$) has mostly been used at a high temperature, yet this provides irreversible chemical damage over the entire film including the non-irradiated part. Thus, we have independently employed much milder etching conditions without any oxidant additives in the alkaline etching solution [1]. The goal of this work is to pursue the possiblity of varying beam parameters and applying the effect of the etching pretreatment to control the pore size and shape.

Commercially-available PVDF films of thickness 25 μm were irradiated at room temperature with swift heavy ions from the TIARA cyclotron of JAEA and the UNILAC linear accelerator of GSI. The ion fluence was fixed at 3×10^7 ions/cm^2. The irradiated film was then etched in a 9 mol/dm^3 aqueous KOH solution at 80˚C. The membrane surface was observed by scanning electron microscopy. The conductometric analysis was performed for monitoring of pore evolution and growth versus etching time.

Because of the resulting negligibly-low bulk etch rate, the pore diameter reached the plateau finally, and we were able to recognize the etching of the damage zone in order to very easily estimate its size. It is interesting to note that this plateau diameter, d_{final}, would therefore depend solely on the dose distribution in each track. Based on the fact that irradiation with a higher-LET beam gave larger d_{final}, the LET can be the most crucial factor determining the pore size. The pretreatment effect involved an oxidation of the chemical species within the latent tracks, which accelerated the chemical dissolution for efficient pore evolution. Figure 1 shows the conductometry results for the PVDF films irradiated with 450 MeV ^{129}Xe ions. This clearly demonstrates that the pretreatment with a gaseous oxidant shortened the breakthrough time. Ongoing in-situ/on-line analyses at the M-branch of the UNILAC would shed light on the detailed chemistry of not only ion-induced degradation but also the post-irradiation reactivity.

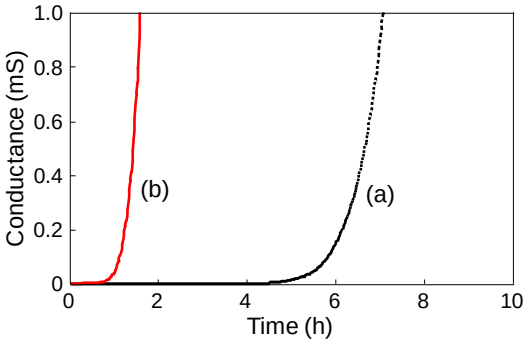

Figure 1. Measured conductance vs. etching time for the PVDF films irradiated with 450 MeV ^{129}Xe and then (a) untreated or (b) treated with ozone gas before the etching.

Reference

[1] T. Yamaki et al., ECS Trans. 35 (2011) 1-12.

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Secondary Electron Emission from Water Vapor by 6.0-MeV/u C^{6+} Ion Impact: Cross-Section Data and Their Application to Radiobiological Investigations

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We present absolute doubly differential cross sections (DDCSs) of electron emission (1 eV~10 keV and 20~160°) in collisions of 6.0 MeV/u C^{6+} ions with water vapor. The angular distributions of DDCSs disagreed with the CDW-EIS theoretical calculations at the backward angles (>100°), while singly differential cross section (SDCS) agreed well with the CDW-EIS, particularly in the low-energy region (<200 eV). Also, we developed an event by event Monte Carlo track structure simulation code for 6.0 MeV/u C^{6+} ions in water, in which primary interactions including elastic scattering, ionization, excitations were taken into account and the tracks of ejected secondary electrons were generated using the electron track code KURBUC. Comparisons of radial dose distributions, deduced form the ion track simulation, with the Chatterjee model showed meaningful and significant discrepancies in the core region, implying the necessity of corrections of the model.

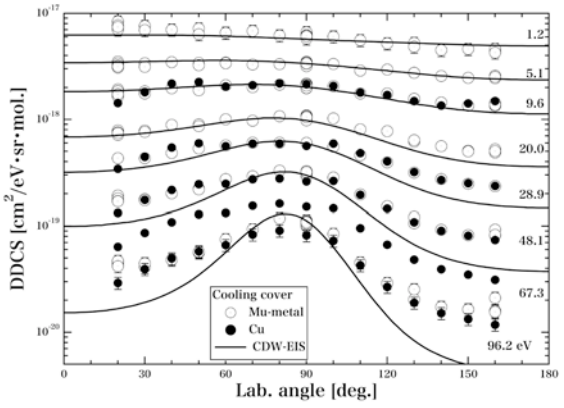

Figure 1. Comparison of the angular distributions of DDCSs at several electron energies of 1~100 eV with the CDW-EIS theoretical calculations.

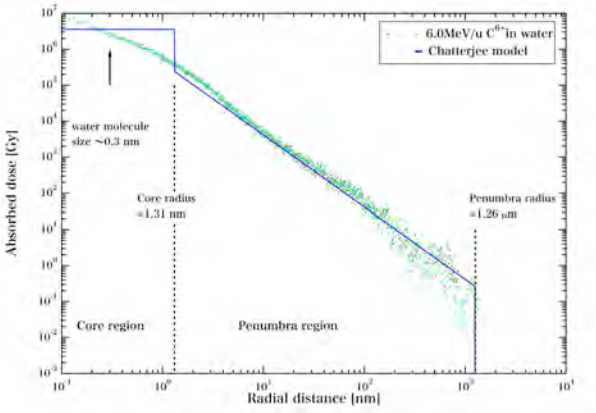

Figure 2. Comparison of radial dose distributions around 6.0 MeV/u C^{6+} ion tracks in water with the Chatterjee model.

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Effect of ion irradiation on the thermal stability of thin polymer films

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Polymer molecules in thin layers are often in an unfavorable coil conformation, as compared to bulk conditions and may present a decreased stability upon mild thermal treatments, leading to roughening or dewetting of the layers. In this work, we have investigated the stability of poly(methyl methacrylate) films, exposed to a low fluence irradiation, against annealing under different atmospheres (air, N_2 and vacuum). 300 keV H^+, 2 MeV H^+ and 18 MeV Au^{7+} ions were used to bombard the samples, using various fluences, depending on the ion species and energy. The films (2 to 50 nm thick) were spun onto Si wafers with a layer of native oxide. For samples annealed in air or N_2 atmosphere, annealing was performed *ex-situ* at 100°C for up to 24h. The annealings in vacuum were performed *in-situ* immediately after the irradiation without breaking the vacuum. The films subjected to thermal treatments, without any irradiation showed an increased roughness; the effect being more pronounced for samples annealed under vacuum. The effect of the irradiation only on samples bombarded at room temperature was to slightly increase the surface roughness with increasing fluence, thus favoring the dewetting process. This was observed for both H^+ and Au^{7+} irradiations. However, for samples bombarded with H^+ and annealed in vacuum at 100°C, the radiation effect was to slow down markedly the roughness increase, stabilizing the film. This effect was not observed for samples irradiated with the 18 MeV Au beam at high temperature. Such differences in behavior are tentatively attributed to the type of damage or modification introduced by each beam. The more diluted electron shower introduced by the H^+ beam apparently favors crosslinking and entanglements of the chains, improving thermal stability, whilst damage and degradation is the dominant effect for the Au^{7+} beam.

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Annealing behavior of thermal diffusivity in ceramics irradiated by 30MeV electron

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In developing of future fusion reactors and other nuclear applications, ceramics are the key materials to survive severe irradiation environment. It has been reported that neutron-irradiated ceramics showed significant degradation in thermal diffusivity [1]. Thermal diffusivity after irradiations which depend on the irradiation conditions have been studied partly, on the other hand, the thermal diffusivity during the irradiation is still not estimated.

The thermal diffusivity at the irradiation temperature is evaluated from the dependence of thermal diffusivity on measurement temperature, and it can be considered to represent the thermal diffusivity during irradiation with several assumptions [2]. An important assumption is the amount of transient defect that exist very short time during the irradiation is enough small. This assumption is now studied using positron annihilation measurement [3], and that almost verify the assumption. But now another assumption is required to obtain the thermal diffusivity during the irradiation, that is, the irradiation temperature is constant. It means that at a same heat load, a temperature of a specimen is calculated from the thermal conductivity, but at irradiation condition, thermal conductivity of specimen decreased, and that rise the temperature of the specimen. The increasing temperature anneals the irradiation induced defects, and that put back the thermal conductivity. At last, the thermal conductivity and the temperature of specimen is not obtained simply, but obtained by kinetic analysis using activation energy of defects and the irradiation flux.

However, heavily neutron irradiated ceramics contains many type of defects, and behavior of such defects is complicated and not clarified well. Accordingly, in this work, 30MeV electron accelerator, KURRI-Linac, is used to induce only point-defects in bulk ceramic materials. The specimens are φ10x0.5mm α-Al2O3, AlN, β-Si3N4 and β-SiC ceramics, and they were electron-irradiated to 0.01dpa at 310K. After the irradiation, the thermal diffusivity is measured at room temperature. Then, isochronal annealing was performed, and the recovery behavior in thermal diffusivity was studied. The recovery behavior was compared with that of neutron irradiated specimen. That represented the difference in distribution of defects between electron and neutron irradiated specimens.

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Time-resolved Analysis of Reactions in Waster by Heavy Ion. - $Br_2^{\bullet-}$ Formation Yield in NaBr Aqueous Solution-

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Heavy ion beams have specific irradiation effects different from those of low LET radiations. The effects are attributed to heterogeneous distributions, diffusion and chemical reactions of transient species produced along ions' trajectories. Water, in which radiation induced reactions are well-known by low LET radiations, was used to understand the specific effects. Hydroxyl radical ($^{\bullet}$OH) is one of the most important water decomposition radical. Bromide ion was selected as a probe reagent of $^{\bullet}$OH, and produced reaction intermediate, $Br_2^{\bullet-}$, was observed by a time resolved spectroscopic method [1]. 100 mM NaBr aqueous solution was irradiated with pulsed ions. H^+ (20 MeV/u) and C^{5+} (18.3 MeV/u) ions were used and their energies were decreased by inserting Al films of various thicknesses at the upstream of the samples. The formation and decomposition of $Br_2^{\bullet-}$ were recorded at 375 nm (ε [$Br_2^{\bullet-}$] = 9000 $M^{-1}cm^{-1}$) as shown in Figure 1. It is reasonable that faster decay of $Br_2^{\bullet-}$ by C^{5+} ion should be derived from densely generated $^{\bullet}$OH since $Br_2^{\bullet-}$ disappears mainly bimolecular reaction which depends on the concentration of $Br_2^{\bullet-}$. The formation yield (*G*-value: species/100eV) of $Br_2^{\bullet-}$ was estimated from the peak value of the absorbance, and decreased with decreasing incident energy and increasing atomic number of the ions as shown in Figure 2. These results shows the same tendency of the ion species and energy dependence of OH yields estimated from theoretical calculation [2], the values are lower than that of $^{\bullet}$OH. This difference attribute to the reaction behavior of Br^- and $^{\bullet}$OH and its subsequent reactions. Theoretical analysis based on the reaction kinetics is in progress.

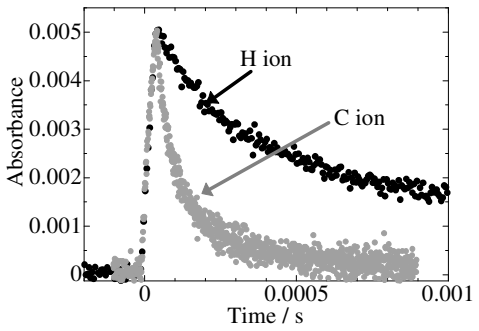

Figure 1. Time profile of normalized light absorbances of $Br_2^{\bullet-}$ at 375 nm irradiated with H^+ (16.3 MeV/u) and C^{5+} (15.8 MeV/u) ions.

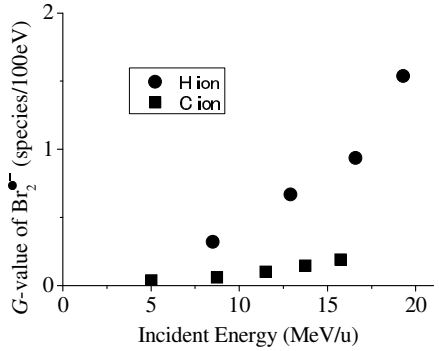

Figure 2. Incident energy effect on $Br_2^{\bullet-}$ formation yield in NaBr aqueous solutions irradiated with H^+ and C^{5+} ions.

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Thermoluminescent response of Nanocrystalline $BaSO_4$:Eu to 85 MeV Carbon Beams

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Nanotechnology and nanomaterials have attracted researchers from different fields [1], especially from the field of luminescence. Recent studies on various luminescent nanomaterials have shown their relevance in dosimetry of ionizing radiations for the measurements of high doses using the Thermoluminescence (TL) technique, where the conventional microcrystalline phosphors saturate [2–4]. Ion beams have been used for diagnostic and therapeutic purposes [7,8] due to their favorable profile of dose deposition at the end of the range known as the Bragg peak. While dealing with human beings, doses from these beams need to be measured with great precision and accuracy. Henceforth detailed investigations of suitable thermoluminescent dosimeters (TLD) for dose verification in ion beam irradiation are required. This paper investigates the TL response of nanocrystalline $BaSO_4$ doped with Eu to 85 MeV carbon beam. Synthesis was done using Co-precipitation technique by mixing Barium chloride and ammonium sulphate solutions. To investigate the crystallinity and particle size, analytical techniques such as X-ray diffraction (XRD) and Transmission electron microscopy (TEM) were used which revealed the average particle sizes to 45 nm with orthorhombic structure. Samples in pellet form were irradiated by 85 MeV carbon beam in the fluence range of $1x10^{10}$-$5x10^{13}$. TL glow curves of the irradiated samples shows two prominent glow peaks at around 460 K and 495 K. The TL response is linear upto 1 $x10^{13}$ fluence after which saturation was observed. The wider linear TL response of nanocrystalline $BaSO_4$: Eu and low fading makes it a superior candidate as a dosimeter to be used for detecting the doses of carbon beams.

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WITHDRAWN

On-Line Diffusion Experiments by Implanting Radiotracer Beam of ^{8}Li

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We have developed a radiotracer method for diffusion studies in solid, by using, as the tracer, the short-lived α-emitting radioisotope of ^{8}Li. In the method, we implanted the beam of ^{8}Li of about 4MeV into a depth, where most α-particles stop in the sample. After implantation, the primary implantation profile is broadening with time by diffusion and then the α-particles emitted by ^{8}Li diffused toward the surface can survive and come out of sample with measurable energies. Then a charged particle detector, located close to the sample surface, could selectively detect α-particles from ^{8}Li diffusing toward the sample surface, since the implantation-depth is deeper than the average range of α-particles in the present case. Therefore, the temporal evolution of alpha particle yields that come out of the sample is supposed to be a measure of the diffusivity of Li [1]. The method has been successfully applied to measure the lithium diffusion coefficients in a typical defect-mediated lithium ionic conductor of LiGa [2], well demonstrating that the method is very efficient to measure the diffusion in the micro-meter regime per second. Further development, as an extension of the present method, is proposed to measure the diffusion on the nanoscale in lithium ionic conductors.

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WITHDRAWN

Nanocrystalline Phosphor $Ba_{0.12}Sr_{0.88}SO_4$:Eu for Ion Beam Dosimetry

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Nanoparticles of $Ba_{0.12}Sr_{0.88}SO_4$:Eu has been irradiated by Li^{4+}, C^{6+} ion beams with a fluence range of $1x10^{10}$–$5x10^{13}$ ion/cm^2. The thermoluminescence (TL) glow curves along with the response curves of this nanophosphor have been investigated and compared with those of the corresponding microcrystalline samples. TL glow curve of the nanophosphor exposed to γ-rays has also been included in the letter with the aim of reporting some of the comparative measurements. The glow curves of the ion-beam irradiated nanomaterials are similar in their shapes to those induced by gamma rays, with a small shift in the peak positions. The TL intensity of the ion-beam irradiated nanomaterials is found to decrease, while going from low to high atomic number Z ions i.e., $Li^{4+}\rightarrow C^{6+}$. Similar trend was also observed in the linearity of the TL response curves. The response curve of Li ion irradiated nanomaterials is sublinear in the whole range of studied fluences. C ion has also a more or less similar response. These results for the nanomaterials are much better than that of the corresponding microcrystalline sample irradiated by Li^{3+} ions in comparison of other sulphates. The curve was sublinear up to the fluence $5x10^{13}$ ion/cm^2 and then saturates at higher fluences. The wider sublinear TL response of the nanocrystalline $Ba_{0.12}Sr_{0.88}SO_4$:Eu makes it superior to its corresponding microform and thus makes it a suitable candidate as a dosimeter to be used for detecting the doses of ions, especially the Li and C ions for their application in cancer radiotherapy and radiation biology.

Diamond-Like Carbon Sputtering by Laser Produced Xe Plasma

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The diamond-like carbon sputtering was investigated, which was occurred by Xe ions from the laser plasma X-ray (LPX) source. A LPX, using radiation from high-energy-density plasma of a target produced by laser, is expected for use in industrial applications. We have developed a LPX by using solid Xe target and it demonstrated a high average power of 20W in wavelength from 5 to 17nm [1]. Generally, plasma emits debris consisting of ions, neutrals, fragments, vapor etc. of a target, with X-ray simultaneously, and they damage mirrors near the plasma, quickly degrading their reflectivity. In our LPX, Xe ions, which were major of the plasma debris [2], sputtered the mirror and we needed sputtering resistant mirror. Carbon data previously measured by Kolasinski et al. [3] showed that the carbon was difficult to sputter comparing to Ru and Au that are generally used as mirror material. Then, we measured sputtering rate of the DLC, Ru, and Au mirror by using a quartz crystal microbalance (QCM). Our results indicated that the DLC sputtering rate for normal incident ions was one order higher than the previous data. We consider that it was a characteristic effect in a laser plasma and due to a synergy effect of the ion bombardments and UV~X-ray radiation from the Xe plasma.

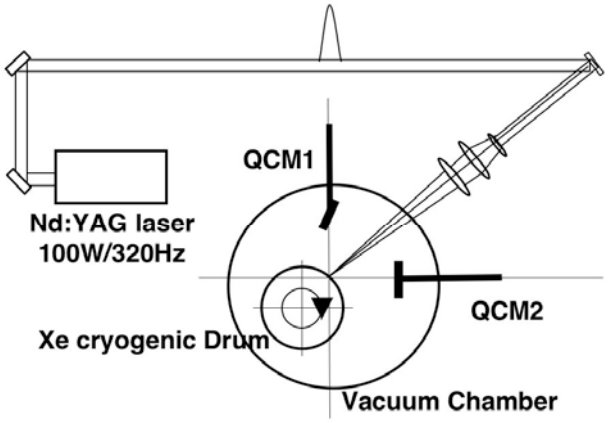

Figure 1. Experimental setup. The QCM1 and 2 sensor was tilted at 20° and 90° angle with respect to the incident ion beam, respectively.

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WITHDRAWN

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Synthesis of semiconductor compound nanostructures using ion-track membrane and their characterization

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The aim of the present work is to synthesize of semiconductor compound nanostructures of different shape and size. The tracks were created in the polycarbonate (PC) Makrofol KG foils of thickness 20 μm by using 13.6 MeV/n U^{238} ions having flux of $10^6/cm^2$ followed by subsequent etching. Electrochemical deposition technique has been used for the fabrication of nanostructures of ZnS, ZnSe and Ag_2Se. The structural and morphological properties were investigated using x-ray diffraction (XRD) and scanning electron microscopy respectively. Optical properties of synthesized structures were also studied using Simadzu (1600 Model) UV-visible spectrophotometer.

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