Australian National University

ICACS & SHIM 2024

24 - 29 Nov, 2024 | Canberra, Australia

BOOK OF ABSTRACTS

Welcome Message

Dear Colleagues and Friends,

It is with great pleasure that we welcome you to the 30th International Conference on Atomic Collisions in Solids (ICACS) and 12th International Symposium on Swift Heavy Ions in Matter (SHIM), held at the Research School of Physics, Australian National University in Canberra, Australia.

Since its inception in 1965 in Aarhus, Denmark, ICACS has been dedicated to exploring the intricate interactions between particle beams and condensed matter. Over the years, ICACS has traversed the globe, fostering comprehensive discussions on phenomena induced by a wide array of projectiles, including singly and multiply charged ions, atoms, clusters, photons, electrons, positrons, and antiprotons. Similarly, the SHIM conference series, which started in 1989 in Caen, France, has united researchers working with high-energy heavy ions across diverse disciplines such as radiation effects in solids, atomic physics, plasma physics, radiation biology, medicine, and nanotechnology. With a focus on both basic and applied research, SHIM has been instrumental in bridging theoretical and experimental approaches within these fields.

In 2018, ICACS and SHIM were held jointly for the first time in Caen, France, marking the beginning of a new era of collaborative learning and mutual enrichment for both communities. This successful amalgamation continued in 2022 at the University of Helsinki, Finland, and now brings us together here for the first time in Australia.

The 2024 conference program promises to be an enriching experience, featuring invited lectures alongside oral and poster presentations in a single-track format. We extend our deepest gratitude to all participants, presenters, and sponsors who have contributed to making this conference possible. Your dedication and enthusiasm are the driving forces behind the ongoing success of the ICACS and SHIM conference series.

We hope this gathering will not only advance our collective understanding but also foster new collaborations and lasting friendships.

Once again, welcome to Canberra. We wish you a productive and inspiring conference.

Sincerely,

Prof. Patrick Kluth
Chair, ICACS & SHIM 2024

Dr. Shankar Dutt
Secretary, ICACS & SHIM 2024

ICACS International Scientific Committee

Last Name	First Name	City (Country)
Djurabekova	Flyura	Helsinki (Finland)
Facsko	Stefan	Dresden (Germany)
Grande	Pedro	Porto Alegre (Brazil)
Karaseov	Platon	St. Petersburg (Russia)
Montanari	Claudia	Buenos Aires (Argentina)
Ogawa	Hidemi	Nara (Japan)
Primetzhofer	Daniel	Uppsala (Sweden)
Riccardi	Pierfrancesco	Cosenza (Italy)
Rothard	Hermann	Caen (France)
Schenkel	Thomas	Berkeley (USA)
Trautmann	Christina	Darmstadt (Germany)
Tsuchida	Hidetsugu	Kyoto (Japan)
Tökési	Károly	Debrecen (Hungary)
Wang	Zhiguang	Lanzhou (China)

SHIM International Scientific Committee

Last Name	First Name	City (Country)
Amekura	Hiro	Tsukuba (Japan)
Apel	Pavel	Dubna (Russia)
Avasthi	Devesh	New Dehli (India)
Beuve	Michael	Lyon (France)
Djurabekova	Flyura	Helsinki (Finland)
Ishikawa	Norito	Ibaraki (Japan)
Kluth	Patrick	Canberra (Australia)
Lang	Maik	Knoxville (USA)
Ma	Xinwen	Lanzhou (China)
Medvedev	Nikita	Prague (Czech Republic)
Monnet	Isabelle	Caen (France)
Papaleo	Ricardo	Porto Alegre (Brazil)
Rothard	Hermann	Caen (France)
Severin	Daniel	Darmstadt (Germany)
Trautmann	Christina	Darmstadt (Germany)

Local Committee

Conference Chair

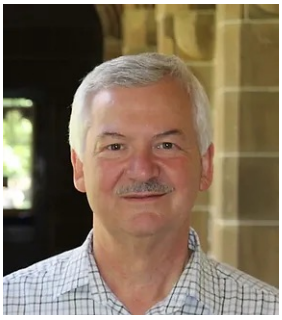
Patrick Kluth
Research School of Physics
Australian National University

Conference Secretary

Shankar Dutt
Research School of Physics
Australian National University

Committee Members

Jodie Bradby



Robert Elliman

Felipe Kremer

Christian Notthoff

Nahid Afrin

Taleb Alwadi

Jessica Wierbik

Hendrik Heimes

Scope

ICACS

- Charge-exchange processes
- Particle excitation and ionization
- Energy loss, scattering and channelling of primary and secondary particles
- Electron, atom, ion and photon emission processes
- Slow highly-charged-ion interactions at surfaces
- Radiation damage and materials modification, including nuclear-energy materials
- High energy density physics with intense ion beams and in relation to plasma physics
- Collision-induced physical, chemical and biological reactions

SHIM

- Interactions of swift heavy ions with gases, liquids, solids and plasma
- Electronic excitation, charge transfer processes, and local energy deposition
- Conversion of electronic excitation energy into atomic motion, and atomic displacements
- Material modifications, ion track formation and modification
- Creation of point defects and defect clusters, sputtering, mixing and recrystallisation
- Materials response in extreme environments
- Chemical and biological radiation effects
- Swift heavy ion-induced processes in organic and inorganic materials
- Radiobiology and tumour therapy with ion beams
- Heavy-ion micro- and nanotechnology
- Effects of swift heavy ions on electronic devices
- Geological, astrophysical and other applications based on high-energy accelerators
- Dynamics of nuclear reactions and investigation of nuclear structure and dark matter

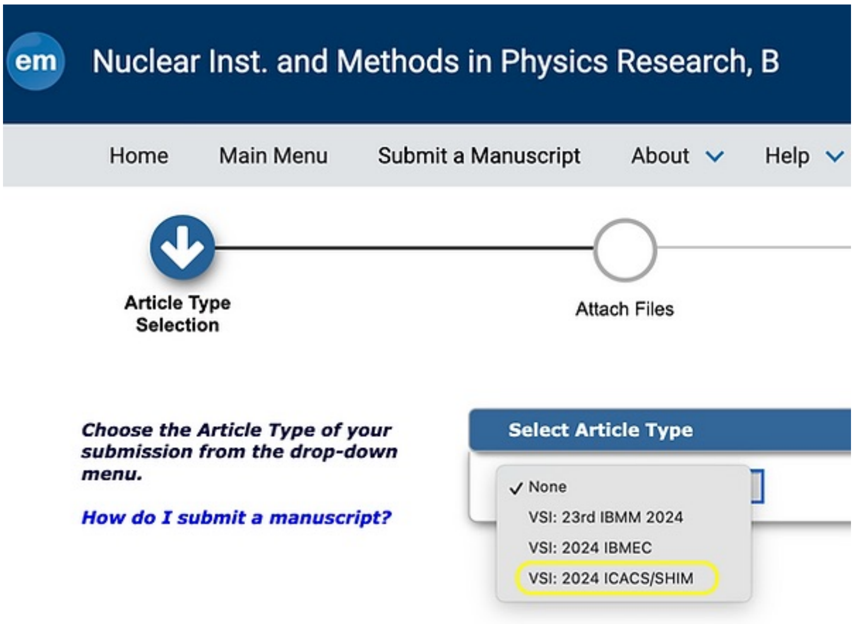
Proceedings

The proceedings of ICACS and SHIM 2024 will be published as a Special Issue in Nuclear Instruments and Methods in Physics Research Section B (NIM B). Manuscripts are submitted to EES through the Special Issue portal and go through a peer review process to the same standard as for regular NIMB articles.

All submitted papers must be clearly written in excellent English and contain only original work, which has not been published by or is currently under review for any other journal or conference. Only manuscripts of contributions presented at the conference will be considered for publication. Invited talks as well as oral and poster contributions will be included in the conference proceedings.

To submit a manuscript of the REI-21 conference proceedings, please, use the link: `https://www.editorialmanager.com/nimb_proceedings/default2.aspx`

After login, choose the Special Issue "VSI: 2024 ICACS/SHIM" from the drop down and then proceed accordingly.



A detailed submission guideline is available as "Guide for Authors" at: `http://www.elsevier.com/locate/issn/0168583X`

Deadline for submission of proceedings is extended to 28 Feb 2025. We strongly encourage you to submit the manuscript!

Code of Conduct

By registering for and attending ICACS-SHIM 2024, you agree to conduct yourself in a professional manner and follow the code of conduct below.

1. **Respect and Inclusivity:** Our conference values the diversity of participants and encourages inclusive dialogue. Discrimination or harassment of any kind, including but not limited to race, religion, age, gender, disability, nationality, or sexual orientation, is strictly prohibited.
2. **Professional Conduct:** All participants should maintain a high level of professionalism throughout the conference. Disruptive or inappropriate behaviour, including offensive language or imagery, is not permitted.
3. **Constructive Dialogue:** We encourage constructive, respectful dialogue and debate. Personal attacks or belittling comments about people's work or ideas are not acceptable.
4. **Intellectual Property:** Respect the intellectual property rights of all participants. Do not use someone else's work without proper credit, and respect confidentiality requests by speakers and attendees.
5. **Privacy:** Do not share private information about other participants without their explicit consent. This includes taking or distributing pictures, videos, or audio recordings.
6. **Reporting Violations:** Participants are encouraged to report any violation of the Code of Conduct to conference organizers. We commit to investigate all reports and take appropriate action.

Failure to comply with this Code of Conduct may result in removal from the conference without refund, and the individual may be barred from future events.

This Code of Conduct is not exhaustive or complete. It serves to set a general standard for participant behaviour. We expect everyone attending the conference to create a safe, positive, inclusive, and welcoming environment.

Conference Schedule

24th November, 2024

16:00 - 18:00 Welcome Reception and Registration

25th November, 2024

08:00 onwards Registration

09:00 - 09:20 **Conference Opening**

Session Chair : Flyura Djurabekova

09:20 - 09:50 **Invited Talk - 1**
Friedrich Aumayr
TU Wien (Vienna University of Technology), Austria
Surface erosion under ion bombardment: Case studies in space weathering and nuclear fusion research

09:50 - 10:10 **Contributed Talk - 1**
Jacques O'Connel
Nelson Mandela University, Port Elizabeth, South Africa
The influence of the near surface environment on hillock formation

10:10 - 10:30 **Contributed Talk - 2**
Hermann Rothard
Centre de Recherche sur les Ions, les Matériaux et la Photonique, Normandie Univ, ENSICAEN, UNICAEN, CEA, CNRS, CIMAP, 14000 CAEN, France
Swift ion irradiation and complex organic molecules in cold space environments

10:30 - 11:00 **Morning Tea**

Session Chair : Rob Elliman

11:00 - 11:30 **Invited Talk - 2**

Raquel Giulian

Federal University of Rio Grande do Sul, Brazil

Antimonide Nanofoams Induced by Ion Irradiation

11:30 - 11:50 **Contributed Talk - 3**

Taleb Alwadi

Australian National University, Canberra, Australia

Ion track formation and porosity in InSb and GaSb after swift heavy ion irradiation

11:50 - 12:10 **Contributed Talk - 4**

Mamour Sall

CIMAP, Caen, France

Towards efficient green light emission by swift heavy ion irradiated-InGaN/GaN multi-quantum wells

12:10 - 12:30 **Contributed Talk - 5**

Lilong Pang

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

Study on the ion irradiation effect of nano-structural TiAlN coating

12:30 - 13:30 **Lunch**

Session Chair : Hermann Rothard

13:30 - 14:00 **Invited Talk - 3**

Hidetsugu Tsuchida

Quantum Science and Engineering Center, Kyoto University, Japan

Observing the damage to biomolecules induced by ion beams in liquid jets

14:00 - 14:20 **Contributed Talk - 6**

Naruki Uno

Quantum Science and Engineering Center, Kyoto University, Japan

Impact of swift cluster ion irradiation on the process of decomposing nucleotide biomolecules

14:20 - 14:40 **Contributed Talk - 7**

Manoj Kumar

M.M.H. College, Ghaziabad-201001, India

Electron impact scattering studies for C_6H_6

14:40 - 15:00 **Contributed Talk - 8**

Jacob Cook

Binar Space Program, Curtin University, Perth, Australia

Simulated cislunar radiation effects on wide bandgap semiconductor based smallsat power module

15:00 - 15:30 **Afternoon Tea**

Session Chair : Christina Trautmann

15:30 - 16:00 **Invited Talk - 4**

Jie Liu

Institute of Modern Physics, Chinese Academy of Sciences, China

Effects of swift heavy ions on wide band-gap materials and devices

16:00 - 16:20 **Contributed Talk - 9**

Christopher Schroeck

GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany

Swift heavy ion irradiation for high-pressure investigations on bismuth nanowire networks

16:20 - 16:40 **Contributed Talk - 10**

Nahid Afrin

Department of Materials Physics, Research School of Physics, Australian National University, Canberra, Australia

Charge-based molecular separation using track-etched silicon dioxide nanopore membranes

16:40 - 17:00 **Contributed Talk - 11**

Mohan Lee

Materials Research Department, GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany

3D gold nanowire networks with tailorable surface wettability engineered through ion-track nanotechnology

26th November, 2024

Session Chair : Hidetsugu Tsuchida

09:00 - 09:30 **Invited Talk - 5**

Tapobrata Som

Institute of Physics, Bhubaneswar, India. Homi Bhabha National Institute, Mumbai, India

Ion induced self-organized pattern formation: Amazing possibilities

09:30 - 09:50 **Contributed Talk - 12**

Pablo Mota Santiago

Australian Synchrotron - ANSTO, Melbourne, Australia. Lund University, Lund, Sweden

3D mapping of nanoscale density fluctuations in swift heavy-ion irradiated materials

09:50 - 10:10 **Contributed Talk - 13**

Jessica Wierbik

Australian National University, Canberra, Australia

The anisotrophy of the ion track cross-section in single-crystalline materials

10:10 - 10:30 **Contributed Talk - 14**

Shyamal Chatterjee

IIT Bhubaneswar, Jatni, India

Ion beam engineering of nanostructures for augmented effects in sensing and energy storage

10:30 - 11:00 **Morning Tea**

Session Chair : Fridrich Aumayr

11:00 - 11:30 **Invited Talk - 6**

Eleni Ntemou

Uppsala University, Sweden

Dynamic processes in ion-matter interaction: electronic excitation and charge exchange below the Bohr velocity

11:30 - 11:50 **Contributed Talk - 15**

Masedi Carington Masekane

Institut Ruđer Bošković, Zagreb, Croatia

X-ray production by heavy ion-atom collision symmetries for Total Ion Beam Analysis

11:50 - 12:10 **Contributed Talk - 16**

Daniel Primetzhofer

Uppsala University, Uppsala, Sweden

Electronic excitations at very low ion energies: experimental challenges

12:10 - 12:30 **Contributed Talk - 17**

Pedro Grande

Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil

Stopping power from Bohmian Mechanics

12:30 - 13:30 **Lunch**

Session Chair : Hiroshi Amekura

13:30 - 14:00 **Invited Talk - 7**

Miguel Sequeira

Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany

Exploring Radiation Hardness in Group-III Nitrides: From Fundamentals to Applications

14:00 - 14:20 **Contributed Talk - 18**

Rajdeep Kaur

Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Exploring ion beam-induced modifications of the resistive switching in metal oxide films

14:20 - 14:40 **Contributed Talk - 19**

Masanori Koshimizu

Shizuoka University, Hamamatsu, Japan

Thermoluminescence properties of rare-earth-doped $Ca_2B_2O_5$ ceramics after irradiations of heavy charged particles

14:45 - 17:00	**Poster Session & Snacks**
17:00 - 18:00	**International Committee Meeting**
18:00 onwards	**International Committee Dinner**

27th November, 2024

Session Chair : Daniel Primetzhofer

09:00 - 09:30 **Invited Talk - 8**

Louise Goodwin

Center of Research on Ions Materials and Photonics, GANIL, Caen, France

Point defect creation for quantum applications in AlN by SHI irradiation under a finely controlled atmosphere

09:30 - 09:50 **Contributed Talk - 20**

Fshatsion Gessesew

The University of Melbourne, Melbourne, Australia

Exploring phase-transformed V_3Si *superconducting material through rutherford backscattering spectrometry analysis*

09:50 - 10:10 **Contributed Talk - 21**

Jinglai Duan

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

Ion track technology-based mechanical metamaterials

10:10 - 10:30 **Contributed Talk - 22**

Diana Merezhko

Institute of Nuclear Physics, Almaty, Kazakhstan

The effect of high and low dose neutron irradiation on mechanical properties and localization of austenitic stainless steels

10:30 - 11:00 **Morning Tea**

Session Chair : Daniel Severin

11:00 - 11:30 **Invited Talk - 9**

Maik Lang

The University of Tennessee, Knoxville, USA

Characterization of radiation effects in ceramics with spallation neutron probes

11:30 - 11:50 **Contributed Talk - 23**

Paramita Patra

Variable Energy Cyclotron Centre, 1/ AF Bidhannagar, 700064, Kolkata, India

A first-principles study of stacking fault energy in Ni-based alloy: role of alloying elements

11:50 - 12:10 **Contributed Talk - 24**

Sergey Kislitsin

Institute of Nuclear Physics of Ministry of Energy of Republic of Kazakhstan, Almaty, Kazakhstan

Proton irradiation temperature impact on the tungsten structure and properties during post-radiation annealing in the temperature range 873K-1273K

12:10 - 12:30 **Contributed Talk - 25**

Norito Ishikawa

Japan Atomic Energy Agency, Tokai, Japan

Complex Nanostructures Originating from Tracks Created Near the Edge of SiO_2 Quartz Irradiated with Swift Heavy Ions

12:30 - 13:45 **Lunch**

14:00 - 19:00 **Conference Outing**

28th November, 2024

Session Chair : Pedro Grande

09:00 - 09:30 **Invited Talk - 10**

Aleksi Leino

University of Helsinki, Finland

Simulating the formation of functional nanostructures in swift heavy ion irradiated materials

09:30 - 09:50 **Contributed Talk - 26**

Kai Nordlund

University of Helsinki, Finland

Beyond the ZBL: using modern quantum chemistry to obtain accurate pair-specific repulsive potentials

09:50 - 10:10 **Contributed Talk - 27**

Ruslan Rymzhanov

Joint Institute for Nuclear Research, Dubna, Russian Federation.
The Institute of Nuclear Physics, Almaty, Kazakhstan

Bulk, overlap and surface effects of swift heavy ions in CeO_2

10:10 - 10:30 **Contributed Talk - 28**

Flyura Djurabekova

University of Helsinki, Finland

Phase transitions during ultrafast development of swift heavy ion tracks in amorphous materials

10:30 - 11:00 **Morning Tea**

Session Chair : Jacques O'Connel

11:00 - 11:30 **Invited Talk - 11**

Ana L.F. De Barros

Federal Center for Technological Education Celso Suckow da Fonseca CEFET-RJ, Brazil

Formation of prebiotics in outer space by heavy ion projectiles

11:30 - 11:50 **Contributed Talk - 29**

Md. (Arif) Arifuzzaman

Australian National University, Canberra, Australia

Defect Engineering in 2D Materials for Reduced Contact Resistance

11:50 - 12:10 **Contributed Talk - 30**

Jian Zeng

Institute of Modern Physics, Chinese Academy of Sciences (CAS), Lanzhou, China

Irradiation effects of MoS_2/Graphene heterojunction phototransistors induced by swift heavy ions

12:10 - 12:30 **Contributed Talk - 31**

Shi-Rui Zhang

Australian National University, Canberra, Australia

Synaptic field effect transistor based on charge trapping in ion-implanted gate dielectrics

12:30 - 13:30 **Lunch**

Session Chair : Devesh Kumar Avasthi

13:30 - 14:00 **Invited Talk - 12**

Zuzana Slavkovská

Department of Nuclear Physics and Accelerator Applications, Australian National University, Australia

Radioimpurity measurements for direct dark matter detector studies

14:00 - 14:20 **Contributed Talk - 32**

Pavo Dubcek

Ruđer Bošković Institute, Zagreb, Croatia

Graphene perforation by grazing incidence swift heavy ion irradiation

14:20 - 15:00 **Introduction to:**

HIA Facilities by **Dr. Tom McGoram** and **Dr. Christian Notthoff**

Ion Implantor Labs by **Prof. Rob Elliman**

15:00 - 17:00 **HIA, Ion Implantor Lab and SHRIMP Facility Tour + Afternoon Tea**

18:00 onwards **Conference Dinner**

29th November, 2024

Session Chair : Maik Lang

09:00 - 09:30 **Invited Talk - 13**
Hiroshi Amekura
National Institute for Materials Science, Japan
Ion tracks in diamond

09:30 - 09:50 **Contributed Talk - 33**
Christina Trautmann
GSI Helmholtzzentrum, Darmstadt, Germany
High-pressure platform for swift heavy ion irradiations: probing structural transformations under extreme conditions

09:50 - 10:10 **Contributed Talk - 34**
Guanghua Du
Institute of Modern Physics, CAS, Lanzhou, China
Nanoscale fabrication and application using single gev ions

10:10 - 10:30 **Contributed Talk - 35**
Alexander Azarov
University of Oslo, Centre for Materials Science and Nanotechnology, Oslo, Norway
Dynamic defect annealing in Er implanted $LiNbO_3$

10:30 - 11:00 **Morning Tea**

Session Chair : Raquel Giulian

11:00 - 11:20 **Contributed Talk - 36**
Arno Janse van Vuuren
Nelson Mandela University, Gqeberha, South Africa
The effect of Al-impurity concentrations on the microstructural response of polycrystalline Si_3N_4

11:20 - 11:40 **Contributed Talk - 37**
Yoshiaki Kumagai
Nara Women's University, Nara, Japan
Simulating energy-loss spectrum in thin water sheets using phits code for developing a novel MeV-ion beam experiment setup

11:40 - 12:00 **Contributed Talk - 38**

Djamel Kaoumi

North Carolina State University, Raleigh, USA

Irradiation induced phase transformation in β-Ga_2O_3 through in-situ ion irradiation in a TEM

12:00 - 12:15 **Conference Closing**

Poster Presentations

P1 **Natsuko Fujita**
Japan Atomic Energy Agency, Toki, Japan
Hydrocarbon dissociation efficiency in carbon dioxide samples using an exhaust gas filter

P2 **Fumina Minamitani**
Japan Atomic Energy Agency, Gifu, Japan
Single-year analysis of Tree-ring cellulose by a compact laser ablation system for radiocarbon measurement

P3 **Sayaka Oishi**
Nara Women's University, Nara, Japan
Development of ultra-short-pulse beam injector with the laser-driven acceleration for interactions at surfaces

P4 **Akari Okano**
Nara Women's University, Nara, Japan
Design for the clarification of X-ray emission phenomena from solids by spatio-temporally focused ion beams

P5 **Kai Okazaki**
Nara Institute of Science and Technology, Ikoma, Japan
Effects of linear energy transfer on thermoluminescence properties of Eu-doped CaF2 ceramics

P6 **Kensei Ichiba**
Nara Institute of Science and Technology, Nara, Japan
Thermoluminescence properties of $Y_3Al_5O_{12}$:Ce transparent ceramics at different linear energy transfers

P7 **Mikhail Merezhko**
Institute of Nuclear Physics, Almaty, Kazakhstan
Radiation-induced recrystallization and its role in the formation of corrosion resistance and mechanical properties of ferritic-martensitic steels

P8 **Wentao Wang**
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China.
University of Chinese Academy of Sciences, Beijing, China
Optical properties of nanoholes in low refractive index polymer films

P9 **Satoshi Jinno**
Japan Atomic Energy Agency, Toki, Japan
Development of an ion-funnel reaction cell for suppression of isobaric interference in chlorine-36 measurements

P10 **Hinako Imamura**
Nara Women's University, Nara, Japan
Development of an experimental method for measuring stopping cross-sections in liquid phase using mev-projectile ions

P11 **Yoshiaki Kumagai**
Nara Women's University, Nara, Japan
Simulating energy-loss spectrum in thin water sheets using phits code for developing a novel mev-ion beam experiment setup

P12 **Bing Ye**
Institute of Modern Physics, Chinese Academy of Sciences, Gan Su, China
Characterization of heavy ions produced by protons passing through shielding & packaging and induced seu in nano-devices

P13 **Kunikazu Ishii**
Nara Women's University, Nara, Japan
Classical orbital simulation of rainbow scattering patterns induced by fast ions passing through graphene

P14 **Kanae Saito**
Nara Women's University, Nara, Japan
Survival rate and dissociation phenomena associated with the penetration of diatomic molecular ions through graphene

P15 **Julia Liese**
Ludwig-Maximilians-Universität, München, Germany
Time-resolved optical interferometry of the interaction of heavy ions with water

P16 **Anna-Katharina Schmidt**
LMU-Munich, Munich, Germany
Acoustic measurement of the energy deposition of heavy ions in water at 4°c

P17 **Ahlam Alharbi**
Flinders University, Adelaide, Australia
Determining the stopping power of low kinetic energy ne+ projectiles in self-assembled monolayers

P18 **Pedro Grande**
UFRGS, Porto Alegre, Brazil
Nanostructures induced by slow highly charged ions on ultrathin PMMA films

P19 **Ryosuke Terasawa**
Meijo Univercity, Nagoya-shi, Japan
Dynamic behaviors of lithium ions at positive electrode/solid electrolyte interfaces under charging conditions with different rates using ion beams analysis

P20 **Shengxia Zhang**
Institute of modern physics, Lanzhou, China
Morphology of latent tracks in the oblique incident TMDCs

P21 **Lijun Xu**
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
Thermal stability of latent tracks in β-Ga_2O_3 *induced by swift heavy ions*

P22 **Yasushi Hoshino**
Kanagawa University, Yokohama, Japan
Annealing effect of P-implanted diamond by MeV-ion irradiation

P23 **Haizhou Xue**
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
Cryogenic electron microscopy study for the latent ion tracks in polyimide induced by swift heavy ion irradiation

P24 **Sergey Kislitsin**
Institute of Nuclear Physics of Ministry of Energy of Republic of Kazakhstan, Almaty, Kazakhstan
Comparative studies of radiation damage of $Cr_{18}Ni_9Ti$ *steel irradiated with iron, nickel and krypton ions up to high damage dose*

P25 **Mamour Sall**
CIMAP, CAEN, France
Surrogates of type II collagen under irradiation : the influence of the side chain structure on defects creation

P26 **Ayana Tachibana**
Department of Nuclear Engineering, Kyoto University, Kyoto, Japan

Dependence of linear energy transfer on damage to nucleotide molecules

P27 **Ruslan Rymzhanov**
Flerov Laboratory of Nuclear Research, Joint Institute for Nuclear Research, Dubna, Russian Federation
Irradiation temperature effect on stability of SiC irradiated with swift heavy ions

P28 **Tapobrata Som**
Institute of Physics, Bhubaneswar, India. HBNI, Mumbai, India
Artificial nociceptor realized in Au-ion implanted TiOx memristor at nanoscale

P29 **Masedi Carington Masekane**
Institut Ruđer Bošković, Zagreb, Croatia
Research Infrastructure Access in Nanoscience & Nanotechnology

P30 **Pavo Dubček**
Ruđer Bošković Institute, Zagreb, Croatia
Comparison of grazing incidence swift heavy ion track properties formed on CaF_2 and SiO_2

P31 **Leon Kirsch**
GSI Helmholtzzentrum, Darmstadt, Germany
Ultrasonic beam monitoring and energy loss measurements of relativistic heavy ions

P32 **Alexander Azarov**
Peter the Great S.-Petersburg Polytechnic University, St.-Petersburg, Russian Federation
Structure damage accumulation in α-Ga_2O_3 irradiated with P and PF_4 ions

P33 **Jianrong Sun**
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
Study on the evolution and mechanism of helium bubbles in BCC phase high/medium-entropy alloys

Abstracts

Monday

November 25, 2024

IT - 1

Surface erosion under ion bombardment: Case studies in space weathering and nuclear fusion research

Friedrich Aumayr ORCID iD

TU Wien - Institute of Applied Physics, Vienna, Austria

Abstract

Bombardment of surfaces with energetic atoms or ions results in material erosion (sputtering), particle implantation and changes in surface morphology as well as changes in elemental composition. Most laboratory experiments on sputtering have so far focused on ideally flat and monoelemental samples. However, realistic materials such as the walls of fusion reactors or the rocky surfaces of moons or airless planets are rough and consist of compounds of several different elements. In addition, the surface morphology and chemical composition typically change dynamically with prolonged exposure to plasma or solar wind ions (material mixing, re-deposition of sputtered material, etc).

Recently, three-dimensional versions of modern computer codes based on the binary collision approximation, such as SDTrimSP-3D and TRI3DYN, have become available, which are able to simulate sputtering processes on such realistic 3D surfaces.

In this talk several experimental case studies will be presented which show how well it is already possible to achieve excellent agreement between simulation and experimental results. This is demonstrated with examples from (a) plasma-wall interaction in fusion plasmas and (b) solar wind-induced space weathering of Mercury analogue materials and Lunar dust from the Apollo XVI landing site.

CT - 1

The influence of the near surface environment on hillock formation

Dr Jacques O'Connell ORCID iD[1], Dr Vladimir Skuratov[2], Dr Ruslan Rymzhanov[2]

[1]Nelson Mandela University, Port Elizabeth, South Africa. [2]FLNR, Joint Institute for Nuclear Research, Dubna, Russian Federation

Abstract

Surface hillocks induced by SHI impact is a common phenomenon which has been extensively studied by AFM, SEM, TEM and MD. By now it is generally accepted that hillocks are produced through the expulsion of molten material from the hot track due to a thermally induced over-pressure state within the track. Recent TEM analysis of different materials have shown that hillocks may be amorphous or crystalline and epitaxial to the target crystal. The target material plays an important role in the crystallinity of hillocks through the ability of the molten target to recrystallize within the short relaxation period (J. Appl. Phys. 127, 015901 (2020); doi: 10.1063/1.5109811). Factors such as crystal complexity, melt viscosity and surface tension determine recrystallization rate and the dynamics of material ejection. In this presentation we will consider the influence of the structure of the near surface volume of the target on hillock crystallinity and shape. It was found, for instance, that surface amorphization can suppress crystallization of hillocks. Through the use of multilayer targets, we will also consider mass transport near the surface. Since the presented results are based on direct TEM observation of the hillock structures, it serves as experimental support to previous MD based simulation of the hillock formation process.

CT - 2

Swift Ion Irradiation and Complex Organic Molecules in cold Space Environments

Dr. Philippe Boduch, Dr. Alicja Domaracka, Dr. Cintia Pires da Costa, Dr. Hermann Rothard

Centre de Recherche sur les Ions, les Matériaux et la Photonique, Normandie Univ, ENSICAEN, UNICAEN, CEA, CNRS, CIMAP, 14000 CAEN, France

Abstract

In cold space environments, the synthesis of complex organic molecules (COMs) occurs following radiolysis of small molecules (H_2O, CO, CH_4, NH_3 etc.) on surfaces (e.g. dust grains dense in molecular clouds, icy bodies of the outer solar system). COMs can also be formed by implantation of reactive ions (like C or S ejected by Io's volcanism) trapped in the magnetospheres of giant planets in the icy surfaces of their satellites. Irradiation of COMs also occurs in condensed phase in radiobiology (dosimetry and radiation protection, cancer therapy). It is thus necessary to study formation and survival of COMs under swift charged particle irradiation of icy samples in a wide temperature range (10-300K).

We performed ion irradiation experiments related to COMs at different accelerator facilities (GANIL, Caen/France, ATOMKI, Debrecen/Hungary GSI, Darmstadt/Germany). Infrared absorption spectroscopy FTIR and mass spectrometry QMS allow in situ observation of processing of the icy layers. Ex-situ analysis of residues is performed by e.g. high-resolution mass spectrometric methods. In the future, within the PEPR Origins [pepr-origins.fr], a unique multi-beam irradiation device (UV photons, keV electrons and keV-GeV ions delivered by GANIL/Caen, the MIRRPLA platform, will be open to the various scientific communities (astrophysics, radiobiology, environmental and materials sciences) as well as to industry via the CIMAP-GANIL user platform CIRIL.

IT - 2

Antimonide Nanofoams Induced by Ion Irradiation

Dra. Raquel Giulian ORCID iD, Dr. Charles Airton Bolzan, MS Leandro T. Rosseto, Julio C. Rohr, Luiz F. H. Drehmer, Rafael L. dos S. Taschetto, Ana Paula Lima, Dr. Gilberto L. Thomas, Dr. Antônio M. H. de Andrade, Dr. Livio Amaral

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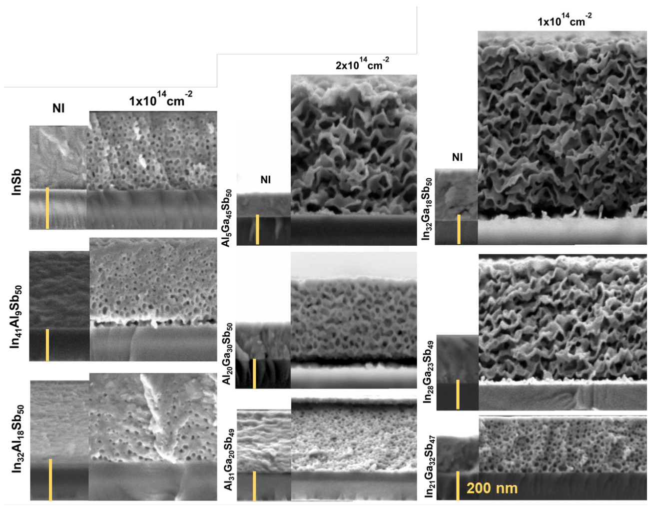
Abstract

Semiconductors are commonly implanted or irradiated with heavy ions to increase the number of defects in the matrix and enhance specific electrical and optical properties. A very peculiar effect is observed upon ion irradiation of antimonides, in the nuclear or electronic stopping power regime: the formation of a porous, sponge-like structure with nanometric dimensions. The nanometric foams induced in these compounds by ion irradiation exhibit giant surface-to-bulk ratio, which can be very good for the development of devices which rely on surface reactions, like gas detectors. Here we show the ion irradiation effects on ternary compound films containing In, Ga, Al and Sb deposited by magnetron sputtering. Samples were irradiated with 8 MeV Au^{+3} (16 MeV Au^{+7}) ions, at room temperature, with ion fluences ranging from 10^{12}–10^{14} cm^{-2}. The atomic composition and structure of porous films were probed as a function of irradiation fluence by Rutherford backscattering spectrometry, scanning electron microscopy and x-ray diffraction analyses. Variations in the relative concentration of In, Ga and Al in the ternary antimonide compounds allow variations of lattice parameters and bandgap, and also influence the ion irradiation-induced porosity. The structural modifications induced by ion irradiation are discussed. The thermoelectric properties of the materials, before and after irradiation, were also investigated.



Scanning electron microscopy images from InAlSb (left), AlGaSb (center) and InGaSb (right) films, deposited by magnetron sputtering on SiO_2/Si. The non-irradiated (NI) and irradiated films are shown side by side, with same scale, for each compound.

CT - 3

Ion track formation and porosity in InSb and GaSb after swift heavy ion irradiation

Mr Taleb Alwadi ORCID iD[1], Dr Christian Notthoff ORCID iD[1], Dr Shankar Dutt ORCID iD[1], Ms Jessica Wierbik ORCID iD[1], Ms Nahid Afrin ORCID iD[1], Prof Raquel Giulian[2], Prof Patrick Kluth ORCID iD[1]

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Abstract

InSb and GaSb are narrow bandgap semiconductors, which makes them a good candidate for high-speed electronic devices and infrared detectors. An intriguing feature of InSb is that it can be rendered porous upon heavy ion irradiation in the low energy, and medium energy regime. However, only two previous studies about swift heavy ion irradiation in InSb mention ion tracks in InSb. We have investigated the ion track formation and porosification in InSb after irradiation with 185 MeV ^{197}Au ions at various fluences. In addition, we present a comparison between the processes in InSb and GaSb which irradiated under identical irradiation conditions in our previous work. Rutherford backscattering spectrometry in channeling geometry reveals an ion track radius of about 16 nm for irradiation normal to the surface and 21 nm for off-normal irradiation at 30° and 60°. Scanning electron microscopy shows significant porosity that increases when irradiation was performed off-normal to the surface, with a preferential orientation of the pores at about 45° relative to the surface normal, independent of the irradiation angle. Moreover, InSb demonstrate notably higher swelling compared to GaSb. Furthermore, InSb and GaSb thin films with different thicknesses, grown using Magnetron Sputtering, were irradiated with 185 MeV ^{197}Au ions. The SEM images indicate that the volume of pores increases with the irradiation fluence, reaching a saturation point. Subsequently, the thicker films transition into a structure consisting of multiple crumbled sheets, while thinner films adopt a single crumbled sheet morphology.

CT - 4

Towards efficient green light emission by swift heavy ion irradiated-InGaN/GaN multi-quantum wells

Dr Mamour Sall[1], Louise Goodwin[1], Alexis Dujarrier[1], Dr Vincent Pacary[1], Dr Yvette Ngono[1], Yann Doublet[1], Marie-Pierre Chauvat[1], Amandine Baillard[1], Dr Pavel Loiko[1], Dr José Olivares[2,3], Dr Padhi Santanu Kumar[3], Dr Marco Peres[4,5], Dr Katharina Lorenz[4,5], Dr Miguel Sequeira[6], Dr Clara Grygiel[1], Emmanuel Balanzat[1], Dr Isabelle Monnet[1]

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Abstract

The nitride semiconductors, (Al,Ga,In) N present remarkable optical and electronic properties. They have been widely used for optoelectronic applications with high-efficiency blue light-emitting diodes (LEDs) based on InGaN/GaN multiple quantum well (MQW) structures [1]. Emission at higher wavelength, for instance in the green, could be obtained by increasing the concentration of indium but with a strong quantum-confined Stark effect due to piezoelectric polarization [2]. To mitigate this effect, we created atomic intermixing at the InGaN/GaN MQW by using Swift Heavy Ion (SHI) irradiation. The resulting chemical composition gradient has been suggested to improve the MQW emission efficiency [3].

Through a careful combination of well-chosen energies SHI irradiation and low temperature thermal treatment, either during or after irradiation, we successfully created a compositional gradient at the MQWs interfaces while preserving the material luminescence (Fig. 1).

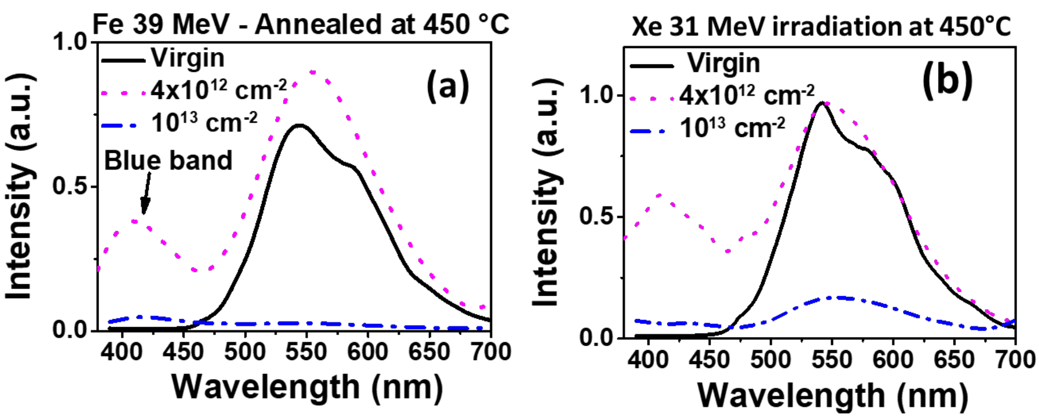

Fig. 1: (a) Photoluminescence (PL) spectra of the ^{56}Fe 39 MeV irradiated-MQW after thermal annealing at 450 °C for 2 hours. (b) PL spectra of the MQWs before and after irradiation at 450 °C with ^{129}Xe 31 MeV at different. The luminescence in the green region is preserved; the blue emission is due to intermixing at the interfaces.

CT - 5

Study on the Ion Irradiation Effect of Nano-structural TiAlN Coating

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Abstract

Transition metal nitride coatings have the characteristics of high hardness, high thermal stability, high chemical inertness, and resistance to friction and wear. They have potential application prospects as surface protective coatings for reactor structural materials. In this work, the nanocrystalline TiAlN coating prepared by multi-arc ion plating method is taken as the research object. A series of irradiation experiments with different irradiation doses and temperatures are carried out by using self-ion N, Fe ion and He ion respectively.

The XRD results show that even at 10 dpa TiAlN coating maintains the original lattice structure, and no amorphous or irradiation phase transition occurs, indicating that the coating has a good ability to resist irradiation. In the cases of the irradiation with 38.7 and 19.6MeV Fe ions, a large number of dense N bubbles are generated near the surface of the coating due to the electron energy loss effect. In the case of N or He ion irradiation, both ions have similar behavior in the coatings. At room temperature, they only form linear bubbles along the grain boundaries, and at high temperature, they form spherical bubbles inside the grains and discontinuous chains of spherical bubbles at the grain boundaries. Ion irradiation can cause softening of TiAlN coating, and the softening degree increased with the increase of irradiation dose at room temperature, and the irradiation softening recovered under high temperature irradiation.

IT - 3

Observing the damage to biomolecules induced by ion beams in liquid jets

Associate Professor Hidetsugu Tsuchida ORCID iD[1,2], Doctoral student Tetsuro Ohta[2], Doctoral student Naruki Uno[2], Master's student Ayana Tachibana[2], Dr. Takeshi Kai ORCID iD[3], Lecture Yusuke Matsuya ORCID iD[4,3], Dr. Takuya Sekikawa ORCID iD[3], Associate Professor Takuya Majima ORCID iD[2], Professor Manabu Saito ORCID iD[2]

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Abstract

Our research focuses on exploring the radiation effects on biological matter in charged-particle radiation therapy for cancer. As living organisms are mainly composed of liquid water, cells are susceptible to damage by chemical reactions with the radiolytic products of water. Because the damage induction process involves complicated mechanisms of chemical reactions, it is not yet fully understood.

We aim to comprehend the effects of radiolytic products of water on radiation-induced damage at the Bragg peak region, which is an important research topic in cancer therapy. To achieve this, we irradiated nucleotide and glycine peptide molecules in both aqueous and solid states with fast ion beams. Our goal was to determine the radiation-induced damage to these molecules in water at the Bragg peak region of particle therapy.

We used a liquid jet technique to introduce a liquid sample into a vacuum through a narrow nozzle. The sample was then exposed to 4 MeV carbon beams generated from an accelerator. To identify the damage site of the molecule, we used time-of-flight mass spectrometry to measure the secondary ions released from the sample.

In this presentation, we will discuss the role of radiolytic products in biomolecular damage by comparing the mass spectra of aqueous to those of solid targets.

CT - 6

Impact of swift cluster ion irradiation on the process of decomposing nucleotide biomolecules

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Abstract

We conducted experiments to investigate the unique irradiation effect of swift cluster ions on the damage of biomolecules. Swift cluster ions collide with solid targets in a distinct way, where multiple atoms collide simultaneously in a confined area. This leads to an irradiation effect that differs from monatomic ion irradiation. Although several experimental studies have documented various phenomena, it is still being determined how these effects impact the damage of biomolecules.

In our experiments, we used cluster ions with MeV energy to irradiate solid-phase nucleotide molecules. We used C_n^+ (n = 1,4) projectiles with an energy of 1.0 MeV per carbon atom from a 2 MV tandem Pelletron accelerator. A target was uridine 5'-monophosphate sodium salt (UMP), which is made up of uracil, ribose, and phosphoric acid. We used a linear-time-of-flight mass spectrometer to measure positive secondary ions emitted from the target. This helped us identify the fragmented site in the UMP.

In this figure, we compared the intensity distributions of fragment ions emitted from UMP molecules under two different types of irradiations: C^+ and C_4^+. When exposed to C_4^+ irradiation, the intensity patterns were distinct, with particular fragment ions such as $OHNa_2^+$, $CNNa_2^+$, $CNONa_2^+$, and $PO_2Na_2^+$ showing a significant increase. Among these fragment ions, $CNNa_2^+$, the uracil component, exhibited the most substantial increase. This indicates that cluster irradiation leads to heightened base damage within the nucleotide molecule. The presentation will discuss how cluster irradiation promotes base damage in nucleotide molecules.

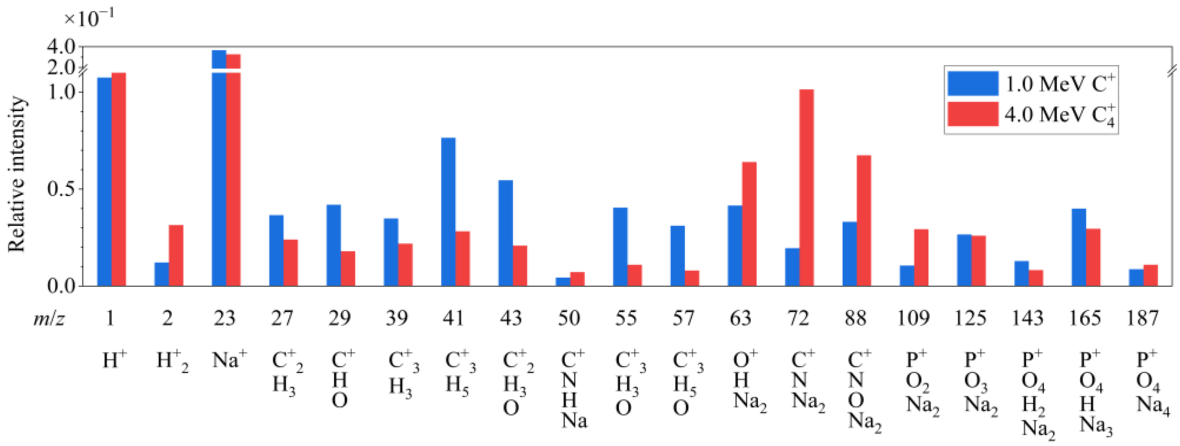

Figure: Relative intensity distributions of fragment ions emitted from the UMP by C^+ and C_4^+ with an energy of 1.0 MeV per carbon atom.

CT - 7

Electron impact scattering studies for C_6H_6

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Abstract

The electron impact ionization cross sections for atoms/molecules are of great importance for the evaluation of radiation chemical data, the thermodynamic measurement, for mass spectrometric studies of ion-molecule reactions and for space and plasma physics. Benzene (C_6H_6) is industrially important aromatic molecule which used as a primary reagent in pharmaceutical and petrochemical industries and in planetary atmosphere particularly, in haze formation in Titan atmosphere [1].

In the present study, we have calculated the total ionization cross sections for Benzene (C_6H_6), by electron impact in the incident electron energy range from ionization potential to 5 keV by employing a well-established Jain-Khare semiempirical approach based on Bethe and Möllor cross sections [2]. The present results are found in satisfactory agreement with avaiable theoretical calculations [3,4,5] and experimental data [6] are presented in figure.

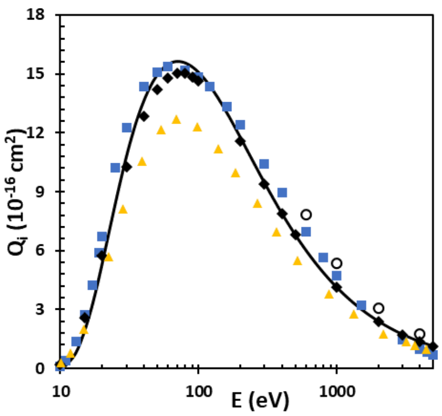

Figure. Total ionization cross-sections for C_6H_6 molecule as a function of incident electron energy E. Solid line- present our calculations, BEB calculations-♦-Kim and Irikura [3], ▲- Hwang et al. [4], ■-SCOP calculation [5] and o-Schram et al. [6].

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CT - 8

Simulated Cislunar Radiation Effects on Wide Bandgap Semiconductor based SmallSat Power Module

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Abstract

Cislunar and Deep Space is a highly challenging operational environment for spacecraft. One of the primary difficulties encountered is the effects of Galactic Cosmic Radiation (GCR) on spacecraft electronics. For spacecraft to operate in this environment, technology must be used that can overcome the negative effects of GCR. Radiation hardened electronics used for this purpose are commonly bulky and power-inefficient, making it unsuitable for small spacecraft where subsystem size and efficiency are a priority. Despite having limited size and mass, SmallSat-scale missions are increasingly being accepted as a valid platform for science missions where the spacecraft is expected to operate in cislunar or deep space. Traditional SmallSats have difficulties achieving sufficient operational lifetime in this environment while remaining within power and mass limits; therefore, there is a need for new technologies that can overcome this challenge. Wide Bandgap (WBG) semiconductors are highly applicable for development in this area. To progress the adoption of WBG semiconductors in spacecraft, their functionality in space needs to be verified. Analysis of literature will be performed and compared with the capabilities offered at the Heavy Ion Accelerator Facility, to generate an appropriate test environment that replicates a cislunar radiation environment. A prototype power module, under development, will then be tested in this proposed environment. The results of this testing will be used to determine the limits of operation of the device, the variation over an accelerated operational lifetime, and to make suggestions for design changes that could extend the operational duration of the module.

IT - 4

Effects of swift heavy ions on wide band-gap materials and devices

Professor Jie Liu, Professor Pengfei Zhai, Associate Professor Peipei Hu, PHD Student Xiaoyu Yan, PHD Student Shiwei Zhao, Associate Professor Zongzhen Li, Assistant Professor Lijun Xu, PHD Wensi Ai, Associate Professor Jian Zeng, Associate Professor Shengxia Zhang, Assistant Professor Li Liu, Professor Huijun Yao, Professor Youmei Sun, Professor Jinglai Duan

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Abstract

Wide bandgap semiconductors, including SiC, GaN, and Ga_2O_3, are known for their exceptional physical properties, which provide substantial benefits for applications requiring high voltage, high frequency, and high temperature. These materials have seen applications for power supply and communication systems both terrestrially and in space. Nonetheless, it has been found that wide bandgap materials are unexpectedly highly susceptible to heavy ion irradiation, bringing significant challenges for their deployment in radiational environments. This work summarizes the results of irradiation effects on SiC, GaN, and Ga_2O_3 materials and devices, conducted at the Heavy Ion Research Facility in Lanzhou (HIRFL) [1-5]. After the irradiation, ion tracks were observed in the semiconductor materials and devices regardless of the supplied voltage. This damage could lead to electrical property degradation or even device failure. Simulations of the internal electric field and carrier concentration are performed to establish the relationship between material damage and the change in electrical characteristics of the device. Furthermore, this work proposes a possible failure mechanism for wide bandgap power devices under heavy ion irradiation, contributing to the understanding of radiation effects in these devices.

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CT - 9

Swift Heavy Ion Irradiation for High-Pressure Investigations on Bismuth Nanowire Networks

Christopher Schroeck[1,2], Ioannis Tzifas[1], Michael Wagner[1], Lkhamsuren Bayarjargal[2], Kay-Obbe Voss[1], René Meja[1], Sinan Orkunt[1], Emanuil Zeqo[1], Christina Trautmann[1,3], Bjoern Winkler[2], Maria Eugenia Toimil-Molares[1,3]

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Abstract

Swift heavy ion irradiation is a powerful tool in materials research, particularly in terms of materials modification and engineering. In combination with chemical track etching and electrochemical deposition, swift heavy ion beams can be employed to synthesize high aspect ratio nanowires. This approach enables systematic investigations of size-dependent properties of nanowires, due to excellent control regarding wire diameter geometry and minimum size distribution. This contribution presents a study on the size dependence of phase transitions on nanowires under high static pressures.

High-pressure stability fields of nanomaterials can deviate significantly from their bulk counterparts, in terms of transition pressures and crystallographic structures of phases. Therefore, the investigation of size-dependent stability ranges may open up new pathways regarding the synthesis and recovery of novel materials, providing valuable insight into the impact of the sample geometry.

Here we present the investigation of the size-dependent high-pressure phase transitions of bismuth nanowire networks (Bi-NWNWs) synthesized by ion track nanotechnology. The wire diameters were varied from 30 to 100 nm and the NWNWs mounted together with bulk-like microcrystals in diamond anvil cells. The samples were stepwise compressed up to 20 GPa and their crystallographic properties characterized by beams of synchrotron diffraction. Additional experimental results concerning the systematic investigation of the high-pressure behavior of $Bi_{1-x}Sb_x$ nanomaterials, as well as the exposure of the pressurized nanomaterials to swift heavy ion irradiation will also be discussed.

CT-10

Charge-based molecular separation using track-etched silicon dioxide nanopore membranes

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Abstract

Charged-based separation is a promising technique for the purification of biomolecules such as proteins, peptides, and viruses from a complex biological mixture. Thin membranes with a narrow pore size distribution and well-defined surface properties are required for efficient separation but difficult to fabricate. In this study, we present silicone dioxide nanopore membranes as a promising platform for the charge-based separation of molecules of similar size. Membranes with conical nanopores were fabricated in silicon dioxide by irradiation with 2.2 GeV ^{197}Au ions followed by chemical etching from one side in 2.5% HF solution. The silicon dioxide surface carries hydroxyl groups (-OH), which offer a negatively charged nanopore surface. The transport rate of charged dyes, including methylene blue, orange ii, and ponceau 4R through the membrane was investigated. It was found that the transport rate of positively charged methylene blue through the nanopore membrane was almost 30 times higher than the negatively charged orange ii or ponceau 4R. This indicates that the molecular transport through the nanopore with a similar charge is hindered by the electrostatic repulsion of the surface charge and the interaction with the electric double layer. By providing selective, efficient, and low-loss charge-based separation, this membrane could be used in nanofluidic devices for example to facilitate efficient separation of biomolecules.

CT - 11

3D Gold Nanowire Networks with Tailorable Surface Wettability Engineered through Ion-Track Nanotechnology

Ms. Mohan Li ORCID iD[1,2], Dr. Henning Bonart ORCID iD[3], Mr. Daniel Zellner[1], Dr. Prof. Maria Eugenia Toimil-Molares ORCID iD[1,2]

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Abstract

This study highlights the ability to achieve different wetting states by tailoring the diameter and density of nanowires in three-dimensional gold nanowire networks. The wetting properties of these nanostructured materials are crucial for a wide range of applications like functional surfaces, liquid transport, microfluidic devices, and sensors. We investigated the surface-wetting behavior of freestanding gold nanowire networks with precisely controlled diameters and densities, where the nanowires are oriented at 45° to the horizontal plane and interconnected from four directions. They were fabricated by the ion-track nanotechnology, namely by electrochemical deposition in ion-track etched membranes, where the nanochannels' orientations was provided by the ion beam directions. Sessile drop measurements on these tailored nanostructured films revealed a transition from hydrophilic to hydrophobic behavior as porosity increased from 20% to 98%. Notably, the hydrophobic networks displayed the rose-petal effect, where water droplets repelled but remain pinned to the surface. These findings demonstrate the potential to precisely tune surface wetting characteristics through innovative nanostructure designs.

Abstracts

Tuesday

November 26, 2024

IT - 5

Ion-induced self-organized pattern formation: Amazing possibilities

Prof. Tapobrata Som

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Abstract

Ion-beam-induced self-organization is of interest due to its tremendous potential in various areas of research. In particular, nanoscale pattern formation on surfaces and their nanoscale functionalization lead to the opening of new avenues. The use of sub-keV to tens of keV ion energy to fabricate various types of fascinating patterns is considered to be a complex process that depends on several experimental parameters like ion-energy, -fluence, -incident angle, sample temperature, substrate rotation, crystalline nature, etc. where ion induced roughening of surfaces and irradiation enhanced diffusion play important roles. Thin films or nanoparticles grown on patterned surfaces as templates, having anisotropic morphologies, do exhibit anisotropic physical properties (e.g. optical, electrical, magnetic, plasmonic, etc.). I shall address many such amazing possibilities by employing different modes of atomic force microscopy (AFM) and other microscopic techniques, revealing the efficacy of ion-induced patterns.

CT - 12

3D mapping of nanoscale density fluctuations in swift heavy-ion irradiated materials

Dr Pablo Mota-Santiago[1,2], Dr Jonas Engqvist[2], Dr Shankar Dutt[3], Miss Jessica Wierbik[3], Dr Andre Coelho Conceicao[4], Prof Patrick Kluth[3], Dr Tomas Plivelic[5]

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Abstract

Small-angle X-ray scattering (SAXS) has been among the principal techniques used to characterize the morphology of the damage trail left by swift heavy ions in polymeric materials, both in bulk and thin-films. This technique, as demonstrated by Wang et al. [1], has successfully revealed variations in the radial dimensions and density profiles, showing a strong correlation with the polymer nanostructure. However, the potential of wide-angle X-ray scattering (WAXS) to unveil atomic scale structural changes in the polymer network induced by SHI and their effects on the material's integrity and mechanical properties, remains underexplored.

In this work, we present the first results of simultaneous SAXS/WAXS to characterize the morphology of the ion trails as well as investigating strain formation on the polymer network, rearrangement of the polymer chains and radiation damage effects. The study was carried out in glassy polymers, such as polycarbonate (PC), and semicrystalline polymers like polyethylene terephthalate (PET). Despite encouraging, the measurements lack of three-dimensional information associated with SHI traces. Thus, we also discuss complementary CT-SAXS/WAXS experiments (imaging SAXS/WAXS) which allow for the correlation of multiscale 3D structural changes with ion fluence and the cumulative effects of multiple-impacts, closing the gap between experimental observations and simulations.

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CT - 13

The anisotropy of the ion track cross-section in single-crystalline materials

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Abstract

When swift heavy ions (SHIs) with MeV to GeV energies penetrate crystalline solids, they form amorphous defect structures resembling narrow straight damage trails [1]. These *ion tracks* with radii of a few nanometers and lengths of up to tens of micrometres serve as a well-suited proxy for fission track damage in minerals interesting for geo- and thermochronology. Synchrotron-based small-angle X-ray scattering (SAXS) effectively investigates ion track damage in minerals like fluorapatite and quartz [2], providing statistically reliable measurements by averaging out structural fluctuations on an atomic level.

This precision enables to assess the anisotropy in the damage profile produced by SHIs. Given crystals' anisotropic physical and structural properties, ion track formation in most crystals likely results in anisotropic track cross-section shapes. This is the first study precisely quantifying the structural anisotropy of the complete ion track cross-section in single-crystal fluorapatite ($P6_3/m$) and quartz ($P3_121$) employing SAXS. The track radius was measured as a function of the in-plane angle by rotating the ion track axis from 0° to 360°. SAXS data reveal a non-spherical cross-section shape of tracks within the (010) plane in quartz and (100) plane in fluorapatite, with the track's radius varying in dependence of the in-plane angle, exhibiting differences between the maximum and minimum radius of 9% in quartz and 8% in fluorapatite.

These results enable the establishment of correlations between structural properties of the track's host material and ion track properties, elucidating the extent to which the local crystal structure influences the track formation process. Thus, this study helps to understand the fundamental solid-state processes involved when irradiating single-crystals with SHIs.

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CT - 14

Ion beam engineering of nanostructures for augmented effects in sensing and energy storage

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Abstract

Ion beam is known to have great potential to modify low-dimensional materials towards beneficial applications [1]. Our studies on ion beam modification of 1D and 2D materials demonstrated interesting ways to tune performances of sensing of hazardous gases or multi-fold enhancement of electrode storage capacity. For instance, titanate nanotubes grown on titanium electrode acted as good electrode materials to store charges. The post-irradiated nanotubes undergo large-scale joining, which results in three times higher specific charge storage capacitance than that of as-prepared titanate. Detailed analysis shows that joining, enhancement of surface area, decrease of charge diffusion barrier and availability of additional states near Fermi energy are responsible for such enhancement of capacitance [2]. The effect of surface defects and nano-joining shows remarkable effects on gas sensing properties of 2D MoS_2 and $MoSe_2$ [3]. Our studies demonstrate that these 2D materials show enhanced sensing performance with higher sensitivity of ammonia gas, reduced response and recovery time and higher stability over a long period of time. While the ion beam modifications are well explained using TRI3DYN simulation, the DFT simulation predicts that Mo and Se vacancies decisively control the gas sensing performance.

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IT - 6

Dynamic processes in ion-matter interaction: electronic excitation and charge exchange below the Bohr velocity

Dr Eleni Ntemou ORCID iD, Mr Radek Holeňák ORCID iD, Dr, Professor Daniel Primetzhofer ORCID iD

Uppsala University, Uppsala, Sweden

Abstract

Energy dissipation of ions moving in matter depends on the ion velocity and on the atomic number of the ion and the target nuclei. In the low-velocity regime (below the Bohr velocity), electronic excitations are trajectory-dependent and they show a dynamic, non-adiabatic character. Due to the dependence of processes such as charge exchange processes in atomic collisions and formation of molecular orbitals on the interaction distance between ion and target atoms, they are accessible to different extents along channeling in comparison to random trajectories in crystalline targets.

For low velocities, considering exclusively electron-hole pair excitations in binary collisions, ab initio calculations for a free electron gas predict a proportionality between the specific energy loss and the ion velocity. In experiments, however, deviations from velicity proportionality attributed to excitation thresholds of electronic states have been observed.

We present transmission experiments using the Time-of-Flight Medium Energy Ion Scattering System at Uppsala University. We investigated energy deposition phenomena in conjunction with measurements of the exit charge states implementing ion beams (H to Ne) directed through 50 nm Si and SiC single crystalline membranes. Our results highlight large differences in the mean exit charge state and the energy deposition between random and all channeling orientations. Also, we observe that smaller channel size yields higher mean charge and higher energy loss. The higher energy loss along with the higher mean charge state points to strong contributions from local processes e.g. electron promotion and collision-induced reionization. In channeling orientations, excitation threshold phenomena are observed.

CT - 15

X-ray production by heavy ion-atom collision symmetries for Total Ion Beam Analysis

Dr. Masedi Carington Masekane[1], Dr. Ivančica Bogdanović Radović[1], Prof. Mandla Msimanga[2,3], Dr. Zdravko Siketić[1], Dr. Mamogo Masenya[2], Prof. Sabata Moloi[4]

[1]Institut Ruđer Bošković, Zagreb, Croatia. [2]iThemba Laboratory for Accelerator Based Sciences, Johannesburg, South Africa. [3]Tshwane University of Technology, Pretoria, South Africa. [4]University of South Africa, Florida, South Africa

Abstract

The use of heavy ions in the implementation of Particle Induced X-ray Emission (PIXE) spectroscopy remains attractive due to the exploitation of high stopping powers as well as relatively high X-ray production cross sections (XPCS) at comparative proton velocities. Synergies of Ion Beam Analysis (IBA) techniques based on heavy ion stopping in matter applied self-consistently with Heavy Ion PIXE thus have the potential to provide a more consolidated 3D description of a target material (i.e., depth profiles and lateral elemental and/or molecular distributions), so called Total IBA. While the potential for the qualitative implementation of heavy ion Total IBA is feasible, the quantitative application of PIXE with heavy ions as probes remains limited due to a lack of reliable XPCS data. Currently, widely adopted theoretical models used for the approximation of ionisation cross sections are based on protonic excitation, which cannot be adapted for heavy ions. Furthermore, the currently sparse database of experimental XPCS remains scattered in the literature, prompting the need for additional measurements for the development and/or validation of current and/or new models. In the present work, measured experimental XPCS data for up to near-symmetric collisions due to C, Si, Cu, Ag and I ions incident in Sn, W, Au and Bi targets in the 0.2 MeV/u – 1.0 MeV/u ion energy range are presented. Agreement and discrepancies between experiment and theory are discussed in terms of the dominant multiple ionisation effects, and the potential use of semi-empirical and machine learning models.

CT - 16

Electronic excitations at very low ion energies: experimental challenges

Daniel Primetzhofer

Uppsala University, Uppsala, Sweden

Abstract

The electronic energy deposition of ions with keV and sub-keV energies is critical for materials modification, but also materials analysis in a wide range of applications such as implantation, sputtering ablation and deposition. Yet, an experimental assessment of the average energy transfer to the electronic system is difficult, for reasons such as listed in the following, not exhaustive points: a) the low penetration depth of low energy ions increases the relative importance of surface effects and potential impurities, b) even ensuring pure target systems in the volume requires in-situ approaches for all but the least reactive (e.g. noble metals) systems, c) the increased relative weight of elastic energy losses requires a disentanglement of this energy loss contribution. Moreover, the general approach of defining stopping power as an average quantity becomes challenged by the fact, that the trajectories over which the average is taken become comparatively short. Similarly, for the stopping cross section defined as an integral over all impact parameters, an inherent, significant impact parameter selectivity of the specific experimental approach may affect results, in particular when considering e.g., impact parameter dependent charge exchange effects and their interplay with electronic excitations. In this contribution, we critically assess a few recently obtained datasets for low-energy ions, focusing on hydrogen and helium in transition metals and their compounds. Results are compared with predictions from calculations and potential inaccuracies in extraction of energy loss data from experimental datasets are discussed.

CT - 17

Stopping power from Bohmian Mechanics

Prof. Pedro Grande ORCID iD, Prof. Raul Fadanelli ORCID iD

Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil

Abstract

Bohmian Mechanics [1], also known as the de Broglie-Bohm theory or pilot-wave theory, is an interpretation of quantum mechanics that posits the existence of a guiding wave along with particles. In this framework, particles are governed not only by the Schrödinger equation but also by their trajectories determined by the guiding wave. This interpretation provides a deterministic account of quantum phenomena while retaining compatibility with experimental results, offering a unique perspective on the nature of quantum reality, and for the first time it is used to describe the electronic stopping power of bare ions in solids.

In our work [2], we solved the classical equations of motion and the Poisson equation self-consistently, equivalent to the nonlinear Vlasov-Poisson equation. Thus, we obtained the complete noncentral self-consistent electron-ion potential, enabling us to calculate the ion stopping power. We employed Bohmian mechanics to convert our classical calculations into fully quantum mechanical ones. This was accomplished by utilizing the Bohm quantum mechanical potential, which relies on electronic density and is evaluated based on classical trajectories. This approach provides a novel alternative to traditional quantum calculations for determining the electronic stopping power, and its application will be exemplified at this conference. Furthermore, we illustrate the use of the present methods to investigate the stopping of different projectiles on Si and of highly charged ions on 2D materials as a function of the projectile states.

References

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IT - 7

Exploring Radiation Hardness in Group-III Nitrides: From Fundamentals to Applications

Miguel C. Sequeira[1], Mamour Sall[2], Flyura Djurabekova[3], Kai Nordlund[3], Isabelle Monnet[2], Clara Grygiel[2], Christian M. Wetzel[4], Katharina Lorenz[5,6]

[1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany. [2]CIMAP, CEA-CNRS-ENSICAEN-UNICAEN, Caen, France. [3]Department of Physics, University of Helsinki, Helsinki, Finland. [4]Department of Materials Science and Engineering & Department of Physics, Rensselaer Polytechnic Institute, New York, USA. [5]Instituto de Engenharia de Sistemas e Computadores – Microsistemas e Nanotecnologias, Lisbon, Portugal. [6]Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Abstract

Group-III nitride semiconductors, recognised for their excellent mechanical, thermal, and electronic properties, are used across several applications, from high-power electronics to solid-state lighting. Additionally, their high resistance to radiation is being explored for the next generation of radiation-hard electronics, despite the reason for this property remaining unclear, particularly in layered structures used in devices based on quantum wells (QWs) and other 2D electron gas systems.

Here, we discuss the response of these semiconductors, including GaN, $In_xGa_{1-x}N$ and the InGaN/GaN multi-QW system, to strongly ionising radiation such as Swift Heavy Ions (SHI). Two-Temperature Model (TTM), Molecular Dynamics and Transmission Electron Microscopy reveal that GaN tends to recrystallise in the region melted by the ions, leading to high thresholds for permanent track formation [1] and diverse ion track morphologies [2]. Surprisingly, incorporating In in GaN up to an optimal concentration further increases the radiation resistance of the material. However, for higher InN molar fractions, the recrystallisation is greatly deteriorated, and higher levels of damage are observed.

We then study the effects of SHI on InGaN/GaN QWs, where TTM reveals that the high electronic conductivity of the 3 nm InGaN layer acts as an energy dissipator efficient enough to reduce the ion-induced damage in the entire QW structure. These results can lead to new radiation damage mitigation techniques, predict functional changes in devices under radiation exposure, and improve device design.

[1] M. C. Sequeira et al., *Communications Physics,* 4 (2021) 51.

[2] M. C. Sequeira et al., *Small* (2022), 2102235

CT - 18

Exploring ion beam-induced modifications of the resistive switching in metal oxide films

Rajdeep Kaur[1], Tuan Thien Tran[1], Daniel Primetzhofer[1,2], Petter Ström[1]

[1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden. [2]Tandem Laboratory, Uppsala University, Uppsala, Sweden

Abstract

Oxide thin films are extensively studied due to their diverse electronic and optical properties, which have applications in everyday life.[1] Some oxide films exhibit resistive switching (RS) i.e., they adjust their resistance based on voltage magnitude and polarity and retain their resistive state when the voltage is turned off. RS properties such as switching voltage, resistance ratio and reproducibility can be modulated, to a certain extent, by factors like film thickness.[2] Ion beams provide a method with better control and precision in modifying these properties. Our research focuses on films of Al_2O_3 and TiO_2, sandwiched between Pd layers which serve as electrodes for electrical characterization. The thin films are deposited on SiO_2/Si substrates using magnetron sputtering. The preliminary results show bipolar RS in bi-layer Al_2O_3/TiO_2 films, transitioning from high to low resistance (SET) at a negative potential and vice versa (RESET) at a positive potential. In this study, we explore ion beam-based methods as a tool to improve our understanding of the underlying mechanism behind the RS phenomenon and tune the properties of these oxide films for improved memristor functionality. These investigations are performed by studying the effect of (i) the formation of ion tracks when irradiated by ions with energies of a few tens of MeV and (ii) localized change in stoichiometry/defect creation by controlled ion implantation, on RS properties of the films.

References:

1. Xiang, X., et al. *ACS Appl. Electron. Mater.*, 2021, **3:**1031–1042.

2. Lee, S., et al. *IEEE Electron Device Lett.*, 2018, **39:**668–671.

CT - 19

Thermoluminescence properties of rare-earth-doped $Ca_2B_2O_5$ ceramics after irradiations of heavy charged particles

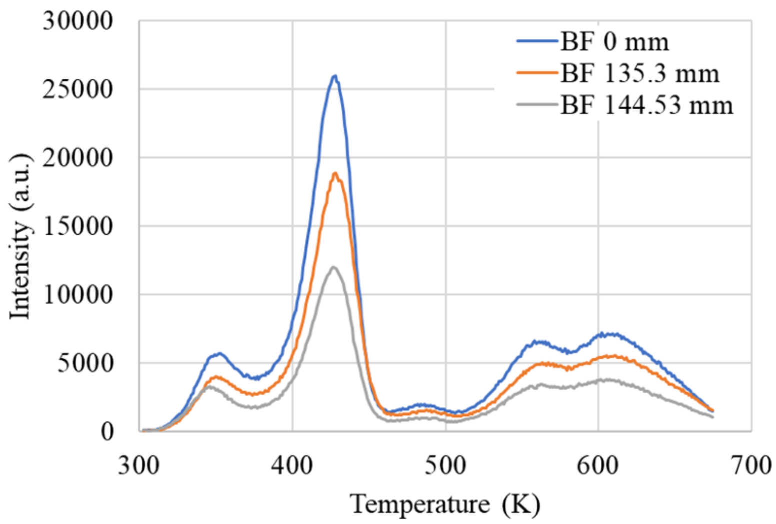
Prof. Masanori Koshimizu[1], Hajime Komiya[2], Yusuke Koba[3], Yutaka Fujimoto[2], Keisuke Asai[2]

[1]Shizuoka University, Hamamatsu, Japan. [2]Tohoku University, Sendai, Japan. [3]QST, Chiba, Japan

Abstract

It is widely known that heavy charged particles produce dense electronic excitation along their trajectories. The deposited energy density per unit length of trajectory is defined as linear energy trasnfer (LET), and the LETs of heavy charged particles are high. Different LETs generally results in different responses of dosimeter materials based on storage phosphors, which is a problem in dosimetry for heavy particle therapy. To obtain dosimeter materials having desired LET-dependent response, we have been analyzing LET effects in thermoluminescence of storage phosphors with different compositions. In this study, we focus on the effects of dopant elements and concentration on the LET-dependent response of rare-earth-doped $Ca_2B_2O_5$ ceramics.

Thermoluminescence glow curves of the rare-earth-doped $Ca_2B_2O_5$ ceramics after irradiation of heavy charged particles were obtained. The samples were irradiated with 150-MeV/n He at HIMAC, QST, Japan. The LET was changed by using binary filters with different thicknesses. The thermoluminescence glow curves of Ce-doped $Ca_2B_2O_5$ after irradiations of He with different thicknesses of binary filters are presented in the figure. The thermoluminescene intensity decreased with the increased thickness of the binary filter, which results in an increase in LET. The decrease in the thermolumnescence intesity at high LET was also observed for other rare-earth-doped $Ca_2B_2O_5$. The LET dependence was pronounced for rare earth dopants that are capable of hole trapping and generates charge-compensating defects as possible trap centers for electrons or holes. This result indicates that the increase in the concentration of the trapping sites results in steeper LET dependence.



CT - 20

Exploring Phase-Transformed V_3Si Superconducting Material Through Rutherford Backscattering Spectrometry Analysis

Mr Fshatsion Gessesew ORCID iD[1], Dr Manjith Bose ORCID iD[1], Dr Kumaravelu Ganesan ORCID iD[1], Dr Brett Johnson ORCID iD[2], Dr Qi Lim ORCID iD[1], Professor Jeffrey McCallum ORCID iD[1]

[1]The University of Melbourne, Melbourne, Australia. [2]RMIT University, Melbourne, Australia

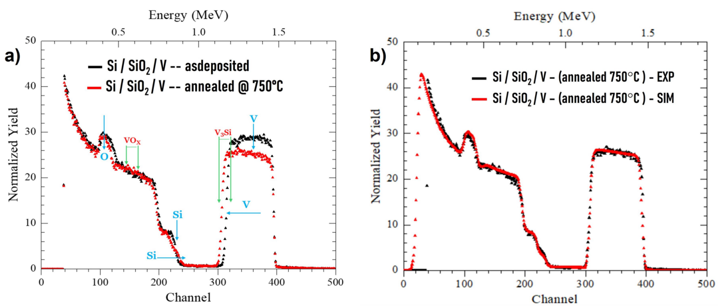
Abstract

Vanadium silicide, V_3Si, exhibits a superconducting (SC) transition at a relatively high transition temperature, T_C ~ 15 K. V_3Si can be formed via a range of Si-V phase transformation processes with V films deposited on Si or SiO_2 substrates. To date, there are no reports of functional devices made from V_3Si. Our goal is to investigate the properties and capabilities of V_3Si films for construction of functional SC devices especially for quantum technologies.

We investigate V_3Si films formed by direct deposition of V on Si or thermally grown SiO_2 on Si followed by high vacuum electron beam annealing to induce the phase formation to V_3Si. Rutherford backscattering spectrometry (RBS) has been employed throughout the sample growth process to investigate the material composition with respect to depth profile using a ^{+4}He ion beam. Analysis of RBS data via Xrump software confirms the formation of V_3Si at the SiO_2/V layer interface. The V_3Si layer thickness ranges 60 - 70 nm with annealing temperatures from 750°C to 800°C. The RBS result in **Figure-1** illustrates the formation of a phase-transformed V_3Si layer in one of our processed samples. Additionally, the samples were bonded into a chip carrier for electrical characterization in a He cryostat. Optical microscopy (OM) and transmission electron microscopy (TEM) studies were conducted on suitably prepared samples.

This report presents results on the successful formation of SC V_3Si using the phase transformation technique, based on analysis with RBS, TEM, and low temperature electrical characterization.

The authors acknowledge support from the NCRIS Heavy Ion Accelerator Platform.



c)

	Before annealing (asdeposited –Si/SiO_2/V)		After annealed at 750°C (Si/SiO_2/V_3Si/VOx)	
LAYER	THICKNESS (nm)	COMPOSITION	THICKNESS (nm)	COMPOSITION
1st	330	V 1	300	V 1 : O 0.32
2nd	230	O 2 : Si 1	60	V 3 : Si 1
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Figure-1: Rutherford backscattering analysis of Si/SiO_2/V sample. **a**) Comparison of RBS spectra between the as-deposited (330 nm **V** on 230 nm thermally grown **Si/SiO_2**) and annealed samples at 750°C. **b**) Elemental composition and thickness analysis using Xrump simulation with (**c**) results presented in table.

IT - 7

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CT - 18

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CT - 19

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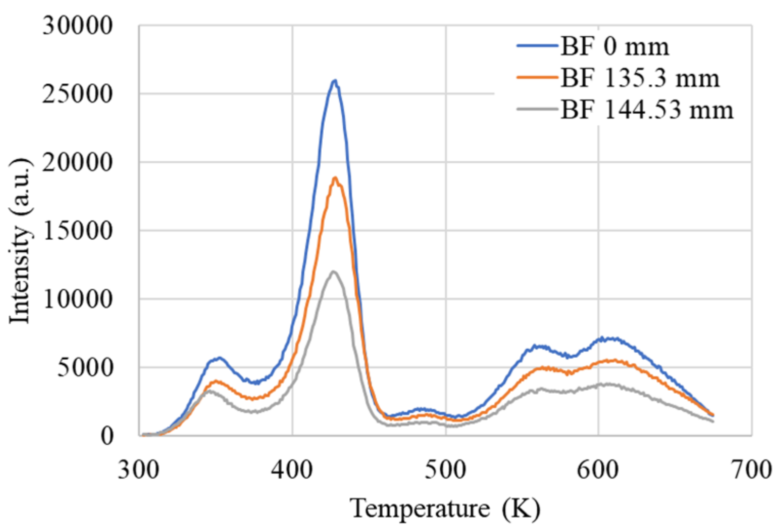

Abstracts

Wednesday

November 27, 2024

IT - 8

Point defect creation for quantum applications in AlN by SHI irradiation under a finely controlled atmosphere

Louise GOODWIN[1], Alexis DUJARRIER[1], Vincent PACARY[1], Pavel LOIKO[1], José OLIVARES[2], Santanu Padhi[2], Clara Grygiel[1], Isabelle MONNET[1], Yvette Ngono Ravache[1], Emmanuel BALANZAT[1], Mamour SALL[1]

[1]CIMAP, Caen, France. [2]CMAM, Madrid, Spain

Abstract

Single deep-level point defects in wide bandgap materials have attracted great attention as they could be used as single photon emitters with desirable spin properties for applications in quantum information processing. For instance, the nitrogen-vacancy (NV^-) center in diamond is distinguished by its robustness as a qubit [1]. This exceptional property of the NV^- center in diamond has stimulated the search for qubits in similar systems. In AlN, which possesses the advantage of a higher maturity in current optoelectronic circuits compared to diamond, several point-defect qubit candidates have been proposed based on DFT calculations. Transition metal-vacancy complexes (Ti_{Al}-V_N and Zr_{Al}-V_N) [2] and an oxygen-vacancy complex (V_{Al}-O_N) are among these qubit candidates [3].

The advantage of SHI irradiation for creating such defects for quantum applications is the ability to separate the defects in individual nanometric columns, along the trajectory of the ions. Several promising results will be presented on the creation of the oxygen-vacancy complex by using GANIL SHI irradiations under controlled atmospheres (O_2, N_2, Ar, or a mixture of these gases) [4] (Figure 1). Some early results on the activation by SHI irradiation of transition metal-vacancy complex (Zr_{Al}-V_N) in Zr pre-doped AlN will also be presented.

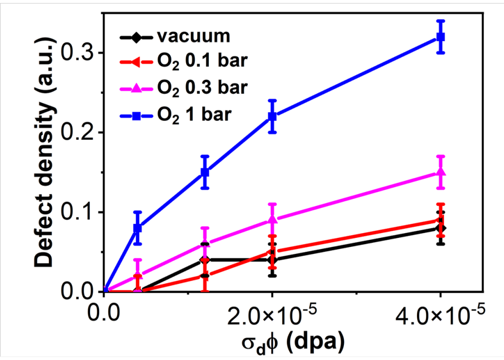

Figure 1 : Evolution of the defect density as a function of the number of dpa under different irradiation atmospheres (Vacuum, P_{O2} = 0.1 bar, 0.3 bar, 1 bar)

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CT - 20

Exploring Phase-Transformed V_3Si Superconducting Material Through Rutherford Backscattering Spectrometry Analysis

Mr Fshatsion Gessesew ORCID iD[1], Dr Manjith Bose ORCID iD[1], Dr Kumaravelu Ganesan ORCID iD[1], Dr Brett Johnson ORCID iD[2], Dr Qi Lim ORCID iD[1], Professor Jeffrey McCallum ORCID iD[1]

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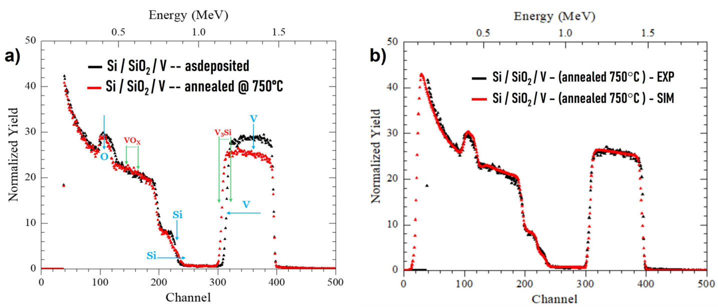

c)

LAYER	Before annealing (asdeposited –Si/SiO_2/V) THICKNESS (nm)	COMPOSITION	After annealed at 750°C (Si/SiO_2/V_3Si/VOx) THICKNESS (nm)	COMPOSITION
1st	330	V 1	300	V 1 : O 0.32
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CT - 21

Ion Track Technology-Based Mechanical Metamaterials

Prof. Dr. Jinglai Duan, Dr. Hongwei Cheng, Dr. Xiaoxia Zhu, Dr. Shuangbao Lyu, Dr. Ran Huang, Dr. Jie Liu

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

Abstract

Mechanical metamaterials refer to a class of composite materials with artificially designed architectures and exhibit extraordinary mechanical properties that traditional materials do not have. Among them, energy absorption mechanical metamaterials can absorb mechanical energy more efficiently, which requires the material itself to have both high strength and high strain capacity. But in general, there is a trade-off between strength and strain capacity and these two are hardly obtained simultaneously.

In this presentation, we will report a new type of nanobeam lattice which is in quasi-body-centered cubic (quasi-BCC) architecture. Such nanolattices with beam diameters as thin as 34 nm were successfully fabricated by ion track technology, using gold and copper as model materials. The mechanical tests show that, even at a relative density lower than 0.5, the compressive yield strengths of the gold and copper quasi-BCC nanobeam lattices exceed their bulk counterparts. Surprisingly, their energy absorption capacities surpass all previously reported micro/nano-lattices. Based on theoretical analysis and simulations, we disclose that such extraordinary properties are ascribed to the synergy of size effect, geometrical architecture, and intrinsic properties of gold and copper. We then used such metamaterials as the anode of lithium-ion batteries. Benefitting from excellent mechanical robustness, high porosity, and low tortuosity of pores, the nanobeam lattice serves well as the "host" of lithium metal anode and the cycle life of anode is therefore significantly improved.

Our work may provide a new idea for extending ion track technology to emerging multidisciplinary fields of interest.

CT - 22

The effect of high and low dose neutron irradiation on mechanical properties and localization of austenitic stainless steels

Mrs. Diana Merezhko ORCID iD, Mr. Mikhail Merezhko ORCID iD, Dr. Kira Tsay ORCID iD

Institute of Nuclear Physics, Almaty, Kazakhstan

Abstract

Changes in microstructure as a result of prolonged neutron exposure at elevated temperatures in the exceptionally harsh environment of a nuclear reactor core could lead to loss of ductility that usually occurs at relatively low-temperature irradiation and tends to cause microscopic and macroscopic strain localization.

This work is devoted to the study of the patterns of plastic deformation of 08Cr16Ni11Mo3Ti and 12Cr18Ni10Ti (316Ti and 321 analog) austenitic stainless steels irradiated in the BN-350 fast reactor(Aktau, Kazakhstan). Samples for studying were irradiated in a wide range of doses and temperatures. The deformation mechanisms of austenitic stainless steels were revealed using combination of tensile testing, in situ magnetic measurements, DIC, and microstructural analysis.

In terms of mechanical properties of irradiated wrappers of fuel and screen assemblies, it was found that the specimens cut from the very bottom of the wrapper(very low doses of irradiation) could not be used as an analog of an unirradiated state, a typical methodological approach for internal reactor components studies. The mechanical properties, in this case, were close to the material irradiated at conditions similar to WWR water pool type reactor: strengthening and significant decrease in ductility in comparison to unirradiated state.

Nevertheless, high-dose irradiation at high temperatures led to an increase the ductility. The temperature of irradiation influences more than the dose or dose rate. High-dose irradiation with a high dose rate at high temperature is equivalent (in terms of effect on mechanical properties) to irradiation at a low dose rate at very low doses.

IT - 9

Characterization of Radiation Effects in Ceramics with Spallation Neutron Probes

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Abstract

The development of radiation-resistant materials for various nuclear applications and their performance in harsh environments has been central to many research efforts over the past decades. However, there still exist gaps in understanding fundamental modes of radiation-induced material degradation. We show that neutron total scattering measurements with pair distribution function (PDF) analysis can be utilized to uniquely characterize the structural properties of swift heavy ion irradiated materials, including complex (e.g., $A_2B_2O_7$ pyrochlore) and simple oxides (e.g., AO_2). Irradiation experiments were performed at the UNILAC accelerator of the GSI Helmholtz Center with 8.6 MeV/u heavy ions. Such projectiles produce sufficiently large irradiated sample mass (~100 mg) required for analysis at the Nanoscale Ordered Materials Diffractometer (NOMAD) beamline at the Spallation Neutron Source (Oak Ridge National Laboratory). Neutron probes enable a detailed analysis of both the cation and anion defect behavior as well as short-range order, which is particularly important for investigating radiation effects with no long-range periodicity. Our results demonstrate that structural changes induced under irradiation are more complex than previously thought, with distinct processes occurring over different length scales and a high degree of local atomic order. For example, disordered crystalline and amorphous pyrochlore oxides are both composed of very similar atomic-scale building blocks despite the very different long-range structures. Tetragonal zirconia that is produced by ion irradiation of monoclinic ZrO_2 exhibits a similar structural heterogeneity with nanoscale orthorhombic domains. These examples highlight the importance of short- and medium-range analysis for a comprehensive description of radiation effects in materials.

CT - 23

A First-Principles Study of Stacking Fault Energy in Ni-based alloy: Role of Alloying Elements

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Abstract

Ni-based alloys have emerged as promising structural materials for advanced Gen IV nuclear reactors due to their superior high-temperature properties. During the operation of a reactor, the materials undergo radiation damage due to the energetic neutrons, resulting in loss of structural integrity because of the formation of defects clusters, dislocation loops, stacking faults, etc [1]. These, in turn, play a significant role in controlling the mechanical properties of the material. Thus, the study of the reliability of the alloys and their performance under high-temperature radiation environments is crucial. One of the important Ni-based alloys is Inconel 718. First-principles calculation based on density functional theory has been used to calculate and compare the stacking fault energy and density of states (DOS) of pure Ni, individual alloying elements (Cr, Fe, Mo, Nb) in the Ni, and finally for Inconel 718. The result shows that the addition of alloying elements to pure Ni reduces the SFE, with the larger reduction seen in Inconel 718. This is also elucidated by the reduction of the density of state (DOS) value upon the addition of the alloying elements. This is because of the interruption of alloying elements on the distribution of d-electrons for pure Ni atoms on the SF planes, which further has an effect on the atomic bonding in the planes and reflects in the SFE value. The lower SFE will alter the irradiation response of the material.

References

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CT - 24

Proton irradiation temperature impact on the tungsten structure and properties during post-radiation annealing in the temperature range 873K-1273K

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Abstract

Results of the structure and properties study of high-purity tungsten irradiated with 350 keV protons at room and 773K temperatures and subsequent isochronous annealing in the temperature range 873 – 1273 K are presented. High-purity tungsten with structure parameters corresponding to ITER tungsten was chosen as the object of research. Proton irradiation up to fluence of 5×1017 cm-2 was carried out at UKP-2-1 accelerator of the Institute of Nuclear Physics in Almaty. Structure and properties of tungsten were studied after successive two-hour anneals in the temperature range 873–1273 K using X-ray diffractometry, scanning electron microscopy, atomic force microscopy, and hardness measurements. It was found:

• Irradiation with 350 keV protons, in contrast to neutron irradiation in hydrogen environment, does not lead to recrystallization up to temperature of 1500K.

• Irradiation at room temperature leads to the formation of gas-filled bubbles (blisters). The blisters do not break to the surface. After post-radiation annealing at 1300K, the blisters dissolve. Irradiation at 773K leads to the formation of breaked-on-surface blisters. Annealing to 1273K leads to appearance of secondary blisters in place of the opened ones.

• Irradiation at 773K leads to degradation of the structure and properties of the surface, which are not recovered upon annealing to 1300K. Irradiation at room temperature leads to significantly smaller changes in the surface structure. The structure and properties are recovered upon annealing at 1300K.

This work was implemented under financial support of the Program of targeted financing of the RK Ministry of Energy NoBR23891530.

CT - 25

Complex Nanostructures Originating from Tracks Created Near the Edge of SiO_2 Quartz Irradiated with Swift Heavy Ions

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Abstract

The ion tracks formed in thin TEM samples of crystalline SiO_2 (quartz) irradiated with swift heavy ions (e.g. 200 MeV and 1.7 GeV Au ions) at normal incidence were observed by transmission electron microscopy in the direction of the irradiation. In the thicker parts of the sample, the ion tracks are imaged as dark circular objects of homogeneous contrasts which correspond to amorphous ion tracks. This result is consistent with the previous studies [1,2]. On the other hand, in the thinner parts of the sample the ion tracks are found to have a concentric structure consisting of a low-density core region and a surrounding damaged region, where the latter region is probably in amorphous state.

When the ion tracks are created very close the edge of the TEM sample, the tracks exhibit a variety of shapes similar to a volcano-like shape whose crater size depend on the proximity of the tracks to the sample edge. When the ion trajectory is close to the free surface, explosive forces from the track center obviously result in significant material ejection. We assume that the concentric track structure in the thin part of the samples is likewise a consequence of this radially, outward-directed explosive force.

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Abstracts

Thursday

November 28, 2024

IT - 10

Simulating the Formation of Functional Nanostructures in Swift Heavy Ion Irradiated Materials

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Abstract

Swift heavy ion (SHI) irradiation can be utilized to create functional nanostructures, including chains of NV centers in diamond as quantum registers [1], and pores in graphene and molybdenum disulfide for filtering purposes. Enhancing the functionality of these nanostructures requires a comprehensive understanding of the formation process, where simulations play a central role in guiding experimental efforts and elucidating underlying mechanisms.

Atom-level simulations incorporating the effects of ionized and excited electrons can be performed using the two-temperature molecular dynamics model (2T-MD) [2]. The predictive power of such simulations heavily relies on empirically parameterizing the model. However, recent software developments [3] make it viable to obtain the electron-phonon contribution to the effective coupling parameter, G, and heat conductivity using density functional perturbation theory even in insulating materials. Moreover, the recent experimental observation of ion tracks in diamond [2] provides a valuable comparison with theory, as monatomic crystalline materials are the easiest to study computationally. Another central development is the means to compute the straggling in electronic stopping power [4], which is especially important for simulating the irradiation of 2D materials. We discuss our recent simulation results incorporating these computational advancements and explore their implications.

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[4] F. F. Selau et al. Thin Solid Films 783, 140038 (2023)

CT - 26

Beyond the ZBL: using modern quantum chemistry to obtain accurate pair-specific repulsive potentials

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Abstract

The basis for any theoretical or computational treatment of atomic collisions in solids is the repulsive interatomic potential. Hence the ion beam field has studied the repulsive interatomic potentials systematically, and developed a wide selection of repulsive interatomic potentials. In the 1980's, Ziegler, Biersack and Littmark (ZBL) had carried out systematic calculations of purely repulsive potentials in the Thomas-Fermi formalism, and by fitting an averaging exponential form to this data, developed a so called "universal" repulsive potential. This potential is used in most codes calculating high-energy ion implantation effects in materials, such as the different varieties of the TRIM and SRIM codes. However, the Thomas-Fermi calculations it is based on were from the 1960's. Hence it is now natural to use more advanced quantum chemical approaches to calculate pair-specific interatomic potentials. We have used the Dmol97 all-electron quantum chemistry approach to calculate all repulsive potentials up to Z = 92, and now taken into use an even more advanced quantum chemistry code that uses a pivoted Cholesky decomposition of the electronic state overlap matrix. Comparison of these results with those of the earlier Dmol97 ones show that the results are consistent to an accuracy ~ 0.5% for all pairs and interaction energies above 100 eV. We also present a fit of a new analytical potential to the new data sets, and show that it is considerably more accurate than the universal ZBL fit.

CT - 27

Bulk, overlap and surface effects of swift heavy ions in CeO_2

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Abstract

The track formation of swift heavy ions (SHI) decelerating in the electronic stopping regime in CeO_2 has been studied using original Monte Carlo code TREKIS [1] combined with the classical molecular dynamics (MD). The approach describes excitation of the electronic system and energy transfer into the atomic subsystem providing initial conditions for the molecular dynamics simulations of subsequent lattice response [2-3].

MD simulations show that the damaged ion track is a CeO_2 discontinuous crystalline region of ~2 nm in size which is surrounded by point defects. Its formation is similar to that in other non-amorphizable solids, e.g. Al_2O_3, MgO [2]: strong disordering (melting) followed by structure recovery. The estimated track formation threshold in CeO_2 is $10.9<S_{th}<17.9$ keV/nm consisting with the experimental value of 15 keV/mn [4]. The recrystallization of the hot ion track can anneal the existing defects, which may explain the experimental saturation of the tracks density with fluence.

Ion impacts of on the surface of CeO_2 result in appearance of spherically shaped crystalline hillocks and conical tracks in the subsurface region of several tens of nanometers depth. The recrystallization process in near-surface area is strongly suppressed by the presence of a solid-vacuum interface and requires much more time than e.g. in CaF_2 [3] having similar crystalline structure.

This research was funded by the Russian Science Foundation (grant No.23-72-01017).

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CT - 28

PHASE TRANSITIONS DURING ULTRAFAST DEVELOPMENT OF SWIFT HEAVY ION TRACKS IN AMORPHOUS MATERIALS

Prof Flyura Djurabekova ORCID iD[1], Dr Henrique Vazquez Muinos ORCID iD[1], Dr Aleksi Leino ORCID iD[1], Prof Kai Nordlund ORCID iD[1], Prof Patrick Kluth ORCID iD[2]

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Abstract

Phase transition induced by a swiftly passing highly energetic ion in an amorphizable crystalline material is clearly visible as an extended track of an amorphous phase within otherwise crystalline matrix. Irradiation of amorphous materials, however, also may leave traces in some materials, at least, as strong variation of atomic densities comprising a so-called core-shell fine structure. The nature of the core-shell structure has been debated suggesting various mechanisms including viscous flow or frozen-in pressure waves.

In this talk, we report unexpectedly fast phase transitions inside the track as a result of simultaneous act of pressure and temperature developing after a swift heavy ion impact. In our molecular dynamics simulations we reveal the origin of the core-shell fine structure observed in amorphous SiO2 and Si3N4, as well as the dense core in a-Si. The fine structure of the results from the different core/shell pressure levels upon solidification, revealing the polyamorphous nature of these materials with strong backbone of the tetrahedral network.

Another example of fast phase transition is observed during swift heavy ion irradiation of amorphous Ge displaying peculiar self-organisation process of a layered nanoporosity. Using molecular dynamics simulations of individual ion tracks, we showed that voids form due to transition from low-density amorphous to high-density liquid phase, giving rise to a flow away from large pores and surfaces. The flow results in a characteristic distance from surfaces and larger pores, below which new voids do not form, and supports the formation of voids at the amorphous/crystalline interface.

IT - 11

Formation of prebiotics in outer space by heavy ion projectiles

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Abstract

Comets and meteorites contain prebiotic organic compounds that are integrated from the Solar Nebula. Cosmic rays and the natural radionuclide decay in the body's mineral rocks are supposed to induce the molecular synthesis. Over the last few decades, numerous investigations have been carried out in laboratory to comprehend the astrochemical evolution, starting from small molecular species, such as carbon monoxide (CO), water (H_2O), carbon dioxide (CO_2), and methane (CH_4), all of them components of ISM ices. To study the formation of prebiotics in outer space, heavy ion beams were carried out inside a high vacuum chamber (10^{-8} mbar) at the IRRSUD beamline of the French Accelerator GANIL.

Chemical reactions on ~ 10 K ices, constituted by Hx Cy Nz Ok, (with x, y, z and k ≥1) molecules, induced by rapid (1-10 MeV/u) heavy ion beam projectiles at different irradiation were investigated. These interactions were designed to model the collisions occurring between cosmic ray with interstellar grains, comets, and icy solar system bodies. Irradiation effects were examined using infrared spectroscopy (FTIR) analysis. The precursor molecules' dissociation cross sections and the new species' creation cross sections were found. As a function of the electronic stopping power, the destruction and formation cross sections of heavy ions are observed to follow the power law $\sigma \sim S_e^n$ (Fig. 1). The analysis includes findings from the literature to confirm the range of this law. The information gathered for this study aims to improve knowledge of complex organic compounds' radioresistance and the creation of radio products.

CT - 29

Defect Engineering in 2D Materials for Reduced Contact Resistance

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Abstract

2D materials are of interest for a broad range of applications due to unique physical properties. However, the performance of electronic devices, such as sensors and field effect transistors, is generally limited by high electrical contact resistance at 2D-metal interfaces. Here, we use graphene as a prototypic 2D material to investigate defect engineering as a means of reducing such contact resistance.

Defects were created in CVD graphene deposited on SiO_2(300 nm)/Si wafers by irradiating with 30 keV $^{12}C^{-}$ ions to different fluences. The defect density and type were subsequently determined by Raman spectroscopy, demonstrating that divacancies are the dominant defect type at low ion fluences, while more complex, topological defects, become increasingly dominant at higher fluences.

Electrical characterisation was performed using back-gated transistor structures with variable electrode spacing. These were fabricated using standard optical photolithography and Cr/Au electrodes. The contact resistance of un-implanted and implanted devices was determined using the Transfer Line Method (TLM); In this approach the device resistance is plotted as a function of electrode spacing, with the contact resistance given by the intercept at zero spacing. The effect of ion implantation on the contact resistance, and the underlying mechanisms will be discussed as part of this presentation.

CT - 30

Irradiation effects of MoS_2/Graphene heterojunction phototransistors induced by swift heavy ions

Associate professor Jian Zeng[1], Hongda Zhang[2], Xirong Yang[2], Associate professor Peipei Hu[1], Lijun Xu[1], Associate professor Shengxia Zhang[1], Professor Pengfei Zhai[1], Professor Jie Liu[1]

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Abstract

Two-dimensional (2D) materials such as graphene, h-BN, transition metal dichalcogenides (TMDCs), black phosphorus, et al., have exceptional electronic and photoelectric properties. Van der Waals heterostructures (vdWH) constructed with various 2D materials are expected to develop a new-generation of ultrathin, high efficiency, broadband and flexible photodetectors, which have a broad application prospect towards outer space exploration. However, due to the ultrathin structure, the defects and impurities induced by irradiation would significantly influence the properties of 2D materials. In this work, we fabricated molybdenum sulfide and graphene vdWH field effect transistors (MoS_2/G FETs) and investigated the evolution of electronic and photoelectric properties induced by swift heavy ions (SHIs) irradiation. At lower ion fluence, SHIs irradiation can optimize the device properties. The decreased resistance R and increased carrier mobilities, total photocurrent I_p and photoelectric responsivity R_p were detected after irradiation. The significant enhancement of I_p and R_p was observed at a fluence of 10^9 ions/cm^2, while when the fluence surpasses 1×10^{10} ions/cm^2, I_p and R_p were slightly changed. At high fluence (1×10^{11} ions/cm^2), the devices properties were deteriorated by SHIs irradiation. What's exciting is that the device can still operate under such harsh irradiation conditions. Defects in MoS_2, graphene and SiO_2 were investigated by Raman spectrum, photoluminescence microscopy and atomic force microscope. The optimized and degraded properties of the devices could be ascribed to competition among doping, local annealing and defect scattering. Our work provides experimental basis for the design and development of future ultrathin, flexible low-dimensional photodetectors with strong irradiation tolerance.

CT - 31

Synaptic field effect transistor based on charge trapping in ion-implanted gate dielectrics

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Abstract

Neuromorphic computing aims to emulate the human brain using parallel networks of solid state synapses and neurons[1]. Novel devices, including: memristors, ferroelectric transistors, synaptic transistors and memtransitors are currently being investigated for such applications [2, 3]. Here, we report the fabrication of a synaptic field effect transistor (FET) based on charge trapping and de-trapping in the gate dielectric.

Back-gated field-effect transistors (FETs) with ultra-thin indium-oxide channel layers were fabricated by squeezing a droplet of In between 300nm SiO_2/p^{++} Si substrates heated to 250 °C in air. After separation and cleaning, this produced a uniform area of InO_x with a thickness ~5 nm that serves as the semiconducting channel of the transistor. Electron beam lithography was subsequently used to define Cr/Au Source/Drain electrodes. The synaptic response of the transistors was achieved by ion-implanting the gate-dielectric prior to InO_x deposition, with the memory effect arising from the capture and emission of charge carriers. Details of these devices and the mechanisms underlying their synaptic response will be discussed.

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IT - 12

Radioimpurity Quantification for Dark Matter Detection

Dr. Zuzana Slavkovska[1], Ferdos Dastgiri[1], Dr. Keith L. Fifield[1], Dr. Michael A.C. Hotchkis[2], Dr. Michaela Froehlich[1], Dr. Dominik Koll[1,3], Dr. Silke Merchel[4,3,1], Dr. Stefan Pavetich[1], Dr. Steve G. Tims[1], Prof. Anton Wallner[1,3]

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Abstract

Dark Matter represents about 85% of all the matter in the Universe, but its nature is not understood. Sodium iodide crystals doped with thallium (NaI:Tl) can be used to directly detect dark matter. Ultra-high purity of the crystals is their crucial feature. Radioactivity from radionuclides intrinsic to the detector materials or surface contamination might mimic dark matter signals and provides a fundamental limit to the detection sensitivity.

The dark matter metrology group at the Australian National University (ANU) is developing ultra-sensitive techniques towards quantification of radio-contaminants. This involves the development of chemical procedures, sample preparation as well as measurements with inductively coupled plasma mass spectrometry and accelerator mass spectrometry using the 14 UD pelletron accelerator at the Heavy Ion Accelerator Facility at the ANU and the 1 MV VEGA accelerator at ANSTO in Sydney. This talk focuses on the radionuclides ^{40}K, ^{129}I and ^{210}Pb, which are expected to be the dominant radioimpurities in low-backgrond direct dark matter detection.

This talk will also introduce SABRE South, a dark matter experiment designed to directly detect annual rate modulation from dark matter interactions using NaI:Tl crystals [1]. The aim of SABRE South is to provide a model independent test of the signal observed by DAMA/LIBRA, which has been measuring purported dark matter signals for over two decades but could not be confirmed by any other experiment [2].

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CT - 32

GRAPHENE PERFORATION BY GRAZING INCIDENCE SWIFT HEAVY ION IRRADIATION

Dr. Pavo Dubček, Dr. Damjan Iveković, Dr. Tihana Čižmar, Dr. Marko Karlušić

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Abstract

CVD-grown graphene on SiO2 substrate was exposed to swift heavy ion irradiation, and when certain conditions (such as ion type, energy, fluence and angle of irradiation) were met, the irradiation resulted in graphene perforation. We used atomic force microscopy and Raman spectroscopy to study the response of graphene to the irradiation and determine conditions that lead to perforation. In particular, 4.8 keV/nm electronic stopping has been established as a threshold value for perforation to occur. The number of perforations detected by AFM is much smaller than the number of ion impacts calculated from the applied fluence. Furthermore, production of vacancies, identified by Raman spectroscopy, is established as a precondition required for graphene perforation. However, large density of defects in graphene, introduced by pre-irradiation under certain conditions, can actually hinder perforation of graphene. For comparison, we also present results of our recent study done on HOPG (graphite) [1].

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Abstracts

Friday

November 29, 2024

IT - 13

Ion Tracks in Diamond

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Abstract

Injecting high-energy heavy ions in the electronic stopping regime into solids can create cylindrical damage zones called ion tracks. However, the tracks are formed in some materials only but not in all the materials. The propensity for tracks to form strongly depends on the properties of the solids: In general, the propensity is higher for insulators and lower for metals, although there are many exceptions. One notable exception was diamond: This insulator was irradiated up to the Bragg peak maximum using GeV uranium ions, but the tracks have never been observed.

Another curious point for the track formation in this material is that diamond does not show the melting transition except under extremely high pressures. With increasing the temperature under ordinary pressures, this material suffers the transformation to graphite and then the sublimation. Since the inelastic thermal spike model presumes the melting transition (or the vaporization transitions in some limited cases) for the track formation. If the tracks could be formed in diamond, they would be formed via a transition that was neither the melting nor the vaporization.

Here, we report, to the best of our knowledge, the first observation of the ion track formation in diamond under C_{60} ion irradiations between 2 and 9 MeV [1].

[1] H. Amekura, et al., Nature Commun. 15, 1786 (2024).

CT - 33

High-Pressure Platform for Swift Heavy Ion Irradiations: Probing Structural Transformations under Extreme Conditions

Ioannis Tzifas[1], Kay-Obbe Voss[1], Christopher Schröck[1,2], Maik Lang[3], Maria Eugenia Toimil-Molares[1,4], Christina Trautmann[1,4,5]

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Abstract

The exploration of materials under simultaneous exposure to various extreme conditions is of interest in diverse multidisciplinary and fundamental research fields, including high-pressure physics, materials research and geosciences. This contribution presents recent developments of the experimental user platform designed to combine extreme static pressures with relativistic heavy ions. Using diamond anvil cells (DACs), small samples can be pressurized to several tens of GPa. The GSI facility accelerates heavy ions up to GeV energies and above, equivalent to ranges of mm-cm, which is sufficient to penetrate the DAC and deposit enormous energy into the pressurized sample. The irradiation platform now houses an online Raman spectrometer to *in situ* monitor beam-induced structural changes under pressure. This requires irradiation through the gasket to access to Raman spectra through the transparent diamond anvils. Ongoing technical improvements and specific pressure- and beam-induced effects in a variety of oxides and minerals are discussed. This includes the formation of new phases far from the thermodynamic equilibrium and the possibility of recovering high-pressure phases upon pressure release.

CT – 34

Nanoscale Fabrication and Application Using Single GeV Ions

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Abstract

When high energy heavy ions bombard into the condensed matter material, the projectile's energy is transferred to the target's electrons and nuclei via Coulomb interactions. For MeV to GeV ions most of their energy is deposited within the radius of 1 nm around the ion trajectory via electronic stopping power (dominant) and nuclear stopping power. The dose deposition of a single heavy ion in the target material can reach up to millions of Gray in the nanoscale-confined volume along the ion trajectory. The interaction induces the target atoms excited or ionized along the ion trajectory, and causes lattice damage in crystals, chain break or cross-linking in polymers, or forms nanoscale latent track and color center in many solid materials. High-energy heavy ions have the advantages of high energy loss, long range and low scattering. This report introduces the basics of the beam interaction with materials, and demonstrates the sub-5nm nanowire fabrication using in-air single ion lithography, nanofluidic fabrication and applications of a single-ion hit microbeam.

CT - 35

Dynamic defect annealing in Er implanted $LiNbO_3$

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Abstract

Disorder removal and optical activation of the implanted atoms typically require post-implant annealing at relatively high temperatures that may lead to the material degradation, especially for thin films. In contrast, disorder formation can be suppressed already during implantation process through dynamic defect annealing which is a handful ion beam technology tool for reducing residual disorder levels in a range of materials [1]. One of the key parameters affecting thermally activated dynamic annealing processes is an irradiation or sample temperature. Thus, in the present contribution we investigate the role of the irradiation temperature on the disorder formation and optical activation of the implanted atoms in Er implanted lithium niobate ($LiNbO_3$) thin films which is a promising material for integrated photonics [2]. Specifically, the $LiNbO_3$ thin films grown on the SiO_2/Si substrate were implanted with 300 keV Er ions to the doses of 0.52-5.2e13 cm^{-2}. The implantation temperature was varied in the range of RT-450 °C. The structural and optical properties of the implanted films were investigated by a combination of PL, RBS/C and SIMS measurements. We demonstrated that dynamic defect annealing can be efficiently used to reduce the radiation disorder and enhance optical activation of implanted Er atoms without significant their redistribution. Further improvements can be achieved by a combination of "hot" implants with post-implantation annealing at moderate temperatures.

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CT - 36

The effect of Al-impurity concentrations on the microstructural response of polycrystalline Si_3N_4.

Dr Arno Janse van Vuuren ORCID iD[1], Dr Vladimir Skuratov ORCID iD[2], Dr Jacques O'Connell ORCID iD[1], Dr Anel Ibrayeva ORCID iD[3]

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Abstract

Certain material properties have a significant impact on the degree of damage which is induced by swift heavy ions (SHIs). The thermal conductivity and the threshold stopping power may both be influences by several material properties such as the presence of dopants/defects, irradiation temperature, and the phase of the material. Other parameters such as particle size and matrix effects for embedded nanoparticles and lattice structure/complexity also play a role in the latent disorder in certain materials [1,2].

In this investigation the role of Al impurities on the microstructural response of polycrystalline silicon nitride (p-Si_3N_4) to SHIs is analysed. Samples were irradiated with Xe (220 MeV) and Bi (670-710 MeV) ions to various fluences ranging from non-overlapping to overlapping ion track regimes. Si_3N_4 with Al impurity concentrations ranging from 0.1 at.% to 3 at. % were examined by means of high-resolution transmission electron microscopy techniques. The threshold electronic energy loss (S_{et}) required to induce amorphous tracks was found to decrease with increasing Al fraction from above 33 keV/nm (0.1 at.% Al) to below 22 keV/nm for specimens containing approximately 3 at.% Al. All specimens are partially amorphized at overlapping ion fluences. The amorphous fraction increases with increasing Al concentrations at the same ion fluence. The presence of Al impurities, which often occupy interstitial sites in Si_3N_4, likely lowers the thermal conductivity through an increase in phonon scattering.

References:

1. Rogozhkin, S.V, et al., NIMB 486 (2021) 1
2. Rymzhanov, R.A., et al. Sci. Rep. 9 (2019) 3837

CT - 37

Simulating Energy-Loss Spectrum in Thin Water Sheets Using PHITS Code for Developing a Novel MeV-Ion Beam Experiment Setup

Dr Yoshiaki Kumagai ORCID iD, Ms Hinako Imamura, Dr Kunikazu Ishii

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Abstract

Fast ion interactions with materials are crucial across scientific domains like astronomy, atmospheric science, and biomedicine. This study examines collision interactions between fast ions and liquid materials, emphasizing their relevance to charged particle cancer therapy. Charged particle therapy, known for precise dose delivery within the human body via the Bragg peak effect, gains recognition. Understanding the collision dynamics of fast ions with liquid materials, especially in the context of liquid water's prevalence in human tissues, is vital for predicting biological responses in radiation cancer therapy.

To enhance understanding, we develop a novel technique to measure stopping cross sections of fast ions in liquid targets. MeV ion beams from a tandem Van de Graaff electrostatic accelerator at Nara Women's University [1] irradiate a thin water sheet generated by a glass microfluidic chip [2]. We measure the energy spectrum of ions passing through the liquid sheet using a silicon-solid detector downstream of the beamline, with a scattering angle of a few degrees.

To design the experimental setup, we employ the PHITS code [3] to simulate the energy spectrum of 2 MeV protons passing through the thin water sheet. We obtain simulated energy spectra as a function of water sheet thickness and proton scattering angle.

In the presentation, we will discuss the details of the simulation results.

[1] N. Shiomi-Tsuda *et al.*, *Nuclear. Inst. Meth.* B, **159** (1999) 123.

[2] J.D. Koralek *et al.*, *Nat. Commun.* **9** (2018) 1353

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CT - 38

Irradiation induced phase transformation in *β*-Ga_2O_3 through in-situ ion irradiation in a TEM

Prof Djamel Kaoumi ORCID iD[1], Bruno Caruso[1], Angelica Lopez Morales[1], Ryan Schoell[2], Prof Farida Selim[3]

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Abstract

Ga_2O_3 has the potential to be used as a semiconductor in harsh environments involving irradiation. Hence, it is important to probe the effects of radiation damage and temperature on the stability gallium oxide crystal structure. This is all the more important than Ga_2O_3 is known to be polymorphic that can be present in six different phases: *α, β, γ, δ, ε* and *κ*. Monitoring radiation effects in terms of possible phase changes and radiation damage is critical to understanding the possible changes in physical properties. In the literature, a phase transformation from *β to κ* was reported in bulk Ga_2O_3 irradiated with ions at room temperature for a given dose. Later, it was reported that the actual phase forming was *γ and not* κ. In order to bring more light onto this irradiation induced phase transformation, a systematic study was done not only to further investigate the mechanisms of the phase transformation in Ga_2O_3 but also the effect of temperature (which has not been reported in the literature). For that matter, irradiations of Ga_2O_3 (grown either by Czochralski (CZ) or Edge-defined Film-Fed Growth (FFG) techniques) were done using 1 MeV Kr ions *in situ* in a TEM. Detailed Diffraction Pattern analysis was performed as a function of irradiation dose, which brought more insight onto the phase transformation and temperature dependence. The experiments showed that, unlike what was suggested in the literature, the phase transformation does not require implantation of ions. The possible mechanism are discussed in this presentation.

Abstracts

Poster Session

P-1

Hydrocarbon dissociation efficiency in carbon dioxide samples using an exhaust gas filter

Ph.D. Natsuko Fujita ORCID iD, Ph.D. Satoshi Jinno, Ph.D. Fumina Minamitani

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Abstract

The isotope ratio of modern carbon is known to be 99:1:10^{-12} for the masses 12, 13, and 14, of which ^{14}C decreases in abundance due to radioactive decay. However, mass spectrometry of carbon samples shows that there are about 10^{-3} ratios of mass number 14. This is mostly hydrocarbons ($^{12}CH_2$, ^{13}CH) with hydrogen attached to carbon-12 and carbon-13. In mass spectrometry, the beam is bent by a magnetic field to measure isotope ratios by mass, but atoms and molecules of the same mass cannot be separated. To measure only ^{14}C, it is necessary to dissociate these molecules and realize a ratio of 10^{-12}. For this reason, radiocarbon accelerator mass spectrometry (^{14}C-AMS) uses an accelerator to remove hydrocarbons.

On the other hand, in automobiles, hydrocarbons are converted to carbon dioxide by passing exhaust gases through a platinum catalyst filter. We will develop a radiocarbon dating method that uses an exhaust gas filter to remove hydrocarbons without using an accelerator. In this study, we investigate the efficiency of hydrocarbon dissociation in carbon dioxide using an exhaust gas filter.

P-2

Single-year analysis of Tree-ring cellulose by a compact laser ablation system for radiocarbon measurement

Ph.D. Fumina Minamitani ORCID iD[1], Ph.D. Natsuko Fujita ORCID iD[1], Ph.D. Satoshi Jinno ORCID iD[1], Ph.D. Takayuki Omori[2], Ph.D. Masataka Hakozaki[3], Prof. Minoru Yoneda[2]

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Abstract

Radiocarbon measurements by a combination of laser ablation (LA) and accelerator mass spectrometry (AMS) is effective in a variety of fields, including geochemistry, anthropology and archaeology, because they allow the analysis of ^{14}C concentration variations in microtissues with high-spatial resolution. Most of the samples applied have been carbonate samples such as stalagmites and corals, and more recently, organic samples such as bones and tree rings have also become applicable. In particular, tree rings are important samples used in the search for cosmic ray anomalies, in which the concentration of ^{14}C increases rapidly due to high-energy particles that are blown to the earth by explosions on the solar surface. However, conventional analytical methods are very costly because they measure a huge number of tree-ring cellulose one by one. If single tree-ring analysis can be expedited by laser ablation sampling, new tree-ring anomalies can be detected efficiently. In addition, the introduction of gas samples by laser ablation will also facilitate the development of rapid measurements and miniaturization of AMS.

In this study, we investigated the practicality of a compact laser ablation sampling system developed for continuous radiocarbon analysis of organic materials to tree-ring cellulose. Specifically, we attempted to detect bomb peak using dated sitka spruce woods.

P-3

Development of ultra-short-pulse beam injector with the laser-driven acceleration for interactions at surfaces

Sayaka oishi[1,2], hironao sakaki[2], sadaoki kojima[2], Thanhhung Dinh[2], Haruya Matsumoto[3], Mahiro Murakawa[3], akari okano[1,2], kunikazu ishii[1]

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Abstract

Laser-driven ion acceleration techniques [1,2] create high-intense beams which focused spatiotemporally are used in the field of radiology for experiments such as the FLASH effect [3] in present. However, non-ordinary accelerator beams, this acceleration technique has the disadvantage that the beam contains many different types of ions (impurity ions on the experiment), which reduces the accuracy of the irradiation experiment. Therefore, impurity ions control by a beam transport system with time-of-flight analysis and pulsed electric field to create a high-intensity MeV-beam for surface interactions at surface.

In this presentation, the principle of laser-driven ion acceleration and the characteristics of the beam are first described. Then, the principle of ion species separation by the time-of-flight method and pulsed electric-field is presented. Finally, the results of the laser-driven ion experiment carried out at National Institutes for Quantum Science and Technology Kansai Institute for Photon Science (KIPS) to generate high-peak intensities of laser-driven ions using a pulsed electric-field of about 10 nanoseconds will be reported.

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P-4

Design for the clarification of X-ray emission phenomena from solids by spatio-temporally focused ion beams

Akari Okano[1,2], Sayaka Oishi[1,2], LIU Chang[1], Yoshiaki Kumagai[1], Kunikazu Ishii[1], DINH THANH HUNG[2], Hironao Sakaki[2], Sadaoki Kojima[2]

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Abstract

Laser-driven ion accelerators have attracted much attention in recent years due to the development of laser technology. Laser-driven ion beams [1] are extremely different in nature from general accelerator beams. While the ion beams from general accelerators are DC current beams with approximately 10^8 to 10^{10} ions per mm^2 per second, laser-driven ion beams are pulsed beams with a time width of about 1 nanosecond and have the same number of ions. When this ultrashort pulsed ion beam is irradiated onto a material, a large amount of X-rays can be predicted to be emitted instantaneously.

X-ray fluorescence analysis (XRF), X-ray diffraction (XRD), and Particle Induced X-ray Emission (PIXE) [2] are well-known analytical methods that use the X-ray emission phenomenon. By measuring the emitted characteristic X-rays with a semiconductor detector, the number of elements contained in the material can be determined. Therefore, we are interested in how the X-ray characteristics change when the spatiotemporally focused laser-driven ions are used for PIXE analysis, compared to a typical accelerator beam.

In this report, we will discuss the design of an experimental setup for comparing the phenomenon of X-ray emission from a target irradiated by the laser-driven ion beams and ion beams irradiated by a tandem accelerator.

[1] A. Maksimchuk, S. Gu, K. Flippo, D. Umstadter and A. Y. Bychenkov: Phys. Rev. Lett. 84, 4108 (2000).

[2] T. L. Alford, L. C. Feldman, and J. W. Mayer, Fundamentals of Nanoscale Film Analysis, Springer (2007).

P-5

Effects of linear energy transfer on thermoluminescence properties of Eu-doped CaF_2 ceramics

Mr Kai Okazaki ORCID iD[1], Dr Masanori Koshimizu[2], Dr Yusuke Koba[3], Dr Takumi Kato[1], Dr Daisuke Nakauchi[1], Dr Noriaki Kawaguchi[1], Dr Takayuki Yanagida[1]

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Abstract

Linear energy transfer (LET) effects on the response of dosimeters based on storage phosphors have been analyzed phenomenologically. To elucidate the dynamics of electrons and holes generated by ionizing radiation and related LET effects, recently, we started the analysis of LET-dependent response of thermoluminescence dosimeters having different compositions, in particular, different dopant concentrations. In this study, we analyzed the LET dependence of the thermoluminescence properties of Eu-doped CaF_2 ceramics with different Eu concentrations.

The samples were irradiated with 160-MeV protons, 150-MeV/n He, or 135-MeV/n C, at HIMAC, QST, Japan. These particles have significantly different LETs. To further change the LET, the particles were decelerated by using binary filters having different thicknesses. After the irradiation, the thermoluminescence glow curves were obtained.

CaF_2:Eu after irradiation of He with different thicknesses of binary filters exhibited a decrease in the thermoluminescence intensity while the glow curve shape was not significantly changed. The LET-dependent thermoluminescence intensity as a function of LET is presented for CaF_2:Eu with different Eu concentrations in Fig. 1. The thermoluminescence intensity decreased with LET, and the decrease was the most pronounced for the sample with the lowest Eu concentration. This result indicates that the LET dependence can be controlled via dopant concentration.

P-6

Thermoluminescence properties of $Y_3Al_5O_{12}$:Ce transparent ceramics at different linear energy transfers

Mr. Kensei Ichiba[1], Prof. Masanori Koshimizu[2], Dr Go Okada[3], Dr Yutaka fujimoto[4], Dr. Yusuke Koba[5], Dr. Takumi Kato[1], Dr. Daisuke Nakauchi[1], Dr. Noriaki Kawaguchi[1], Prof. Takayuki Yanagida[1]

[1]Nara Institute of Science and Technology, Nara, Japan. [2]Shizuoka University, Sizuoka, Japan. [3]Kanazawa Institute of Technology, Kanazawa, Japan. [4]Tohoku University, Sendai, Japan. [5]National Institutes for Quantum Science and Technology, Chiba, Japan

Abstract

Response of thermoluminescence dosimeters generally depends on linear energy transfer (LET). To elucidate the factors related to the LET-dependent response, we analyzed the thermoluminescence properties of $Y_3Al_5O_{12}$:Ce (YAG:Ce) transparent ceramics with different Ce concentrations. Thermoluminescence glow curves were obtained after the samples were irradiated with gamma rays of different doses and heavy charged particles of different linear energy transfers (LETs). The samples were irradiated with the heavy charged particles at HIMAC, Japan, and the LET was changed by using binary filters. The normalized thermoluminescence glow curves of YAG:0.5%Ce after irradiation with 160-MeV protons with different thicknesses of binary filter are presented. The characteristics of the glow curves of the YAG:Ce samples with low Ce concentration significantly depended on the gamma-ray dose or LET. The dependence of the intensities of the glow peaks on the Ce concentration was attributed to the differences in the concentrations of the electron and hole trap sites between YAG:Ce samples. The intensities of the glow peaks recorded at low temperature were higher at low gamma-ray doses and high LETs than they were at high gamma-ray doses and low LETs. The differences in glow curves between similar time-integrated concentrations of electron–hole pairs strongly suggested that the spatial distribution of energy deposition by ionizing radiation affected the trapped states of the electron–hole pairs responsible for thermoluminescence.

P-7

Radiation-induced recrystallization and its role in the formation of corrosion resistance and mechanical properties of ferritic-martensitic steels

Dr. Kira Tsay ORCID iD, Dr Diana Merezhko ORCID iD, Yelena Kim ORCID iD, Dr. Mikhail Merezhko ORCID iD

Institute of Nuclear Physics, Almaty, Kazakhstan

Abstract

High chromium ferritic-martensitic steels are used as structural material in sodium-cooled fast (SFR) neutron nuclear reactor core due to their excellent void swelling resistance. Their performance depends on stability of the dual phase structure of swelling resistant high-strength tempered martensite forming subgrains in a ductile corrosion resistant ferrite. This paper investigates the stability of the dual phase structure of EP-450 steel widely used in Russian SFRs during neutron irradiation.

Specimens were irradiated to 50–53 dpa at 295...405°C in BN-350 SFR located in Aktau, Kazakhstan. Some specimens were irradiated in the WWR-K research water pool reactor located in Almaty, Kazakhstan to doses less than 0.1 dpa. Microstructural examinations before and after irradiation were conducted using Toshiba TM 4000 plus scanning and JEOL JEM-2100 transmission electron microscopes equipped with EDS.

Phase instability of EP-450 steel under high-dose irradiation was observed. The proportion of ferrite and martensite phases changed from 1:1.7 for non-irradiated steel to 2.6:1 for steel irradiated to 53 dpa. It is assumed that the main reason is the processes of recovery and recrystallization under irradiation indicated by structural changes in the residual martensitic phase, associated with a decrease in the density of subgrain boundaries, a simplification of the block structure of subgrains and a decrease in the density of dislocations. Dislocation mechanism of “erosion” of subgrain boundaries in tempered martensite was observed. The role of phase recrystallization on corrosion resistance and mechanical properties of material was studied.

P-8

Optical Properties of Nanoholes in Low Refractive Index Polymer Films

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Abstract

Dielectric nanoholes play a significant role in the fields of optical sensing, manipulation, and transmission, with a series of important research achievements already made. The refractive index is a key physical quantity that affects the interaction between dielectric nanoholes and light. However, due to the limitations in the controllable fabrication of ideal cylindrical hole structures, the optical properties of low-refractive-index dielectric nanoholes remain underexplored. By fabricating low-refractive-index dielectric nanoholes with ideal hole structures through swift heavy ion irradiation and subsequent chemical etching, and combining far-field and near-field optical characterization experiments, the optical properties and principles of low-refractive-index dielectric nanoholes have been explored. This research contributes to a deeper understanding of the optical properties of low-refractive-index dielectric nanoholes and expands the application of heavy ion track-etched membranes in the field of optics.

P-9

Development of an Ion-Funnel Reaction Cell for Suppression of Isobaric Interference in Chlorine-36 Measurements

Ph.D. Satoshi Jinno ORCID iD[1], Ph.D. Natsuko Fujita ORCID iD[1], Prof. Hajime Tanuma ORCID iD[2]

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Abstract

Dating using chlorine-36 (^{36}Cl) contained in groundwater is extremely useful in geological surveys and analysis of global environmental changes. However, detection of ^{36}Cl requires an accelerator mass spectrometer (AMS) of 6 MV or higher to separate it from sulfur-36 (^{36}S) which is an interfering nuclide, and there are only 11 facilities in the world that can meet this requirement. Therefore, the number of facilities capable of measuring ^{36}Cl as an isotopic tracer must be increased to conduct a wide range of surveys can be carried out.

In order to overcome this problem, we conceived the idea of applying a reaction cell using an "ion funnel", which has been popular in polymer chemistry since around 2000, to ultra-trace isotope analysis. The purpose of this project is to establish a method to remove interfering nuclides by advancing the ion-molecule reaction to the limit, and to enable the measurement of ^{36}Cl at many facilities.

To proceed with this study, we conducted a simulation study of the behavior of ions in the ion funnel, including the high-frequency electric field applied to the ring electrode, the potential gradient for downstream transport, and the collision process with the buffer gas. As a result, the experimental parameters, including the frequency and voltage applied to the ring electrode and the pressure of the buffer gas, were determined. Based on this simulation, a prototype ion funnel was fabricated. In the future, after assembling this device and confirming its operation, a proof-of-principle experiment will be conducted.

P-10

Development of an Experimental Method for Measuring Stopping Cross-Sections in Liquid Phase Using MeV-Projectile Ions

Ms Hinako Imamura, Dr Yoshiaki Kumagai ORCID iD, Dr Kunikazu Ishii

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Abstract

The interactions between fast ions and materials are of significant interest across diverse scientific fields, including astronomy, atmospheric science, life sciences, and biology. This study focuses on investigating the collision interactions of fast ions with liquid materials, particularly emphasizing their significance for charged particle cancer therapy. Charged particle cancer therapy leverages the Bragg peak effect to achieve precise dose distributions within the human body, making it increasingly recognized for its efficacy. Understanding the collision interactions of fast ions with liquid materials is crucial for predicting biological responses in radiation cancer therapy, given that liquid water constitutes a major component of human tissues.

In pursuit of this aim, we introduce a novel experimental technique to measure the stopping cross sections of fast ions within liquid targets. A tandem Van de Graaff electrostatic accelerator at Nara Women's University provides ion beams with MeV kinetic energy [1]. The liquid sample is introduced into the vacuum chamber as a thin liquid sheet with a thickness of a few micrometers, facilitated by a borosilicate glass microfluidic chip [2]. The energy spectrum of ions passing through the liquid sheet is measured by a silicon-solid detector located downstream of the beamline, with a scattering angle of a few degrees. The energy losses of ions obtained from the experimental energy spectrum are expected to yield the stopping cross sections of ions in the liquid phase.

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[2] J.D. Koralek *et al*., *Nat. Commun.* **9** (2018) 1353

P-11

Simulating Energy-Loss Spectrum in Thin Water Sheets Using PHITS Code for Developing a Novel MeV-Ion Beam Experiment Setup

Dr Yoshiaki Kumagai ORCID iD, Ms Hinako Imamura, Dr Kunikazu Ishii

Nara Women's University, Nara, Japan

Abstract

Fast ion interactions with materials are crucial across scientific domains like astronomy, atmospheric science, and biomedicine. This study examines collision interactions between fast ions and liquid materials, emphasizing their relevance to charged particle cancer therapy. Charged particle therapy, known for precise dose delivery within the human body via the Bragg peak effect, gains recognition. Understanding the collision dynamics of fast ions with liquid materials, especially in the context of liquid water's prevalence in human tissues, is vital for predicting biological responses in radiation cancer therapy.

To enhance understanding, we develop a novel technique to measure stopping cross sections of fast ions in liquid targets. MeV ion beams from a tandem Van de Graaff electrostatic accelerator at Nara Women’s University [1] irradiate a thin water sheet generated by a glass microfluidic chip [2]. We measure the energy spectrum of ions passing through the liquid sheet using a silicon-solid detector downstream of the beamline, with a scattering angle of a few degrees.

To design the experimental setup, we employ the PHITS code [3] to simulate the energy spectrum of 2 MeV protons passing through the thin water sheet. We obtain simulated energy spectra as a function of water sheet thickness and proton scattering angle.

In the presentation, we will discuss the details of the simulation results.

[1] N. Shiomi-Tsuda *et al*., *Nuclear. Inst. Meth.* B, **159** (1999) 123.

[2] J.D. Koralek *et al*., *Nat. Commun.* **9** (2018) 1353

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P-12

Characterization of Heavy Ions produced by Protons Passing Through Shielding & Packaging and Induced SEU in Nano-Devices

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Abstract

With integrated circuit feature sizes shrinking and the commercial aerospace industry flourishing, single-event upsets (SEUs) triggered by protons have emerged as a critical threat to on-orbit spacecraft anomalies. Recent studies reveal that low-Z secondary ions generated from proton-device material nuclear reactions are progressively dominating the contribution to SEU cross-sections. However, software tools like CRÈME and SPACERAD employed for predicting on-orbit error rates solely account for the shielding effects of spacecraft shielding and device packaging against primary protons, neglecting the impacts of secondary heavy ions produced as protons traverse these shielding layers on device SEUs. This work conducted simulation research based on Geant4 for this situation. The simulated results demonstrate that as device feature sizes shrink and incident proton energies rise, the quantity of secondary ions collected within device sensitive volumes originating from spacecraft shielding and packaging correspondingly increases. Once incident proton energies above 1 GeV, the contributions from secondary ions emanating from shielding layers and packaging to SEU cross-sections in devices with sub-65nm feature sizes become non-negligible. Furthermore, above 5 GeV incident proton energies, these secondary ions and their induced SEU cross-sections even dominate as the primary sources of SEUs.

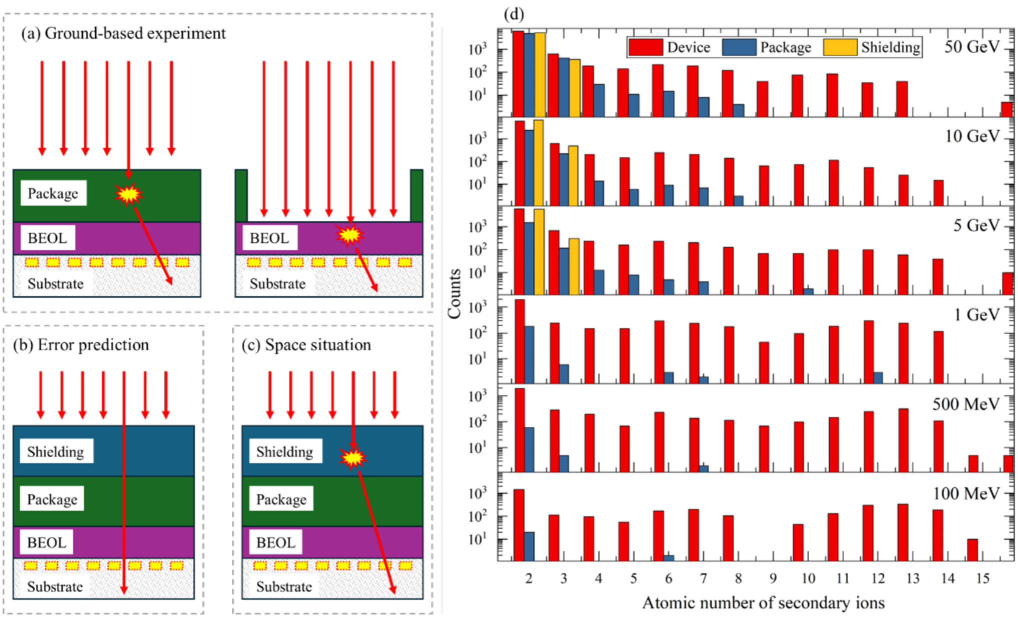

Fig.1 Geant4 models of the different conditions for (a) ground-based experiments, (b) software predictions and (c) space. (d) Secondary ions collected in the device's sensitive volume under the irradiation of protons with different energies.

P-13

Classical Orbital Simulation of Rainbow Scattering Patterns Induced by Fast Ions Passing through Graphene

Associate professor Kunikazu Ishii, Graduate student Kanae Saito, Assistant Professor Yoshiaki Kumagai

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Abstract

We report on classical trajectory simulations of rainbow scattering patterns due to the transmission of fast-ions through a monolayer of graphene. Since graphene is composed of carbon atoms arranged in a honeycomb-like pattern, the transmitted ions are deflected from the carbon atoms that make up graphene by the screening Coulomb potential. The existence of a singularity in the relationship between the scattering angle of the ions and the points of passage (collision parameters from carbon atoms) within the graphene hexagon causes rainbow scattering as the ions pass through graphene. In a previous study, a classical rainbow scattering simulation of 5 keV p^+ transmission was reported [1], in which ions passing through the center of the graphene hexagon form a hexagonal pattern, while ions passing near the carbon atoms form a large circular pattern.

In this study, we report on the simulation of rainbow scattering patterns associated with the penetration of ions in the sub-MeV region through graphene. The effective potentials are discussed by comparison with the rainbow scattering patterns obtained experimentally.

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P-14

Survival rate and dissociation phenomena associated with the penetration of diatomic molecular ions through graphene

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Abstract

Graphene is a two-dimensional material consisting of carbon atoms arranged in a honeycomb-like pattern and is attracting attention as a next-generation nanotechnology material. When ions are transmitted onto graphene, only a single scattering phenomenon can be observed, making it possible to efficiently measure graphene's properties. Multiple charged ion permeation experiments were performed to investigate the electrical properties of graphene, and monolayer graphene provided tens of electrons to neutralize the charge of multiple charged ions at low speed within a few femtoseconds [1].

In this study, we report on charge transfer and dissociation phenomena when diatomic molecular ions pass through graphene monolayers. The distance between carbon atoms in graphene is approximately 0.14 nm. This is comparable to the internuclear distance between the nuclei of a typical diatomic molecule and allows us to observe the orientation dependence of the transmission of diatomic molecules. The experiment was performed using 1.0 MeV Li_2^+ ions produced by the tandem accelerator at Nara Women's University. We introduce the molecular orientation dependence of the survival rate of Li_2^+ through graphene monolayers and report on the charge state distribution of fragment ions.

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P-15

Time-Resolved Optical Interferometry of the Interaction of Heavy Ions with Water

Julia Liese[1], Anna-Katharina Schmidt[1], Timo Pohle[1], Leon Kirsch[1,2], Alexander Praßelsperger[1], Martin Schanz[2], Dmitry Varentsov[2], Johannes Hornung[2], Walter Assmann[1], Zsuzsanna Major[2], Jörg Schreiber[1]

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Abstract

Processes involved in and initiated by the energy deposition of ions in matter, particularly in water, are of great scientific interest and still hold surprises. We developed and tested a method, which allows us to measure the refractive index change of water directly at the Bragg peak. By probing this region with a femtosecond laser pulse and using an interferometric technique, refractive index changes associated with the pressure wave and heating can be detected. By changing the time delay between our probe laser and the ion arrival, different snapshots can be acquired reaching from nanoseconds after the interaction up to milliseconds. We tested this optical detector for the first time with heavy ions (^{238}U and ^{100}Mo) at the SIS-18 accelerator at GSI Darmstadt. Directly after the ion matter interaction we observed opacity changes--likely due to solvated electron formation. At intermediate, microsecond timescales the pressure pulse emerging from the Bragg peak was captured and a complete evolution of the wave propagation was obtained. Additionally, we get a picture of the heating process in the Bragg peak, which lasts up to milliseconds after the ion impact. The temporal resolution is currently limited to nanoseconds by the duration of the ion bunch and lack of better synchronisation, issues that can be overcome in the future. This promises deeper understanding of the effects involved in ions interacting with water, and transparent matter in general.

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P-16

Acoustic Measurement of the Energy Deposition of Heavy Ions in Water at 4°C

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Abstract

Energy deposition of ions in water leads to the emission of a pressure, i.e. ionoacoustic wave. It is commonly described in the thermoacoustic approximation, that is, localized heating and volume change is considered as prime cause of the wave. If this was true, no pressure wave would be expected at 4°C, which was indeed observed after localized absorption of light. Contrary, when initiated by protons, this minimum is shifted to significantly higher temperatures of around 4.5°C, hinting towards an additional, non-thermal excitation mechanism that has not yet been understood and is referred to as ”charge effect” in the literature [1]. We investigated this effect experimentally for the first time in heavy ions(^{238}U and ^{100}Mo) by measuring the polarity change of the pressure wave around the water anomaly at 4°C during beamtimes at the SIS-18 accelerator at GSI Darmstadt. Different behaviour in the lateral and axial acoustic signals suggest a strong unexpected directionality of the non-thermal excitation mechanism. Understanding this non-thermal effects has potential implications for completely new measurement principles, could open up new insights into the fast, pre-thermal processes and even help classifying the relevance of mechanically induced radiation damage. This work was supported by GSI-LMU F&E cooperation LMSCH2025, DFG (491853809) and BMBF (05P21WMFA1). Results are based on an experiment in the context of FAIR Phase-0 at GSI, Darmstadt (Germany).

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P-17

Determining the Stopping Power of Low Kinetic Energy Ne^+ Projectiles in Self-Assembled Monolayers

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Abstract

Neutral Impact Collision Ion Scattering Spectroscopy (NICISS) is used to measure the energy loss in organic self-assembled monolayers (SAMs) on Au using Ne+ with low kinetic energies from 3 to 5 keV. With increasing film thickness, the energy loss of the projectiles increases because the projectile experiences more collisions with target atoms.

Through comparing Monte-Carlo simulations with the NICISS experiments, it was found that contributions from nuclear stopping for Ne+ were significantly larger than for He+ mainly due to the stronger contribution of small-angle scattering of Ne+ making Ne NICISS unsuitable for depth profiling at energies of 5 keV or lower. The measured Ne+ electronic stopping in SAMs is small despite the large atomic number of Ne. Comparing experiments and DFT calculations shows that the latter accurately reproduce stopping powers for Ne+, while SRIM overestimates the stopping power. This contrasts He+ ions, where DFT and SRIM align closely with experiments.

P-18

Nanostructures Induced by Slow Highly Charged Ions on Ultrathin PMMA Films

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Abstract

Surface nanostructures formed by single highly-charged ion (HCI) impacts on ultrathin poly(methyl methacrylate) (PMMA) films were systematically investigated as a function of the thickness h of the layers ($3<h<80$nm). Irradiations with Xe ions of different initial charge states and fixed kinetic energy (260keV Xe^{q+}, q=30-40) and of fixed charge state and different kinetic energies (20-260 keV Xe^{33+}) were performed at the University of Duisburg using the HICS beamline under normal incidence. Scanning force microscopy (SFM) in the peak force mode and under ambient conditions was used to monitor the size and shape of the impact features. The nanostructures induced by the HCI on thin polymer films are shallow cavities (craters), ~12nm in diameter and roughly 1-2 nm deep. Both crater diameter, D_{crater}, and crater depth, Z_{crater}, vary accordingly to the potential and kinetic energy of the ion, as expected. However, the crater dimensions showed very little change for different film thicknesses, even for very thin samples of ~ 3nm. These findings provide experimental evidence that the entire potential energy of the HCI is deposited into the first few nanometers of the material and that the nanostructures produced by the HCI involve material excited at depths smaller than about 3 nm in the films. Although the tips used were Scan Asyst-air from Bruker with a nominal radius of 2 nm, there are metrological challenges for measuring shallow cavities of diameters close to 10 nm using SFM, making the edges of the nanostructures difficult to define with high accuracy, which are also going to be discussed.

P-19

Dynamic behaviors of lithium ions at positive electrode/solid electrolyte interfaces under charging conditions with different rates using ion beams analysis

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Abstract

All-solid-state lithium (Li)-based batteries (ASSB) have been expected as next generation rechargeable batteries. The existing interface between positive and negative electrodes and solid electrolyte (SE) has the highest resistance for the Li^+ ion migration in ASSB and dominant for the characterization of ASSB. Therefore, probing the interfaces and understanding dynamic behaviors of Li^+ ions at interfaces are essential to realize the development of ASSB. In this study, the change in the Li concentration around the $LiCoO_2$ positive electrode/LATP($Li_{1+x+y}Al_xTi_{2-x}Si_yP_{3-y}O_{12}$) SE interface during slow and fast charging conditions was in-situ investigated using elastic recoil detection analysis (ERDA) and time of flight elastic recoil detection analysis (ToF-ERDA) with 9.0 MeV O^{4+} ion beams. ERD spectra on the slow and fast charging conditions revealed that the Li concentration, *x*, in Li_xCoO_2 gradually decreased with increasing the charged voltages up to 2.8 V and, eventually, reached to be approximately 0.2 and 0.3 mol, respectively. For the mechanism on the Li^+ ion transport from the positive electrode to the negative one, the Li^+ ions can overcome at the positive electrode/SE interface with the highest resistance in the sample by applied voltages, diffuse into the SE, and finally accumulate at the negative electrode as intercalation. In the fast charging case, the large amounts of Li accumulated at the interface create the Li concentration gradient inside Li_xCoO_2 and may tend to be returned back to the negative electrode.

P-20

Morphology of latent tracks in the oblique incident TMDCs

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Abstract

Transition metal dichalcogenides (TMDCs)-layered materials have been attracting intense research efforts with totally changed physical scenario. In our work, heavy ion irradiation technology under different conditions was utilized to produce complex defects in TMDC-based devices. Defects with amorphous structure in the core, called latent tracks, were observed averagely distributed in the irradiated TMDCs. Morphology of the tracks varies from nearly circle shape to be cylindrical as the incident direction of heavy ions change from normal to oblique. Visible ellipsoid ends were found in the oblique irradiated samples. With the increasing of the sample's thickness, the middle waist of the tracks narrowed until the tracks became segmented chains. When the incidence angle tilt to 15°, ions skipped on the surface of the free standing few-layer TMDCs. Voids appeared not only at both ends of the track, but also at one end, or in the middle of the track. Electrical transport and optoelectronic properties were concerned. Degradation mechanism related to trap localization in the channel and Schottky barrier at the interface was explored. We believe that our work serves as a foundation for radiation aerospace application of all-in-one devices.

P-21

Thermal stability of latent tracks in β-Ga_2O_3 induced by swift heavy ions

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Abstract

β-Ga_2O_3 is a promising material for high power electronics, deep-ultra-violet photodetectors, and gas sensors due to its ultra-wide energy bandgap (~4.8 eV) and high critical electric field (breakdown field of ~8 MV/cm). Due to its high bond energy, β-Ga_2O_3 is also considered to have high radiation hardness to the displacement damage induced by nonionizing radiation. However, β-Ga_2O_3 materials have been proven to be sensitive to the swift heavy ions. Our previous study found that the electronic energy loss (S_e) threshold of latent track formation in β-Ga_2O_3 was about 17 keV/nm for 5-10 MeV/u heavy ions, which was much lower than the S_e threshold of SiC and GaN. Therefore, these permanent damages (latent tracks) could significantly affect the performance of β-Ga_2O_3 devices in the space radiation environment. In this work, the β-Ga_2O_3 samples were irradiated with 2.4 GeV and 2.9 GeV ^{181}Ta ions at 5×10^{10} ions/cm^2. After that, the irradiated β-Ga_2O_3 were annealed at different temperatures from 473 to 773 K in vacuum. The microstructures of irradiation damages were characterized by transmission electron microscopy. The changes of average diameter and morphology about latent tracks were observed as a function of annealing temperature. The reduction of latent tracks areal density after annealing at 773 K indicates that most latent tracks have been recovered. We suggest that the lower activation energy of thermal recovery processes in β-Ga_2O_3 was the main reason for latent track recovery, compared with SiC, GaN, AlN and diamond. This study could help estimate the service capability of β-Ga_2O_3-based devices under extreme high-temperature irradiation environments.

P-22

Annealing effect of P-implanted diamond by MeV-ion irradiation

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Abstract

The authors implanted P atoms at 50-keV and 140-keV energies with respective fluences of 1×10^{14} cm^{-2} and 2×10^{14} cm^{-2} into diamond. The occupational sites of implanted P atoms were determined in each processing stage of P implantation, ion-beam-induced epitaxial crystallization (IBIEC) annealing by 3-MeV Ne^{2+} ions irradiation at 750°C and thermal annealing at 850°C in vacuum, by quantitatively comparing the random and channeling yields in Rutherford backscattering (RBS) measurements. In the analysis of RBS spectra, simulated distributions were fitted to the experimentally obtained spectra and we quantitatively identified the occupational sites and ratio of implanted P atoms. In addition, we investigated diffusion phenomenon of implanted P atoms during annealing processes from the depth profile of scattered He ions. Consequently, the averaged occupational ratio in the substitutional or highly symmetrical lattice site was stably recorded around 50%. From the depth profile in the RBS spectra, thermal diffusion of implanted P atoms was clearly observed during the last thermal annealing after MeV-IBIEC annealing. We finally discuss the potentials of the MeV-IBIEC irradiation at relatively low temperatures applying to useful and credible annealing method for electrical activation as well as recovery of damaged crystallinity.

P-23

Cryogenic electron microscopy study for the latent ion tracks in polyimide induced by swift heavy ion irradiation

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Abstract

Swift heavy ion irradiation may induce continuous latent tracks in polymetric materials such as polyimide. The tracks are with low material density and high chemical activities. Also, due to negligible cross-section of elastic collisions of swift heavy ions, the tracks are straight, with an extremely high aspect ratio. Those characters make latent tracks in polymers unique, and sequentially lead to important applications such as nuclear track membranes. However, there is a long-standing issue that the fine structure of latent tracks in polymer remain unclear. Especially, high spatial resolution electron microscopy (EM) is very difficult to apply due to a severe damage from focused electron beam.

With recent developments of cryogenic electron microscopy (cryo-EM) technology, researchers have successfully performed EM for electron-sensitive specimens such as biological samples and metal–organic frameworks. In this work, the fine-structure of latent tracks in polyimide membrane are studied using cryo-EM. At liquid nitrogen temperature, thermal damage induced by e-beam was found suppressed remarkably. Together with a well-designed sample preparation process, by using cryo-EM, images of the cross-sections of original latent tracks in a polyimide membrane have been collected. Moreover, the variation of density, elemental contents and chemical bonding in the track region can also be obtained. By this study, we are aiming to develop a method for the characterization of the e-beam sensitive polymetric materials with high resolution. Moreover, improved knowledge of the latent tracks in polymers may contributed to the understanding of ion-solid interactions and energy dissipation processes.

P-24

Comparative studies of radiation damage of Cr18Ni9Ti steel irradiated with iron, nickel and krypton ions up to high damage dose

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Abstract

The results of studies of the effect of irradiation with iron, nickel and krypton ions on the structure and properties of Cr18Ni9Ti structural steel are presented. Irradiation with iron ions with an energy of 98 MeV, nickel ions with an energy of 101 MeV and krypton ions with an energy of 125 MeV forms different surface morphologies, see figure.

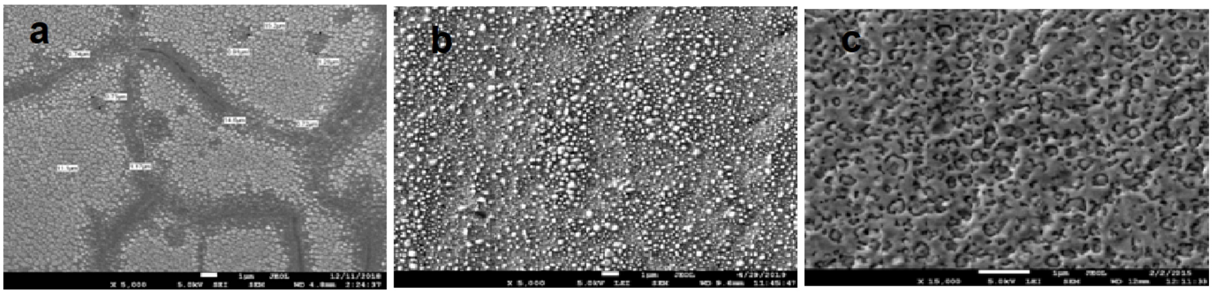

Figure. Surface structure of Cr18Ni9Ti steel irradiated with ions of a) iron, b) nickel, and c) krypton

In the case of irradiation with iron ions, etching of grain boundaries and their depletion in Cr, O and enrichment in nickel are observed, as well as the formation of a columnar structure consisting of chromium oxide. In the case of irradiation with nickel ions, etching is observed, but no noticeable redistribution of the main elements is detected. In the case of irradiation with krypton ions, ion etching of the steel surface is observed with the formation of a coral-shaped structure.

Studies have also been carried out on the structure and properties of Cr18Ni9Ti steel irradiated with low-energy Fe^{+10} and Kr^{+14} krypton ions (20 keV per ion charge). It has been shown that, in addition to changes in the surface structure, low-energy irradiation also causes significant surface sputtering. Structural changes entail changes in the properties of steel, such as hardness and corrosion resistance.

This work was implemented under financial support of the Program of targeted financing of the RK Ministry of Energy NoBR23891530.

P-25

Surrogates of Type II Collagen under irradiation : the influence of the side chain structure on defects creation

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Abstract

Collagen, a major constituent of the extracellular matrix of cartilage, is crucial for tissue mechanical properties. In the context of hadrontherapy, knowing the modifications induced in this material is mandatory. However, due to the complexity of its constitution in terms of amino acids, it is difficult to study the collagen. Surrogates of collagen such as polyglycine (PG), polyproline (P-L-P) or polyalaline (P-DL-A), $(\text{Proline-Proline-Glycine})_{10}$ and $(\text{Proline-Hydroxyproline-Glycine})_{10}$ tripeptides has been studied under both electron and ion beams and their evolution at the molecular level followed using in-situ analyses by Infrared and mass spectroscopy.

It results from these studies that these materials are rather stable under irradiations. Most of the defects are created from the chain reorganization subsequent to the scission of the CO-NH bond. In presence of a lateral chain or group, such as in P-DL-A or in P-L-P, the scission of the $CO\text{-}C_\alpha H$ bond appears significant. Moreover, in the case of P-L-P, the presence of a pyrrolidine cycle and a tertiary amide seems to point towards the increased scission of $N\text{-}C_\alpha H$ or $N\text{-}CH_2$ bonds.

Gas irradiation products such as H_2, CO, CO_2, and CH_4, were identified and quantified in some cases. The effect of Linear Energy Transfer (LET) was observed, notably on poly-DL-alanine films, with increased yields of H_2 and CO at high LET.

P-26

Dependence of linear energy transfer on damage to nucleotide molecules

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Abstract

A new technique called the multi-ion irradiation method has been proposed to reduce the side effects of particle cancer therapy. [1] This technique uses multiple types of ion beams. However, it is essential to understand how the DNA damage is affected when the ion species are varied. In this study, we used various types of ion beams to irradiate nucleotide molecules, which are the basic building blocks of DNA, to investigate the effect of linear energy transfer (LET) on DNA damage.

Solid targets consisting of nucleotide molecules were used in an experiment to investigate the dependence of LET on damage to the molecules. MeV-energy beams of He, Li, and C were irradiated on the target. Time-of-flight mass spectrometry was used to measure the secondary ions emitted from the nucleotide molecule, which helped to identify the damaged site of the nucleotide molecule. The figure shows the ratio of the secondary ion yield produced by damage to the base as comparted to the yield produced by damage to the ribose phosphate site in Adenosine 5′-monophosphate (AMP) when exposured to 2.0 MeV He^+, 1.0 MeV Li^+, and 1.0 MeV C^+ beams. AMP is a nucleotide molecule. As the LET of the projectile ions increased, the damage to the ribose and phosphate sites also increased.

We will discuss the results of other projectile energies and present the relationship between LET and damage to nucleotide molecules.

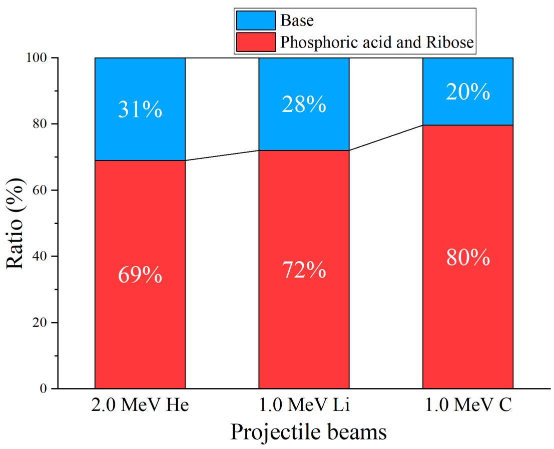

Figure: Dependence of the damage ratio of base and ribose phosphate in AMP on incident ion species.

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P-27

Irradiation temperature effect on stability of SiC irradiated with swift heavy ions

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Abstract

The resistance of SiC to swift heavy ions (SHI) irradiation is well-known. However, no experiments were made on SHI irradiation of this material at elevated (extreme) temperatures. We applied the combination of the Monte-Karlo TREKIS-3 code with molecular dynamics [1] to study the temperature effect at all stages of track formation in SiC: from the ion passage to the stable damaged track formation. Our calculations showed that the energy density deposited to the atomic system around the SHI trajectory increases with the irradiation temperature. At the temperatures higher than 1800 K, this led to formation of a chain of voids along the ion trajectory. Mass was removed from the track core by appearance and sliping of edge dislocations. At temperatures ≤1800 K, the stresses in the track were too low to initiate the dislocation formations and, as a result, the initially damaged track region recrystallized completely within 100 ps. The results show the necessity of introducing a temperature criterion of SiC resistance to SHI irradiation.

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P-28

Artificial nociceptor realized in Au-ion implanted TiO_x memristor at nanoscale

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Abstract

Nowadays, the biomimetic behaviour of the resistive random access memory (ReRAM) device is gaining importance towards neuromorphic computing and sensing applications. In particular, ReRAM-based electronic nociceptors, mimicking bio-receptors as protective gear against external damaging stimuli, hold promise for diverse robotic platforms. However, identifying the operational parameters for a memristor to function as a nociceptor, along with understanding the pre-requisite of the active material properties, is nontrivial and demands a comprehensive knowledge of both the memristive and nociceptive behaviour in a given material system. In this work, we demonstrate artificial nociceptor behaviour in a simple two-terminal TiO_x/p^{++}-Si memristor, mediated by Au ion implantation at an optimal fluence. Au ion implantation creates self-organised ripple patterns on the surface of the TiO_x film and at the same time preferential occurrence of spatially well-separated Au nanoparticle chains along the pattern ridges. As a result, a detailed conductive AFM study acquired on such pattern ridges enables realization of site-specific nociceptive behaviour at nanoscale. Electric field-induced migration of oxygen vacancies within the TiO_x film creates a localised channel preferentially beneath the Au sites. Consequently, the electrical-stimuli-induced fundamental nociceptive phenomena such as a “threshold”, “relaxation”, “overlapping”, “allodynia”, and “hyperalgesia” are realised under a range of voltage stimuli. This study lays the groundwork for designing unique platform for pattern recognition of external damaging stimuli for artificial intelligence systems like humanoid robots.

P-29

RIANA: Research Infrastructure Access in Nanoscience & Nanotechnology

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Abstract

Research in the fields of nanoscience and nanotechnology is vital for global sustainability. As advancements in nanoscience and nanotechnology cannot be achieved without using research infrastructures (RI), the EU-funded RIANA project joined 7 European networks of top-level RIs, providing access to the most advanced techniques relevant for nanofabrication, processing/synthesis, characterization and analytics, along with the capacity for simulations [1]. Highly customized and efficient access to 69 infrastructures spread across 22 European countries (Fig.1) is coordinated via a single-entry point, and enabled through comprehensive scientific and innovation service by senior scientists, facility experts and highly trained junior scientists. The core of RIANA is aligned to attract experienced and new users from academia and/or industry, and will be prioritized for researchers with the brightest ideas to make best use of the RI for nanoscience and nanotechnology in view of sustainability [2].

The excellence of user projects will be upheld by an independent review panel applying sharp evaluation criteria, in particular:

- scientific excellence,
- potential to increase technology readiness level
- level of cross-disciplinarity
- impact on safety for environment
- impact on nanoscience or nanotechnology.

RIANA accepts user proposals based on a “continuous call” that has been launched.

RIANA **Networks**

LEAPS: synchrotron- and free-electron-laser based photon sources
Laserlab: laser sources
e-DREAM: electron microscopy
RADIATE: ion sources
LENS: neutron sources
EuroNanoLab: clean rooms
EUSMI: soft matter research infrastructures, NMR and high-power computing

The RIANA consortium encompassing 7 networks (LEAPS, Laserlab, e-DREAM, RADIATE, LENS, EuroNanoLab and EUSMI) [1].

P-30

COMPARISON OF GRAZING INCIDENCE SWIFT HEAVY ION TRACKS PROPERTIES FORMED ON CaF_2 AND SiO_2

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Abstract

Passage of swift heavy ions through insulators results in permanent structural damage, if the ion energies are above certain level. When the irradiation is done at grazing angles, long ion tracks of uneven height are formed. Typically, they have continuously increasing profile upon which several hillocks are superimposed. Atomic Force Microscopy (AFM) is usually applied in studies of this kind of surface features.

We applied several different heavy ions, having few different energies, to form ion tracks on CaF2 and SiO2 surfaces under grazing incidence. These tracks were studied using AFM. Typically, about 100 tracks have been located on a single AFM image. As the formation of tracks is a statistical process, we developed software which autonomously locates tracks and analyses the details of their features, determining statistical distributions for these. Finally, these properties (length, height and number of hillocks, as well as hillocks height and location along the tracks) are studied as a function of the irradiated material.

P-31

Ultrasonic beam monitoring and energy loss measurements of relativistic heavy ions

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Abstract

The characteristics of the ionoacoustic detectors were investigated at the SIS18 synchrotron at GSI using Xe, Pb and U ions of energies up to 1 GeV/u. Microsecond-pulsed ion beams stopped in water generate an ultrasonic pressure pulse, which can be detected by a piezoelectric transducer. The analysis of the signal in time and frequency domain allows us to locate the initial position of the ion bunch in 3D space as well as to determine the range and thus the ion energy to an accuracy of 1 %. Over a wide intensity range, the signal amplitude has a linear correlation with the beam intensity. Inserting a targets of varying thicknesses and materials into the ion beam yields precise information on the energy-loss. Combined with their exceptional radiation hardness, ionoacoustic detectors hold tremendous potential as ion beam monitors for upcoming high-energy and high-intensity heavy ion facilities. In fact, they could even serve as a promising 'second generation' Faraday cup.

P-32

Structure damage accumulation in α-Ga_2O_3 irradiated with P and PF_4 ions

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Abstract

Gallium oxide (Ga2O3) is a semiconductor material attracting a lot of attention due to its valuable characteristics promising for new generation device applications. The α-polymorph has bandgap of 5.3 eV, which makes it interesting for possible device application. α-Ga2O3 is stable at atmospheric pressure up to 550 °C and can be epitaxially grown on a sapphire substrate. The aim of this work is to investigate dynamics of structure damage accumulation and the effect of dose rate and displacement cascade density on the radiation damage accumulation efficiency in the epitaxial α-Ga2O3 layers under keV monatomic and small cluster ion bombardment. Implantation with 1.3 keV/amu F, P, and PF4 ions was performed 7° off the normal at RT in a fairly wide range of ion fluences and beam flux. The ion-induced change in crystal structure was measured by RBS/C and XRD.

Stable damage distribution in α-Ga2O3 is bimodal at moderate and high flux values. Additional defect peak is seen at small doses between bulk and surface peaks in the case of low flux light ion bombardment. Overall damage formation efficiency increases with ion flux. Nonlinear energy spikes in dense cascades does not play an important role in gallium oxide. The mobile point defect clustering efficiency increase, which depends on the effective density of collision cascades, is the major mechanism responsible for the damage formation enhancement in gallium oxide.

Work was supported by RScF grant # 22-19-00166.

P-33

Study on the evolution and mechanism of helium bubbles in BCC phase high/medium-entropy alloys

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Abstract

The service behavior of materials in extreme environment is one of the major bottlenecks restricting the utilization and development of nuclear reactors. Compared with traditional steels such as T91 and SS316, some high/medium-entropy alloys (HEAs/MEAs) have obvious advantages in strength, toughness, irradiation resistance and corrosion resistance, etc., and have a wide range of the potential applications as nuclear structural materials.

The presence of helium bubbles induces swelling, hardening and embrittlement of nuclear structural materials, resulting in shortened service life. Therefore, the evolution and mechanism of He bubbles in BCC-phase HEAs/MEAs with irradiation tolerance have been investigated from multiple perspectives (irradiation fluence, irradiation temperature, Ti addition, pressure and swelling) using $FeCrVTi_x$ MEAs as model materials. From the viewpoint of the ratios of the diffusion coefficients of a He atom to the diffusion coefficients of a vacancy, the evolution mechanism of He bubbles with temperature in HEAs/MEAs closely corresponds to that of Trinkaus based on pure metals. The nucleation of He bubbles is dominated by the diffusion of He atoms in HEAs/MEAs within the ratio range of $>10^2$. The excellent tolerance of He ion irradiation-induced swelling in $FeCrVTi_x$ MEAs is mainly because He bubbles are near equilibrium pressures with a little under-pressurized, and Ti-added can suppress the nucleation, growth and coarsening of He bubbles in the BCC-phase matrix by increasing local lattice distortion and chemical composition complexity and forming Laves-phase precipitation. Most importantly, this study provides theoretical guidance for designing BCC-phase HEAs/MEAs with outstanding irradiation resistance.

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