MAT science Week

Tuesday 24 April 2018 - Friday 27 April 2018

GSI

MAT Science Week

April 24-27, 2018 at GSI, Darmstadt

Book of Abstracts

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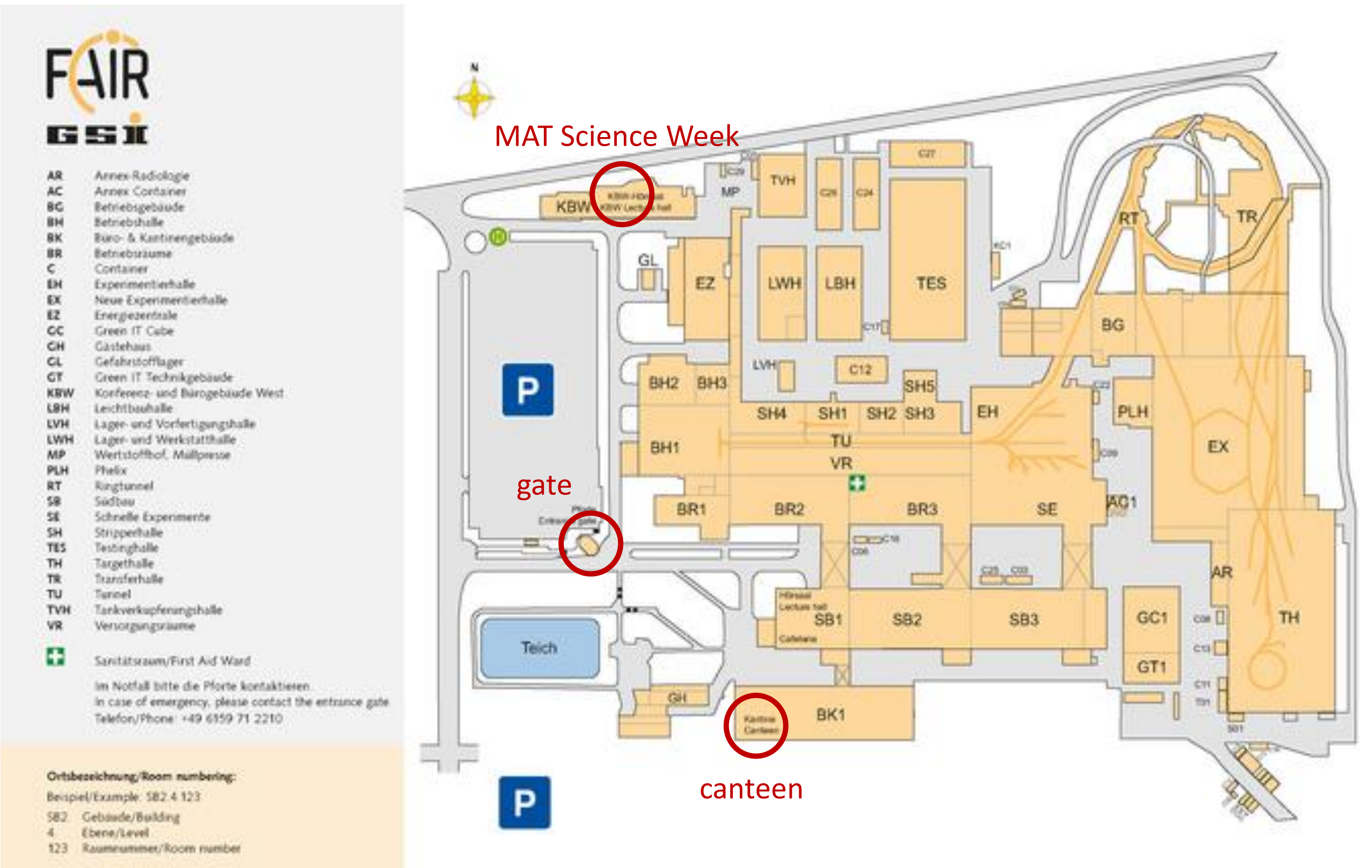

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Tuesday, April 24, 2018

AM 10:00 --- Registration ---

10:30 Mat Science Week - Session 1

10:30 Welcome

10:50 Polymer membranes analyzed by Elastic Recoil Detection and Positron Annihilation Lifetime Spectroscopy - Günther Dollinger (Angewandte Physik und Messtechnik, Universität der Bundeswehr München, Neubiberg, Germany)

11:10 Plasmonic nanostructures prepared by ion track technology and electrodeposition - Ina Schubert (GSI, Darmstadt)

11:30 Ion track-based nanostructures for tuning plasmonic and electrical properties - Jinglai Duan (Materials Research Center, Institute of Modern Physics, Chinese Academy of Sciences) Jie Liu (Institute of Modern Physics, Chinese Academy of Sciences)

11:50 Analysis of the Electric-Double-Layer formation by in-situ Rutherford Backscattering Spectrometry - Nasrin Baghban Khojasteh (Ion Beam Center, Institute of Ion Beam Physics and Materials Research, HZDR)

12:10 Single-ion-induced surface modifications on H/Si(001) - significant difference between slow highly charged and swift heavy ions - Michael Dürr (Justus-Liebig-Universität Gießen(JULGi))

12:30 --- Lunch ---

PM **14:00 Mat Science Week** - Session 2

14:00 Development of an efficient high-current ion source for Accelerator Mass Spectrometry - Hans Hofsäss (University Göttingen)

14:20 Detecting Beryllium-10 from exotic decays by Accelerator Mass Spectrometry (AMS) - Oliver Forstner (FSU Jena, HI Jena)

14:40 Beryllium-7 at DREsden Accelerator Mass Spectrometry - Georg Rugel (Helmholtz-Zentrum Dresden-Rossendorf)

15:00 Production and Characterization of the 163Ho Source for the ECHo Project - Klaus Wendt (University of Mainz)

15:20 KFSI-Meeting (until 16:20), Postersession, and Coffee

17:00 Mat Science Week - Session 3

17:00 Particle Ejection from an Energized Track: Comparison with the Nuclear Sputtering Process - Andreas Wucher (University Duisburg-Essen)

17:20 Investigations and modifications of selected thin films by 1-2 MeV rare-gas ion beams - N.-T.H. Kim-Ngan (Nanostructure Laboratory, Institute of Physics, Pedagogical University, Podchorazych 2, 30-084 Cracow, Poland)

17:40 An energy and mass selective hyperthermal ion beam for ion-assisted thin film deposition purposes - Jürgen W. Gerlach (Leibniz-Institut für Oberflächenmodifizierung e.V., Leipzig, Germany)

18:00 Layer stability and interface properties of single- and bi-layer magnetite films grown on MgO(001) substrates - Magdalena Krupska (Nanostructure Laboratory, Institute of Physics, Pedagogical University, Podchorazych 2, 30-084 Cracow, Poland)

18:20 Applying an Evolutionary Algorithm for Automated Ion Beam Analysis Data Evaluation - René Heller (Helmholtz-Zentrum Dresden-Rossendorf)

19:00 --- Dinner (GSI Canteen) ---

TUESDAY, April 24, 2018

Polymer membranes analyzed by Elastic Recoil Detection and Positron Annihilation Lifetime Spectroscopy

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Extensive characterization is needed to understand the physicochemical properties of polymeric membranes that are used for water purification. Currently, most techniques characterize the (near)-surface region of the membrane, even though its bulk obviously also plays a significant role in the final membrane performance. To achieve depth-profiles of the elemental composition of both integrally skinned asymmetric (ISA) and thin-film composite (TFC) membranes, elastic recoil detection (ERD) is introduced to the field. Volume-averaged chlorine-uptake as well as complete Cl- and H-profiles as a function of membrane depth were obtained after NaOCl cleaning procedures at high pressures (e.g. 10 bar for 2.5 h) of polyamide (PA)-based thin film composite (TFC) membranes. The decrease in H-content upon chlorine exposure could be quantitatively proven for the first time and the influence of pressure, pH and chlorine feed-concentration on the location of chlorine in the membrane was studied. More chlorine is present deeper in the PA-layer with increasing chlorine uptake, either by increasing chlorine dose or by decreasing pH. The chlorine uptake goes in-line with reduced positron lifetime indicating a reduction of open pore size. It demonstrates a “tightening” of the membranes with reduced water permeability.

Plasmonic nanostructures prepared by ion track technology and electrodeposition

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Metallic nanowires have various applications in the fields of sensorics, electronic or energy harvesting. These applications are based on the excitation of collective electronic oscillations in the nanowires called surface plasmons that are generated by the electric field of light. Whereas the resonant plasmonic wavelength of a spherical Au particle is located in the visible light range, for Au nanowires the resonant wavelength can be tuned precisely and shifted to the infrared by varying the wire dimensions. At the resonant wavelength, very high nearfield enhancements are generated on the wire surface that allow for example to enhance the infrared vibrational modes of an analyte present in the wire proximity. Not only individual nanowires, but also coupling of nanowires is attracting great interest since higher nearfield enhancements and new plasmonic modes are generated.
Ion track technology combined with electrodeposition is a powerful technique to synthesize nanowires with well-defined parameters. In this talk, we give an overview of the different Au and Au-Ag nanostructures that we have created with this technique, such as smooth and porous

AuAg nanowires as well as two wires separated by very small gaps or small conducting bridges. Their plasmonic properties were studied dependent on the different nanowire parameters such as length, diameter, porosity, or gap sizes by electron energy loss spectroscopy in a TEM as well as by infrared microscopy.

Ion track-based nanostructures for tuning plasmonic and electrical properties

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Tuning plasmonic and electrical properties of nanostructures is of great importance for exploring new applications. Based on ion track technology, we have developed several interesting nanostructures, including nanowires, nanocones, metasurface, and sharp ridge-rich hierarchical nanopillars. Taking benefit from such a unique technology, we demonstrate that the key parameters of nanostructures, such as materials' composition, shape, size, areal density, crystallinity, and crystallographic orientation, can be well controlled, upon fabrication conditions. As such, we further show that the plasmonic and electrical properties can be tuned, which are particularly for exploring new applications such as sensing and electronic devices. In this work, we report on the recently developed nanostructures and some ongoing research activities, with particular attention to IMP-GSI collaborations on nano research.

Analysis of the Electric-Double-Layer formation by in-situ Rutherford Backscattering Spectrometry

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A setup for in-situ Rutherford Backscattering Spectrometry (RBS) has been installed at the 2 MV Van-de-Graaff accelerator at the Ion Beam Center (IBC) of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR). Online analysis of solid-liquid interfaces as well as electro-chemistry experiments are conducted by this technique. A Si3N4 window separates the liquid from the vacuum in the RBS chamber. A He+ beam (E = 1.7 MeV) is utilized for the RBS measurements. RBS as well as Particle Induced X-Ray Emission Spectroscopy (PIXE) spectra are recorded simultaneously to increase the sensitivity for trace elements. The technique was employed for direct measurements of the Electric-Double-Layer (EDL) formation on Si3N4. Investigations of the EDL formation at solid-liquid interfaces are of great significance due to the various valuable applications such as super-capacitors that can be utilized to provide a backup power supply or applied in various other fields [1-3]. In our preliminary experiments, the specific adsorption of Barium ions from a 1mM BaCl2 solution with various pH values was observed in a direct and quantitative manner. Sensitivity of the technique reaches the ppm range and areal densities can be measured down to 0.1 atomic monolayer.

[1]Kötz et al., (2002). The 12th International Seminar on Double Layer Capacitors and Similar Energy Storage Devices, Dec, USA. [2]Faggioli et al., (1999). J. Power Sources, 84(2): 261. [3]Simon et al., (2008). Nature materials, 7(11): 845.

Single-ion-induced surface modifications on H/Si(001) - significant difference between slow highly charged and swift heavy ions

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Electronic excitation caused by swift heavy ions (SHI) in solids often leads to permanent changes in the crystal structure, either by direct excitation or electron-phonon coupling following the initial electronic excitation. At single crystal surfaces, this leads to modifications of the topography which can be detected in real space by means of scanning probe techniques. For monoatomic projectiles, no such permanent surface restructuring has been reported for crystalline silicon up to a stopping power of 21 keV/nm so far. On the other hand, theoretical models suggest a lower threshold for atomic rearrangement in silicon.
In this study, we increased the sensitivity for ion-induced damage on a silicon surface by using hydrogen-terminated Si(001) surfaces in combination with scanning tunnelling microscopy (STM). Desorption of single hydrogen atoms or molecules leads to a clear signature in the STM images and thus damage could be resolved on the atomic scale. In comparison with slow highly-charged ions (HCI), swift heavy ions show, if at all, a very localized effect on the H/Si(001) surface.

Development of an efficient high-current ion source for Accelerator Mass Spectrometry

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A new efficient negative ion source for Accelerator Mass Spectrometry (AMS) is being built to quantify the ratios of long-lived cosmogenic radionuclides in micrometeorites. Measuring these extremely small ratios is at the technological limits of present AMS systems. The new source is designed specifically to provide a higher AMS detection sensitivity by having an optimal ion-optics design, incorporating new concepts for the construction and operation of the Cs ionizer, optimized Cs ion beam currents and Cs vapor transport, as well as the operation with higher cathode voltages than usual. Moreover, its design is modular providing ease of access and simplifying maintenance while providing better mechanical stability. Several source parameters can be controlled and measured during operation to achieve a better source performance. The new source will consist of a auto-aligning modular ionizer, a Cesium supply with active temperature control of the supply tubes, a novel shroud for the Cs supply and a cathode operated at up to -20 kV cathode bias. The design is optimized using COMSOL ion optics simulations, including space charge effects, thermal transport simulations as well as detailed sputter simulations. The authors would like to thank

the Federal Ministry of Education and Research of Germany for its financial support (project 05K2016), and the HZDR's Ion Beam Center for its essential contribution to the realization of this project.

Detecting Beryllium-10 from exotic decays by Accelerator Mass Spectrometry (AMS)

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The one-neutron halo-nucleus Be-11 decays via beta-minus to the stable nucleus B-11 (t1/2=13.76 s). In rare cases a subsequent emission of a proton leads to the unstable nucleus 10Be. Theoretical calculations predict a branching ratio of this rare decay channel of below 1E-7. With the capability of AMS in measuring ultra-low isotopic ratios (Be-10/Be-9 < 1E-15) the branching ratio of beta-delayed proton decay to Be-10 could be measured for the first time. A beam of Be-11 ions was produced at the radioactive ion beam facility ISOLDE at CERN. After mass separation the ions were implanted in Cu targets. These targets containing the produced Be-10 were spiked with low-level Be-9 and in the form of BeO chemically prepared as AMS targets at HZDR. The resulting Be-10/Be-9 ratios were determined via AMS at the VERA laboratory of the University of Vienna. With the known quantity of added Be-9 the amount of implanted Be-10 was calculated. Due to the low expected branching ratio and the resulting low number of implanted Be-10 atoms a high efficiency paired with a low background of the Be-9 carrier material was necessary. To further widen the spectrum of radionuclides measureable by AMS and lowering the detection limits for similar nuclear physics research, we are planning to implement an optical filtering method for selective suppression of isobars by laser photodetachment (LISEL) at the 6 MV tandem accelerator at HZDR.

Beryllium-7 at DREsden Accelerator Mass Spectrometry

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Half-lives of routine accelerator mass spectrometry (AMS) nuclides typically range from thousands to millions of years. We measured short-lived ^{7}Be (T1/2 = 53.2 d) at the DREsden AMS-facility (DREAMS) [1] as low as 90 mBq, which can be challenging for rapid γ-counting. Simultaneous determination of ^{7}Be and ^{10}Be ($T_{1/2}$ = 1.387 Ma) via AMS is advantageous for improved understanding of production, transport, and deposition of atmospherically produced ^{7,9,10}Be [2]. Data was normalized to a ^{7}Be sample produced via ^{7}Li(p,n)^{7}Be, measured by γ-counting and chemically processed to BeO after adding low-level ^{9}Be carrier (^{7}Be/^{9}Be $\approx 10^{-12}$). The isobar ^{7}Li is completely eliminated by chemistry and the degrader foil technique (at detector ^{7}Be^{4+}, 10.2 MeV, no ^{7}Li^{4+} possible). The blank ratio of 5×10^{-16} ^{7}Be/^{9}Be (0.8 mBq) and simple and

fast chemistry allows for the measurement of rainwater samples, collected in Germany, as small as 10 mL corresponding to a few times 10^{-14} $^{7}Be/^{9}Be$ [3,4].
Thanks to D. Bemmerer (HZDR) and G. György (ATOMKI, Hungary) for help with the ^{7}Be normalization material.
[1] G. Rugel et al., *NIMB* 370 (2016) 94. [2] A.M. Smith et al., *NIMB* 294 (2013) 59. [3] R. Querfeld et al., *JRNC* 314 (2017) 521. [4] C. Tiessen et al. *JRNC* (to be submitted).

Production and Characterization of the 163Ho Source for the ECHo Project

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The ECHo (Electron Capture in Holmium Experiment) collaboration aims at measuring the electron neutrino mass by recording the spectrum following electron capture of 163Ho using metallic magnetic calorimeters. The radioisotope 163Ho (t1/2 = 4570 a) is produced by neutron capture from enriched 162Er in the Institute Laue-Langevin high-flux nuclear reactor. After chemical separation the important step of embedding the sample into the 180x180 [U+1D707]m2 Au-absorbers of the ECHo detectors is carried out by laser mass spectrometric techniques. The application of multi-step resonance ionization at the 60 kV RISIKO mass separator of Mainz University ensures highest efficiency and unrivalled elemental and isotopic selectivity for ultra-pure 163Ho ion implantation with sub-millimeter beam spot. The efficiency and stability of the laser ion source and the implantation process is permanently monitored and improved to minimize any losses of the precious sample material, while an in-situ deposition of gold by parallel pulsed laser deposition (PLD) ensures a homogeneous 163Ho/Au layer production and prevents disturbing sputter effects. To screen the purity of the source from production up to use besides a number of more conventional analytical techniques accelerator mass spectrometry (AMS) of Ho at the AMS-facility of the Helmholtz-Zentrum Dresden-Rossendorf is under development to address the very low content in the 10-9 or lower region of the radiocontaminating isotope 166mHo (t1/2 = 1200 a).

Particle Ejection from an Energized Track: Comparison with the Nuclear Sputtering Process

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New experimental results regarding the mass and charge state distribution of material sputtered under irradiation with swift heavy ions suggest fundamental differences between the particle ejection mechanisms under electronic and nuclear sputtering conditions. In order to illustrate the difference, computer simulations based on molecular dynamics were performed to model the surface ejection process of atoms and molecules from an energized track as induced, for instance, by a swift heavy ion impact. First, the sputter yield is calculated as a function of track radius

and energy and compared to corresponding experimental data in order to find realistic values for the effective energy deposited in the lattice. The sputtered material is then analyzed with respect to its composition, its emission energy and angle distribution as well as its depth of origin below the surface. The results are compared to corresponding data obtained from keV impact induced sputter simulations in order to reveal possible differences, which can then be utilized to interpret measured mass spectral data in terms of sputter yields and understand the different influence of surface contaminations observed under electronic and nuclear sputtering conditions.

Investigations and modifications of selected thin films by 1-2 MeV rare-gas ion beams

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We used 1-2 MeV rare-gas (He, Ar, Kr) ion beams to study and modify the surface and interfaces of thin films of materials with a high potential for applications, such as magnetite Fe3O4 (spintronic devices/sensors at room temperature), titanium oxynitrides TiNxOy (photocatalysis), Ti/V and their oxides-based films (hydrogen storage), uranium nitride UN (nuclear fuels), highly-ordered Pd-Fe alloys (high-density recording materials). We show e.g. that: 1) the stoichiometric Fe3O4 layer on the film surface of the bi-layered of Fe3O4/Fe/MgO(001) films could be well preserved upon Ar+ and Kr+ ion irradiation with e.g. ion fluence of 3.8x10^16 Kr/cm2, while such ion fluence has induced a complete oxidization of the Fe layer, 2) hydrogen amount up to 40-50% can be stored in the Ti layers while it diffuses without accumulation through the TiO2 layer and covering the film surface by palladium would lead to a large increase of hydrogen concentration indicating that Pd could act as a good catalyst, 3) a large hydrogen absorption can be obtained in the V2O5-TiO2 films but hydrogen absorption can induce V2O5-VO2 transition 4) 1 MeV Ar+ ion irradiation could restore the stoichiometry 1:1 and as a consequence increase the total film thickness of UN films, 5) the Pd or Fe layer can survive Ar+ ion irradiation at low damage levels, while the thermal treatment caused a large change of surface morphology.

An energy and mass selective hyperthermal ion beam for ion-assisted thin film deposition purposes

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In thin film growth using physical vapor deposition methods like e.g. magnetron sputtering, energetic particles are involved in the deposition process acting either directly as film-forming components or indirectly as impinging particles which deliver additional energy and momentum to the surface of the growing film. With most of these techniques, there exists a mixture of all these particle fluxes and they can hardly be separated. An exception is the ion-beam assisted deposition technique, which is characterized by simultaneous irradiation of the growing thin film with energetic ions. By this, a ballistic enhancement of the adatom mobility can be achieved. In the case of nitrogen ion beams however, the typically used nitrogen plasma based ion-beam sources counteract the demand to chose the ion-beam parameters as freely as possible, because the resulting ion beam consists of a blend of both molecular and atomic nitrogen ions. In this

contribution, a compact custom setup is presented which allows generating a hyperthermal nitrogen ion beam with variable ion energy and selectable ion mass. This was realized by combining a plasma based ion source with a quadrupole mass filter system, equipped with entry and exit ion optics, ion-beam deflection, as well as ion-beam current monitoring. The key features of this setup are demonstrated and discussed regarding ion-assisted nitride thin film growth using the model system GaN.

Layer stability and interface properties of single- and bi-layer magnetite films grown on MgO(001) substrates

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An increasing interest is focused on the epitaxial magnetite (Fe3O4)-based films due to their potential application as spin dependent transport devices. We present our study of the composition and layer structure of the single-layer Fe3O4 and bi-layer Fe3O4/Fe films epitaxially deposited on MgO(001) substrates. We focus on underlining the influence of thermal annealing and ion beam irradiation on the layer and interface properties to gain information about the film stability and/or its changes in external conditions, such as temperature, air exposure and ion-beam exposure. The films in different states were investigated by combined X-ray reflectometry and Rutherford backscattering spectrometry (RBS). The crystalinity of the films was studied by RBS-channeling experiments. For investigating the atomic transport processes, we used inner-gas and metallic ions (Ar, Kr, Au) with energy of 1-2 MeV to modify (tailor) samples by controlled irradiation experiments. The most important finding is that the bi-layer structure of magnetite films are well preserved upon ion irradiations despite of a large decrease of the layer thickness, whereas it disappeared completely as a consequence of a full oxidation of Fe buffer layer upon annealing.
The ion beam experiments were performed in a collaboration with RBS groups in the Institute of Nuclear Physics of the University Frankfurt/Main and Nuclear Physics Institute, The Academy of Sciences of the Czech Republic, Rez, Czech Republic

Applying an Evolutionary Algorithm for Automated Ion Beam Analysis Data Evaluation

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To extract chemical compositions and layer thicknesses of layered samples from Ion Beam Analysis (IBA) spectra experimentalists typically have to simulate a theoretical spectrum for an initial target configuration and compare the outcome to the measured data followed by the successive re-adjustment of the target model until simulation result and experimental spectrum fit each other. For multi-element layered samples this procedure can get rather time consuming. Although modern IBA spectrum simulation software like SimNRA[1] or WINDF[2] have become quite powerful tools, the analysis of IBA spectra consumes still a significant fraction of an IBA scientist's working time.
In this contribution, we present a new approach for automated IBA spectra fitting by applying an evolutionary algorithm. We show that this approach is well suited and robust for complete and fast IBA spectrum fitting with minimum input of boundary conditions. Furthermore, the

benefits of this algorithm and the particular differences to the simulated annealing approach are pointed out.

Based on this algorithm a platform independent software package has been developed that comprises a clean and easy-to-use graphical user interface. We will introduce this software in a basic overview.

[1] M. Mayer, AIP Conf. Proc. (AIP), 1999, 541-544.
[2] N. P. Barradas, C. Jeynes, R. P. Webb, Appl. Phys. Lett. 71(2), 1997, 291.

Wednesday, April 25, 2018

08:45 Mat Science Week - Session 4

08:45 Optical metasurfaces created by ion irradiation of phase transition materials - Jura Rensberg (Friedrich-Schiller-Universität Jena)

09:05 Secondary Ion and Neutral Mass Spectrometry with Swift Heavy Ions and Highly Charged Ions - Lars Breuer (Universität Duisburg-Essen)

09:25 Abnormal lattice location and electrical activation in chalcogen-hyperdoped Si - Mao Wang (Helmholtz-Zentrum Dresden-Rossendorf)

09:45 Change of Ar diffusion coefficient in glass by heavy ion irradiation - Tieshan Wang (School of Nuclear Sciecne and Technology, Lanzhou University, Lanzhou, China)

10:05 (Bio)molecular detection with track-etched single synthetic ion channel - Mubarak Ali (Technische Universität(TUDA))

--- Coffee ---

11:00 Mat Science Week - Session 5

11:00 Development of In-situ X-Ray Diffraction Measurements during Low Energy Ion Beam Etching - Darina Manova (Leibniz-Institut für Oberflächenmodifizierung (IOM) e.V.)

11:20 Simulation of Ion Beam induced Surface Dynamics - Alrik Stegmaier (2. Physik, Universität Göttingen)

11:40 Counterintuitive temperature dependence of ion beam shaping of Si nanopillars - Karl-Heinz Heinig (HZDR)

12:00 Application of ion beams to fabricate and tune ferromagnetic semiconductors - Shengqiang Zhou (Helmholtz-Zentrum Dresden-Rossendorf)

12:20 Group Photo (until 12:40)

--- Lunch ---

14:15 Mat Science Week - Session 6

14:15 Materials Research irradiation facilities at GSI/Fair - Daniel Severin (GSI, Darmstadt)

14:45 GSI Tour

--- Coffee ---

17:15 Mat Science Week - Session 7

17:15 Welcome by Scientific Director of GSI/FAIR - Paolo Giubellino

17 :45 Enabling in situ diffraction and imaging studies during heavy relativistic ion irradiation and studies of photon-ion interactions: A „Compact Light Source @ SIS 100 @ FAIR - Bjoern Winkler (Goethe Universität)

18:05 1-10 MeV/u cw-heavy ion beams at GSI - Maksym Miski-Oglu (GSI, Darmstadt)

18:25 PRIOR - Proton Microscope for FAIR - Dmitry Varentsov (GSI, Darmstadt)

18:45 Plasma physics at FAIR using intense ion and laser beams - Paul Neumayer (GSI, Darmstadt)

--- Dinner (GSI Canteen) ---

WEDNESDAY, April 25, 2018

Optical metasurfaces created by ion irradiation of phase transition materials

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Active, widely tunable optical materials have enabled rapid advances in photonics and optoelectronics, especially in the emerging [U+FB01]eld of meta-devices. Of the tunable optical materials, one of the most proli[U+FB01]cally studied is the VO2, which undergoes a reversible IMT as the temperature reaches a critical temperature of approximately 67°C due to strong electron correlations. Energetic ion beams are widely used to modify the electronic and structural properties of solids by introducing impurity atoms into the crystal lattice. Commonly, the inevitable formation of irradiation damage during ion bombardment is described as disadvantageously for ion beam doping and subsequent post-implantation annealing procedures are required. Since the electronic structure of strongly electron correlated materials is very sensitive to small amounts of lattice defects, ion beam induced damage formation combined with lithographic patterning can be used to locally adjust the phase transitions of these materials. Using this robust technique, optical metasurfaces, including tunable absorbers with artificially induced phase coexistence and tunable polarizers based on thermally triggered dichroism are demonstrated.

Secondary Ion and Neutral Mass Spectrometry with Swift Heavy Ions and Highly Charged Ions

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Co-author(s): Mr. ERNST, Philipp [1] ; Mr. HERDER, Matthias [1] ; Dr. SEVERIN, Daniel [2] ; Dr. BENDER, Markus [2] ; Prof. SCHLEBERGER, Marika [1] ; Prof. WUCHER, Andreas [3]

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A time-of-flight mass spectrometer to investigate sputtered material under swift heavy ion bombardment installed at the M-Branch of the UNILAC beam line is not only capable of getting mass resolved information about sputtered secondary ions, i.e., ionized atoms, clusters and molecules leaving the irradiated surface, but also allows the detection of their neutral counterparts by means of laser post-ionization. This setup provides the capability to gain information about the composition of the sputtered material and how the secondary ion formation process is influenced by changing the nature of the emission process from nuclear sputtering in the keV regime to electronic sputtering in the GeV regime.
We will present results obtained with this instrument during recent beam times and give an outlook of new experiments planned in the future, where not only the instrument at the M-Branch will be upgraded to increase its capabilities but also a new setup is currently under construction for the CRYRING. The new setup installed there will utilize the possibility to alter the kinetic energy of the projectile and its charge state independently. This offers the opportunity to

investigate the role of potential energy contained in the projectile with respect to the electronic and nuclear sputtering processes. The new setup will also be equipped with an electron and Raman spectrometer to gain information electron emission under these conditions and material changes due to ion interaction.

Abnormal lattice location and electrical activation in chalcogen-hyperdoped Si

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Hyperdoping has emerged as a promising method for designing semiconductors with unique physical properties. In general, these properties are primarily determined by the lattice location of the impurity atoms in the host material. In this contribution, the lattice location of implanted chalcogens in Si was experimentally determined by means of Rutherford backscattering/channeling (RBS/C). The implication on the electrical activation of chalcogens in Si will be discussed with respect to the Hall effect results. The obtained carrier concentration and the RBS angular scans across the <100> and <110> axis reveal that the electrically active/inactive concentration of Te correlates with the concentration of substitutional/interstitial site Te atoms. Surprisingly, contrary to the general belief, we find that the interstitial fraction decreases with increasing impurity concentration. This abnormal dependence of lattice location and electrical activation on impurity concentration suggests that the formation energy for the substitutional Te or Te-Te dimers in Si is lower than for the interstitial Te. This assumption is theoretically verified by the first-principles calculations.

Change of Ar diffusion coefficient in glass by heavy ion irradiation

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Co-author(s): Dr. CHEN, Liang [1] ; Mr. LV, Peng [1] ; Mr. ZHANG, Bingtao [1] ; Mr. YUAN, Wei [1] ; Dr. PENG, Haibo [1] ; Dr. HELLER, Rene [2]

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Glass is a function material with free volume. The gas diffusion coefficient in glass is sensitive to atom size and temperature. This feature could be used as a functional filter of gases. In order to enhance Ar diffusion coefficient in glass without changing mechanical property, heavy ion irradiation was applied in this work. Hollow glass microspheres was irradiated with the 15 MeV Si6+, at different fluences in between 1.0×10E15 to 3.0×10E16 ions/cm2. After irradiation, Ar gas was filled into the hollow glass microspheres under different temperature and pressure. X-ray fluorescence (XRF) spectrometer and quadrupole mass spectrometer (QMS) were used to measure the quantity of argon gas in the hollow glass microspheres. A certain amount of argon gas (0.001~3.10 bar) was found in the hollow glass microsphere at different conditions, which related with not only the irradiation fluence, but also the temperature and the pressure. The preserving abilities of filled Ar gases in the hollow glass microsphere were also tested at room temperature. No significant change of insert gas pressure was found after a few months. It implies that the filled Ar has not leaked out. So the diffusion coefficient of glass have been changed and the on/off function to Ar gas in glass has been created with heavy ion irradiation. A theoretical simulation has been carried out to interpret the on/off function. Further approaches with swift heavy ion irradiation is in plan.

(Bio)molecular detection with track-etched single synthetic ion channel

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Solid-state nanofluidic pores have been attracting considerable attention of scientific community because of their structural and chemical resemblance with biological ion channels for mimicking biological process in living systems. Compared to ion channels, synthetic nanopores exhibit high stability, control over pore dimensions (size and geometry) and their surface chemical properties can be tuned on demand. Therefore, they are considered perfect candidate to design and develop of nanofluidic sensory devices by introducing variety of functional groups on the inner pore surface for the detection of specific analyte (biomacromolecules/ chemicals) through host-guest interactions. The biomolecular recognition processes taking place in confined geometries results in the partial/complete blockage of the pore and/or modulation of pore surface charge polarity. Here, I will present our recent progress in the design and construction of nanofluidic sensory devices based on polymeric track-etched nanopores for the recognition of various (bio)molecular analytes.

Development of In-situ X-Ray Diffraction Measurements during Low Energy Ion Beam Etching

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In-situ X-ray diffraction measurements following the details of ion nitriding of stainless steel have been developed during the last 5 years. Nevertheless, the amount of local information is limited as diffusion and relaxation processes due to the elevated temperature during the process will lead to dynamic processes difficult to be resolved as a function of depth. On the other hand, mechanical polishing of layered systems to gradually remove material and successive analysis by XRD is an established and accepted method.
Here, we propose to use low energy ion beam etching coupled with in-situ XRD to obtain detailed, depth-resolved data. Limiting the ion energy to 1 keV or less will lead to minor modifications of material, avoiding potential plastic or elastic deformation during mechanical removal, restricted to the immediate surface zone of only up to 10 nm. At the same time, the XRD information depth is between 2 and 100 μm, conditional on the specific materials system. With a current density near 100 μA/cm2, a depth resolution of 15 – 25 nm per spectrum can be realized. The analysis of the results can be performed using the intensity of reflections from the layer system as well from an underlying substrate. As the experimental setup is constrained to Bragg-Brentano geometry, surface roughening may result in a continuously degrading depth sensitivity.

Simulation of Ion Beam induced Surface Dynamics

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Structuring of surfaces through ion beam irradiation can be used to create self organizing dune-like waves, dimples, flat surfaces or chaotic patterns. The final structures are a result of the interplay of sputtering, redeposition, projectile implantation, transport and viscous flow, void/bubble formation and the initial surface conditions.
Accurate simulations of structuring are possible through molecular dynamics simulations, but these simulations are computationally too expensive to allow for a prediction of up to micrometer scale structures. A much faster approach is available through the use of continuum models. For this the net effect of the irradiation is expressed as the local change in surface height as a function of and up to forth order spacial derivatives of the local surface height. Typically the resulting equations of motion are taylor-expanded up to second order. Such an approach can be accurate when the surface is relatively flat and shadowing is not important, but the parameters often need to be empirically readjusted for experiments at different impact angles, ion energies or materials. Here we present a new software package that allows for the rapid simulation of surface dynamics for arbitrary, nonlinear equations of motion that can also include nonlocal effects. With this software we explore nonlinear expansions to some of the common models and the effects of shadowing at flat impact angles.

Counterintuitive temperature dependence of ion beam shaping of Si nanopillars

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Silicon nanopillars down to a diameter of ˜20 nm and up to an aspect ratio 3 have been exposed to high-fluence irradiation of 50 keV Si^+ ions. When the pillars are kept at room temperature (RT) they change their shape drastically under 10^{16} Si^+cm^{-2} irradiation: They become bell-shaped, i.e. their heights decreases and their diameters increases strongly. To understand this shaping we performed 3D simulations using the program TRI3DYN [1] which show clearly that this shaping cannot be explained by sputtering effects. The shape change originates probably from ion-induced viscous flow [2, 3]. During irradiation at RT the Si becomes amorphous which allows a plastic deformation. Surprisingly, under irradiation at 400°C the bell-like shaping disappears completely. The nanopillars become thinner without a substantial reduction of their height. This agrees nicely with predictions of our 3D TRI3DYN simulations, i.e. sputtering is at 400°C the dominating mechanism. At high-T irradiation viscous flow is blocked as the Si pillars remain crystalline. The authors acknowledge support from the H2020 project "IONS4SET", contract number 688072. [1] W. Möller, W. Eckstein, Nucl. Instr. Meth. B322 (2014) 23. [2] H. Trinkaus, A.I. Ryazanov, Phys. Rev. Lett. 74 (1995) 5072. [3] T. van Dillen et al., Appl. Phys. Letters 83 (2003) 4315, ibid. 84 (2004) 3591.

Application of ion beams to fabricate and tune ferromagnetic semiconductors

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Mn doped III-V compounds semiconductors have been regarded as the prototype of ferromagnetic semiconductors. However, their preparation presents a big challenge due to the low solubility of Mn. In this talk, I will show how ion beams can be used in fabricating and understanding ferromagnetic semiconductors. First, ion implantation followed by pulsed laser melting (II-PLM) provides an alternative to the widely used low-temperature molecular beam epitaxy approach [1]. II-PLM is successful to bring two new members, GaMnP and InMnP, into the family of III-V:Mn [2]. For the first time, we could prepare GaMnAs and InMnAs with low Mn concentration to cross over the insulator-to-metal transition regime [3]. Second, we use helium ion to precisely compensate hole in ferromagnetic semiconductors while keeping the Mn concentration constant [4]. These materials synthesized or tailored by ion beams provide an alternative avenue to understand how carrier-mediated ferromagnetism is influenced by localization. [1] M. Scarpula, et al. PRL 95, 207204 (2005), S. Zhou, et al., APEX 5, 093007 (2012), S. Zhou, JPD 48, 263001 (2015). [2] M. Khalid et al., PRB 89, 121301(R) (2014), Y. Yuan et al., IEEE Trans. Magn. 50, 2401304 (2014). [3] S. Prucnal et al., PRB 92, 224407 (2015), Y. Yuan et al., PRM 1, 054401 (2017). [4] L. Li, et al., JPD 44 099501 (2011), L. Li, et al., NIMB 269, 2469 (2011), S. Zhou, et al., PR B 95, 075205 (2016), Y. Yuan et al., JPD in press (2018).

Materials Research irradiation facilities at GSI/Fair

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The facility for antiproton and ion research (FAIR) will provide a unique accelerator complex with heavy ion beams up to 10GeV/u and highest intensities. Besides the existing target stations dedicated to materials research (M-branch, X0, and Cave A) two new target stations in the APPA Cave and at CRYRING are planned and under commissioning respectively. The future APPA cave hosts the high energy BIOMAT beamline including a materials research setup. The multi-user experimental area has to cover very different user demands covering a broad range of beam intensities, energies and pulse structures and requiring flexible beam diagnostics and on-line monitoring of beam parameters. The target area includes settings for efficient sample exchange systems for irradiations of small (e.g., biocells) and large (e.g., satellite components) samples in air, a multi-port UHV chamber for irradiations and in-situ material analysis under high vacuum conditions, as well as special high-pressure devices to simultaneously expose samples to pressure, temperature, and energetic ions. In addition, an experimental target station at the extraction beamline of CRYRING is under construction and will be commissioned in 2018.

Welcome by Scientific Director of GSI/FAIR

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Enabling in situ diffraction and imaging studies during heavy relativistic ion irradiation and studies of photon-ion interactions: A „Compact Light Source @ SIS 100 @ FAIR

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It is now possible to acquire a “compact light source”, CLS, which delivers hard x-rays with a brilliance similar to 3rd generation synchrotrons. The CLS is based on a miniature electron

storage ring, in combination with a picosecond laser, where the laser pulse stored in a high-finesse optical cavity acts as an "undulator" to produce x-rays. Such a CLS can be built to have a brightness of 4 x 10^{12} [photons/s/mrad^2/mm^2/4% BW] and, in a next development stage, 10^{14} [photons/s/mrad^2/mm^2/4% BW]. Photon energies are tunable between 8 – 35 keV initially, and up to 100 keV for the next development stage. X-ray pulses are 65 ps long, with a repetition rate of 65 MHz. As the machine is extremely compact it would be possible to place it close to FAIR experimental stations. It would then be possible to either use the intense high energy photon beam for studies of the interaction between ion-beams and photons, or to use diffraction, spectroscopic and imaging approaches to study materials during irradiation with relativistic ions in real time with millisecond time resolution. In times when no ion beams are available, the machine could be used for diffraction, spectroscopic and imaging studies.
The combination of a high energy, brilliant x-ray source with the FIAR facilities would provide unique experimental opportunities not available anywhere else and hence it would now be timely to consider integrating such a machine into the FAIR facilities.

1-10 MeV/u cw-heavy ion beams at GSI

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In 2017 s newly developed superconducting 15-gap RF-accelerator cavity has been successfully tested at GSI . After a short commissioning and ramp up time of some days, a Crossbar H-cavity accelerated first time heavy ion beams with full transmission up to the design beam energy of 1.85 MeV/u. The design acceleration gain of 3.5 MV inside a length of less than 70 cm has been verified with heavy ion beam of up to 1.5 particle mueA. The measured beam parameters showed excellent beam quality, while a dedicated beam dynamics layout provides beam energy variation between 1.2 and 2.2 MeV/u. As a next step towards an entire superconducting heavy ion cw-Linac with variable beam energy (3.5 - 7.3 MeV/u at A/q = 6) the first fully equiped cryo module CM1, will be set up and tested. Results of the recent beam test campaign as well as a scenario for user operation using cw-heavy ion beams from CM1 and entire cw-linac will be presented

PRIOR - Proton Microscope for FAIR

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High energy proton microscopy (HEPM) or radiography is a novel technique for probing the interior of dense objects in static or dynamic experiments by mono-energetic beams of GeV-energy protons. A special system of magnetic lenses is employed for imaging and aberrations correction. Using this technique, one can measure the areal density distribution of a thick sample with sub-percent accuracy, micrometer-scale spatial and nanosecond-scale temporal resolutions. HEPM is of considerable interest for dense plasma physics, materials research, biophysics and medicine. The PRIOR (Proton Microscope for FAIR) facility will use 2 - 5 GeV intense proton beams from SIS-18 or SIS-100 synchrotrons and will allow for a significant step forward in spatial (˜ 10-15 μm) and temporal (˜ 5-10 ns) resolution. In 2014, a PRIOR prototype (PRIOR-I) has been constructed and successfully commissioned at the HHT area of GSI in static and dynamic experiments with intense 3.6 GeV proton beam from SIS-18. The PRIOR-I employs high-gradient (120 T/m) NdFeB permanent magnet quadrupole lenses. The commissioning of PRIOR-I has demonstrated 30 µm spatial and 10 ns temporal resolution with remarkable density sensitivity.

The final design of the PRIOR proton microscope (PRIOR-II) employs small but strong and radiation-resistant electromagnets. It is assumed that the setup will be first used at GSI for static or dynamic experiments, and later will be transferred without modifications to the new experimental area at FAIR. The PRIOR-II facility will provide a magnification of about 3.5 at GSI and up to 8 at FAIR with 10 µm spatial resolution at the object. The first experiments with the PRIOR-II facility are planned for the end of 2019.

Plasma physics at FAIR using intense ion and laser beams

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Intense beams of energetic heavy ions offer a novel path towards volumetric heating of dense millimeter-sized targets. In the APPA cave at the future FAIR facility these capabilities will be exploited to study matter at extreme conditions and dense strongly-coupled plasmas. The talk will give a short introduction to the planned experimental facilities and platforms, as well as examples of experiments planned by the plasma physics collaboration. Also, activities within FAIR phase-0 in the next years will be reported.

Thursday, April 26, 2018 08:45

Mat Science Week - Session 8

08:45 Material modifications under extreme conditions delivered by swift heavy ions - Marcel Toulemonde (CIMAP-GANIL)

09:15 Structural Transformations Induced at Extreme Conditions: Coupling High-Pressure Cells with Energetic Ion Beams - Maik Lang (University of Tenneessee)

09:45 High pressure devices: Design, performance & applications - Stefan Klotz (Université P&M Curie)

10:15 --- Coffee ---

10:45 Mat Science Week - Session 9

10:45 Time-resolved measurements at high pressures using diamond anvil cells - Zuzana Konôpková (European XFEL GmbH)

11:15 Equation of state for strong compression - Wilfried B. Holzapfel (Department of Physics University Paderborn)

11:45 "High pressure" (tba) - Reinhard Boehler

12:15 Discussion

12:45 --- Lunch ---

14:15 Mat Science Week - Session 10

14:15 Acoustic energy loss measurements of GeV ions - Walter Assmann (Ludwig-Maximilians-Universität München, Garching, Germany)

14:45 Avalanches and crackling noise - Ekhard Salje (University of Cambridge)

15:15 Swift heavy ion-irradiated calcite ($CaCO_3$) analyzed by UV-C Laser excited Fluorescence-Spectrometry - Ulrich Anton Glasmacher (Institute of Earth Sciences, University Heidelberg)

15:35 Discussion

16:30 --- Coffee ---

17:00 Mat Science Week - Session 11

17:00 Verification of velocity effect in yttrium iron garnet by HR-STEM observations of latent tracks. - Maxim Saifulin (FLNR, JINR)

17:20 Structural and mechanical properties modifications induced in α-Al_2O_3 under swift heavy ions - Alexis RIBET (CIMAP)

17:40 Radiolysis of nucleobases under heavy ion irradiation: scaling laws for radio-resistance - Aditya Narain Agnihotri (Centre de Recherche sur les Ions, les Matériaux et la Photonique CIMAP, GANIL, CEA/CNRS/ENSICAEN/UNICAEN, Caen, France)

19:30 --- Dinner (Restaurant Weißer Schwan, Arheilgen) ---

THURSDAY, 26 April, 2018

Material modifications under extreme conditions delivered by swift heavy ions

Mr. TOULEMONDE, Marcel[1]

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The slowing down of swift heavy ions in matter leads to the deposition of enormous energy to the electrons of a given target of the order of 1022 W/cm3. This presentation provides an overview of the present knowledge of ion tracks and material modifications induced by swift heavy ions of MeV to GeV energy. Track formation requires a critical energy loss threshold and shows a clear dependence on the material conductivity as well as on the velocity of the ions [1]. Track effects are investigated by a large variety of methods including direct track measurements such as electron microscopy or atomic force microscopy as well as indirect techniques such as small angle X-ray scattering, X-ray diffraction, Rutherford backscattering, Mössbauer spectroscopy, and infrared or Raman spectroscopy. Regarding theoretical approaches, the inelastic thermal spike model [2] is the most promising approach. It will be discussed how material sensitivity is influenced by the electron-phonon mean free path of the material and the radial energy deposition on the electrons. [1] M. Toulemonde, W. Assmann, C. Dufour, A. Meftah and C. Trautmann Nucl. Instr. Meth. B 277 (2012) 28 [2] C. Dufour and M. Toulemonde Ser. Surf. Sci. 61 (2016) 63

Structural Transformations Induced at Extreme Conditions: Coupling High-Pressure Cells with Energetic Ion Beams

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Co-author(s): Dr. TRAUTMANN, Christina [2] ; Prof. EWING, Rodney C. [3]

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Recent advances in the design of diamond anvil cells and techniques for reaching extremely high pressures and temperatures have been combined with irradiations using swift heavy ions. These relativistic ions provide a unique opportunity to access states of matter quite far from thermodynamic equilibrium [1]. Each projectile deposits exceptional amounts of kinetic energy (GeV) within an exceedingly short interaction time (sub-fs) into nanometer-sized volumes of a material, resulting in extremely high energy densities (up to tens of eV/atom). The coupling of extreme energy deposition with high pressures and high temperatures, realized by injecting the relativistic heavy ions through a mm-thick diamond anvil of the pressure cell, dramatically alters transformation pathways and can lead to the formation of new states of matter. This innovative experimental approach allows us to probe the behavior of materials under extreme conditions, to form and stabilize novel phases in a wide range of oxides (e.g., GeO2 and Gd2Zr2O7) [2], and to manipulate the physical and chemical properties of solids at the nanoscale (e.g., CO2). A further application is to investigate the effects of radioactive decay events in compressed and heated minerals of Earth's interior, such as fission-track formation under crustal conditions and phase transitions of damaged minerals (e.g., ZrSiO4) resulting from meteorite impact [3]. This presentation describes the state-of-the-art science in this field by presenting several examples of structural modifications induced by coupled extreme conditions.
[1] J.M. Zhang, M. Lang, M. Toulemonde, R. Devanathan, R.C. Ewing, W.J. Weber, J. Mater. Res. 25 (2010) 1344.
[2] M. Lang, F.X. Zhang, J.M. Zhang, J.W. Wang, B. Schuster, C. Trautmann, R. Neumann, U. Becker, R.C. Ewing, Nature Materials 8 (2009) 793.
[3] M. Lang, F.X. Zhang, J. Lian, C. Trautmann, R. Neumann, R.C. Ewing, J. Synchrotron Radaition 6 (2009) 773.

High pressure devices: Design, performance & applications

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In this talk I will give an introductory review of high pressure devices covering pressures in the range 0.1-100 GPa (1 kbar-1 Mbar) and corresponding sample volumes of approximately 10^4-10^-3 mm^3. I will illustrate typical applications of these devices in material research, in particular at large-scale user facilities, and discuss advantages and their limitations. If there is time, potential science applications using ion irradiation of samples under pressure will be discussed.

Time-resolved measurements at high pressures using diamond anvil cells

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Time-resolved and pump and probe experiments using pulsed-laser heating and the diamond anvil cell technique have recently shown that they can yield information on transport properties of matter [1] as well as they can create and probe warm dense matter [2]. Time-resolved temperature response of an iron sample has been measured in order to provide thermal conductivity constraints in the Earth's core, valuable information not directly accessible by static measurements. The pump and probe experiments utilized intense short laser pulses capable of driving noble gases at high pressures to temperatures where a transition to a metallic state occurred. Such short-lived

states, however, call for fast X-ray probes, which are not available at the synchrotron sources. The unprecedented brightness offered by the European XFEL at hard X-ray energies of up to 25 keV facilitates method-development utilizing diamond anvil cells (DAC). Using rapid compression and pulsed-laser heating combined with DAC technology it is possible to create extreme states of matter, which are short lived and therefore require ultrafast probes in form of short FEL X-ray pulses. The HED instrument [3] will feature a second interaction chamber with a setup fully optimized for research using diamond anvil cells [4]. Rapid compression reaching higher pressures and greater strain rates than in conventional DAC will be realised using a piezo-driven dynamic DAC (dDAC), potentially also combined with pulsed-laser heating. Pulsed-laser heating will be used to create warm dense matter in nanosecond timescales. The X-ray repetition rate of the European XFEL of up to 4.5 MHz will then be used to characterize these extreme states by means of scattering, imaging and/or spectroscopic methods.

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Equation of state for strong compression

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An equations of state for solids is formulated with the correct behavior at very under strong compression and for wide ranges of temperature at first for “regular” solid. Modifications for solid with electronic configuration crossing are discussed and the formulation of a coherent equation of state for the fluid phase is illustrated for argon and water under very strong compression.

"High pressure" (tba)

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Acoustic energy loss measurements of GeV ions

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The energy loss maximum (Bragg peak) at their end of range is a characteristic feature of ions stopping in matter, which causes an acoustic pulse, if ions are deposited in short-enough bunches. This *ionoacoustic effect* has been studied for decades now, mainly for astrophysical applications, and has recently found renewed interest in proton therapy for range measurements in tissue. Within test experiments at the upgraded SIS18 in 2016, ionoacoustic range measurements have been performed in water using 238U and 124Xe ion beams around 300MeV/u, and a 12C ion beam around 200MeV/u with fast beam extraction to get 1 microsecond pulse length. Relative range changes for the different ions and energies were found in agreement with simulations to better than 1%. Given the unique accuracy provided by ionoacoustic range measurements in water and their simplicity, we propose this as a new method for stopping power measurements for ions at GeV energies. After a range-energy calibration of the acoustic detector setup for a certain ion species in water, different materials and thicknesses can be mounted on a target wheel and inserted between the exit window of the beamline and the entrance in the water tank hosting the acoustic detector. From the measured range changes stopping powers can be derived in a fast and efficient manner with high accuracy.

Avalanches and crackling noise

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Radiation damage processes generate acoustic emission (AE) due to defect avalanches. Avalanche processes have been heavily researched (review Salje and Dahmen, 2014) in recent years. The initiation of avalanches is achieved by standing acoustic waves (Baro et al. 2013), stress, strain, electric fields and were demonstrated to be reproduced by computer simulations (Salje et al. 2017). Internal radiation damage in zircon produces avalanches with fixed numbers of displaced atoms per avalanche. The scale invariant avalanche mechanism is hence replaced by scaled single events and their overlap. The predicted transition from power law dynamics to exponential dynamics has not been observed experimentally, however, because the internal stimulus by alpha decay is too weak to generate large enough avalanche processes. Alternatively, heavy ion irradiation is expected to initiate similar responses, which can be used to study the dynamic response to radiation damage in crystalline matrices.
Baro et al.2013 Statistical Similarity between the Compression of a Porous Material and Earthquakes PRL 110, 088702. Salje and Dahmen 2014 Crackling Noise in Disordered Materials Ann Rev CM Physics 5,233 Salje et al.Ultrafast Switching in Avalanche-Driven Ferroelectrics by Supersonic Kink Movements Adv Func. Mat.27,1700367

Shock wave compressibility of epoxy resin for experiments at PRIOR

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Cancelled

In this work, using high explosive generators for acceleration of aluminum plates, the experiments for determination of Hugoniot, the shock wave structure and spall strength in epoxy resin were conducted. Epoxy resin is a common binder for some anisotropic materials, which were studied by the authors earlier (carbon fiber, glass fiber, textolite). The density of the samples is 1.2 g/cm^3, the measured sound speed is 2.63 km/s. The goal of this study is development of targets

for experiments at a novel diagnostic system proton microscope (PRIOR). Shock waves will be produced by a two stage light gas gun, which is developing at the TU Darmstadt. Shock wave profiles were recorded by two laser interferometers VISAR. In each experiment, the structure of compression pulse and the shock wave velocity of epoxy resin were obtained. Shock compression pressure varied by changing of the thickness and the velocity of flyer plates. The velocity varied from 0.7 up to 2.5 km/s. On the velocity profiles, after the shock jump the value of particle velocity is a constant. From the experimental data Hugoniot of epoxy resin was obtained. It can be approximated by a linear dependence of D=2.6+1.18*u, km/s. Also the spall strength was investigated. It's value changes from 280 to 360 MPa, when the strain rate varies from 1.2*10^4 to 7.2*10^4 1/s.
The work is carried out with the financial support of FAIR-Russia Research Center.

Swift heavy ion-irradiated calcite (CaCO3) analyzed by UV-C Laser excited Fluorescence-Spectrometry

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The influence of natural radiation on luminescence behaviour of calcite leads to the assumption that it might be possible to determine the defect concentration, and therefore, the fluence applied to irradiated calcite crystals, by measuring the intensity change of the luminescence peaks. A new mobile UV-C laser excited fluorescence spectrometer system was build to be used at different irradiation beamlines (M-3 branch, SIS-18, and CRYRING) at GSI, Darmstadt for online and in-situ measurements. The system consists of a Crylas 266-200 UV-C pulsed laser (of λ=266 nm, 160 μJ/pulse, 60 Hz), a beam splitter, newly designed sample holder on a software driven 3-axis piezo-stage (PI Q521-300), a mirror, a UV-C beam dump, a longpass filter, two different optical fibres and two UV/Vis spectrometer. The Ocean Optics USB 4000 UV/Vis Spectrometer is used if the material under investigation provides high photon release. The Horiba Jobion Yvon iHR 320 spectrometer with a Pelletier cooled camera is used for low photon counts as it has a very high signal to noise ratio. Calcite crystals irradiated with 11.1 MeV/u Au ions of fluences between 1 x 106 and 1 x 1012 ions/cm2were investigated with the new system. In comparison to non-irradiated calcite crystals, the following changes can be seen with increasing fluence: - Increasing intensity of peaks and the appearance of new peaks.

Verification of velocity effect in yttrium iron garnet by HR-STEM observations of latent tracks.

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The characterization of swift heavy ion induced latent tracks morphology in various materials allows one to see general trends and plays an important role for correct understanding of material damage process due to high density electronic excitations. To date, a number of direct and indirect methods (such as TEM, RBS/c, XRD, SAXS, AFM) have been used to evaluate latent track parameters (diameter and threshold of formation) as a function of electronic energy losses, ion velocity and irradiation temperature. However, there is a certain discrepancy between experimentally measured track sizes when direct and indirect methods are used as well as contradictions between two most commonly used theoretical models (analytical and inelastic thermal spike), regarding the validity of so-called "velocity effect" (VE). Such discrepancies are probably related to a lack of a clear representation of latent tracks morphology in various materials. In this work low and high velocity Kr and Xe ion irradiation of Y3Fe5O12 single crystalls (YIG) have been performed to verify a validity of VE in YIG by means of HR-STEM observation technique. It has been shown that there is a difference in the latent tracks size for low and high velocity irradiated YIG, indicating on the velocity effect. A discussion of possible reasons of inconsistency in track sizes from direct and indirect measurements will be presented.

Structural and mechanical properties modifications induced in α-Al2O3 under swift heavy ions

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Sapphire is a common substrate for a broad variety of materials due to its optical transparency, insulating property and its hexagonal structure allowing often an easy epitaxial growth. During the use in radiative environment, such as space or nuclear industry, the materials intrinsic properties can be modified. Indeed, investigating the behavior of sapphire substrate under ion irradiation and its potential influence on the features of the epitaxial top layer is crucial for a reliable use.
In this work, mechanical properties and structural modifications induced by swift heavy ion irradiation are investigated. (0001)-Al2O3 single crystals have been irradiated along the c-direction by 92 MeV 129Xe at different fluences at GANIL (Caen, France). HRXD and nanoindentation combined with confocal microscopy have been used to characterize samples.
The evolution of the X-Ray patterns and of the mechanical properties are discussed as a function of the fluence. Lattice parameter variations are linked to disorder formation and amorphization. A depth profile is suggested as an explanation for the structural behavior. Correlated to the crystallographic disorder, a decrease in elastic modulus and hardness is observed. It has also be noted an influence of the ion irradiation on the shape of residual indents and on the morphology of the cracks. Complementary RBS/c, Raman spectroscopy and TEM results are discussed for a better understanding of the physical modifications under irradiation.

Radiolysis of nucleobases under heavy ion irradiation: scaling laws for radio-resistance

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Complex organic molecules (COMs) have been detected in outer space [1]. The carbonaceous meteorites found on earth containing traces of nucleobases (i.e. adenine, guanine etc.) also indicate towards their presence in outer space. The later is permeated by ionizing radiations, therefore, COMs constantly suffer irradiation. Survival of COMs depends on their radio-resistance, and measurements of the corresponding destruction rates help to estimate their half-life-time in outer space [2].

We have studied the radiolysis of nucleobases in solid phase by swift heavy ions at very low temperatures (~20K). The experiments were performed at GANIL/France and GSI/Germany facilities. Samples were prepared by liquid evaporation and vapour deposition techniques. The IR absorption spectra of the samples were obtained in situ, before and after irradiation, with a FTIR spectrometer setup [3].

The evolution of IR bands with the ion-fluence allows to deduce apparent destruction cross sections (σ) by fitting with an exponential decay function. The samples were irradiated with several projectiles with different electronic stopping power (Se) to obtain the scaling law. Estimations of survival times in cold universe and comparison to UV radiation will be presented.

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Friday, April 27, 2018

09:00 Mat Science Week - Session 12

09:00 TEM investigations of structural and chemical order in III-N semiconductors irradiated by swift heavy ions - Jean Gabriel Mattei (CIMAP)

09:20 Heavy ion-induced gas desorption in accelerators - Markus Bender (GSI, Darmstadt)

09:40 Photothermal radiometry study of heavy ion beam induced modification of polycrystalline graphite thermal properties -Alexey Prosvetov

10:00 Swift heavy ion irradiation damage in advanced nanostructured alloys - Sergey Rogozhkin (Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Centre «Kurchatov Institute»)

10:20 --- Coffee ---

10:50 Mat Science Week - Session 13

10:50 Heavy Ion Radiation Effects on Hafnium Oxide based Resistive Random Access Memory - Stefan Petzold (TU Darmstadt - Materials Science - Advanced Thin Film Technology)

11:10 Space Radiation Environment and Effects at LIP - Jorge SAMPAIO (Laboratório de Instrumentação e Física Experimental de Partículas)

11:30 Shock synthesis on radiation damaged samples - a new field forinvestigation? - Thomas Schlothauer (Technische Universität Bergakademie Freiberg)

11:50 Discussion

TEM investigations of structural and chemical order in III-N semiconductors irradiated by swift heavy ions

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The nitride semiconductors, (Ga,In)N, which display optical and electronic properties, intend to become one of the next-generation technology for space exploration [1]. Such application requires

studying the behavior of these materials under cosmic radiation, hence InN and GaN specimens were irradiated at the GANIL facility with 950 MeV Pb and 1,4 GeV U. These structural and chemical changes induced by swift heavy ions were investigated though transmission electron microscopy (TEM). High resolution TEM investigations were performed to identify the structural order along the ion tracks and the strain induced in the lattice neighboring the ion tracks [2]. Chemical investigations were carried out by STEM - Electron Energy Loss Spectroscopy (EELS) to describe the chemical order in the neighboring and inside the ion path. Discontinuous tracks in GaN samples and a density fluctuation around the track were identified by STEM HAADF. Chemical profiles plotted across ion tracks indicate a decrease of gallium rate within the ion path while higher density of gallium is clearly observed outside the track. Furthermore, the nitrogen k near-edge fine structure investigation reveals the encapsulation of nitrogen bubbles inside the ion tracks.
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Heavy ion-induced gas desorption in accelerators

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In heavy-ion accelerators such as the heavy ion synchrotron SIS18 at GSI, charge exchanged lost beam ions stimulate the release of gas from the chamber walls and the subsequent pressure increase leads to increased or even complete beam-loss. Consequently heavy ion-induced desorption is an issue for next-generation heavy ion accelerators with highest beam intensities. To come up against dynamic vacuum, several measures have been conducted. In particular the physics behind the ion-induced release of gas was investigated. It could be shown that the desorbed gas is originating mainly from surface-close regions of the target. But in contrast to earlier ideas, sputtering of the oxide layer on metals was not identified as source for desorbed gas. The contribution summarizes the perceptions gathered to date, including desorption yield studies, materials analysis and modeling of the process. Latest experiments on the annealing of critical components revealed the possibility to minimize the desorption yield by two orders of magnitude. The amount and composition of gas contained in materials was measured by thermal desorption spectroscopy and gives insight into the origin of desorbed gas. At superconducting structures of new accelerators, gas can be accumulated at the surface over time and therefore investigations on desorption of frozen gas ice were started.

Photothermal radiometry study of heavy ion beam induced modification of polycrystalline graphite thermal properties

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Polycrystalline graphite (PG) is one of the best candidate materials for applications in extreme radiation environments. It exhibits superior thermo-mechanical properties, resistance to elevated temperatures and stresses, low density leading to low linear energy transfer and reduced beam-induced activation. Recent studies report on ion beam induced hardening and increased electrical resistance of irradiated graphite materials [1]. Additionally, modifications of thermal properties leading to changes in efficiency of dissipation of the heat deposited by high intensity ion beam should be carefully investigated. In this work, the evolution of thermal effusivity and characteristic thermal diffusion time for polycrystalline graphite samples irradiated with 4.8 MeV/u and 5.9 MeV/u Au ions and with 4.8 MeV/u U ions at the UNILAC accelerator at GSI was studied using the photothermal radiometry (PTR) technique. PTR permits a non-destructive depth analysis and can evaluate the thermal properties of thin multilayer systems [2]. In this study, PTR is applied to characterize a 50-70 μm thick ion beam- damaged layer on pristine graphite substrate. The thickness value of the irradiated layer calculated by SRIM was experimentally confirmed by Raman spectroscopy and SEM imaging on the sample's cross-section. The results show a significant degradation of thermal effusivity down to 20% of the pristine value and a slight decrease of volumetric heat capacity of irradiated graphite at the maximum reached ion fluence of 5e13 i/cm2. The measured thermal properties of the irradiated layers reflect values characteristic to glassy carbon. This study can help in better understanding of swift heavy ion interaction with graphite and induced material modification.
[1] C. Hubert, K.O. Voss, M. Bender, K. Kupka, A. Romanenko, D. Severin, C. Trautmann, M. Tomut, Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms 365 (2015) 509–514. [2] C. Jensen, M. Chirtoc, N. Horny, J.S. Antoniow, H. Pron, H. Ban, J. Appl. Phys. 114 (2013).

Swift heavy ion irradiation damage in advanced nanostructured alloys

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The most promising materials for operation under high fluxes of high-energetic irradiations are complex heterogeneous systems strengthened by nanoscale inclusions and phases. Energy loses in such structures is nontrivial. Objects of this study are two titanium alloys (Ti-5Al-4V-2Vr and Ti-6Al-4V) and ODS Eurofer steel. The effect of irradiation at room temperature on the microstructure was studied by high-resolution transmission electron microscopy with energy-dispersive spectroscopy. Investigation of the initial state of titanium alloys revealed bimodal grain distribution: a large number of hardening β-phases enriched in vanadium inside α-phases. Irradiation with Au ions (4.8 MeV/nucleon, up to 1×10^13 cm^-2) leads to the formation of inclusions in the α phase with an average size of 2±1 nm. These features are coherent with the matrix, aligned along the irradiation direction and can be ascribed to pre-precipitates of the β phase. Irradiation of ODS Eurofer with swift Au (4.8 MeV/nucleon; 1×10^11 and 5×10^12 cm^-2) and Xe (1.2 MeV/nucleon; 1×10^13 1×10^14 cm^-2) ions led to the formation of amorphous areas within large (>8 nm) oxide particles . These features are probably tracks produced along the ion paths. The average size of the observed tracks is 3±1 nm, and their density correlates with the total ion fluence. An amorphous transition layer was observed at the interface of large oxide particles after irradiation with Au ions.

Heavy Ion Radiation Effects on Hafnium Oxide based Resistive Random Access Memory

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Classical FLASH technology shows limited radiation tolerance making it sensible to radiation induced errors, e.g., single event upsets. Charge based memories are becoming more and more sensitive to radiation with further downscaling leading to a lack of radiation hard memories beyond Mbit storage capacities. There is, thus, great demand for new intrinsically radiation hard NVM technologies. Since the storage of information in Resistive Random Access Memory (RRAM) is ascribed to a conductive filament of oxygen vacancies, the information is not based on charge but on a physical microstructure related state within the device, providing high resistance towards ionizing radiation, as shown for high energy protons, γ-radiation and X-ray-radiation. This makes RRAM based on hafnium oxide interesting for applications in harsh environments, such as energy plants or (aero) space applications. For such applications, the effect of heavy ion radiation on the switching behaviour needs to be investigated. Therefore, hafnium oxide based RRAM (TiN/HfOx/Pt/Au) stacks[1] were irradiated with 1.1 GeV Au-ions with fluences up to 10^12 ions/cm^2 and evaluated regarding pristine resistance, forming voltage, and data retention.
[1] S. U. Sharath, Adv. Funct. Mater. 27, 1700432 (2017)

Space Radiation Environment and Effects at LIP

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The Laboratório de Instrumentação e Física Experimental de Partículas (LIP) is the reference institution for experimental particle physics and associated technologies in Portugal. It was created in May 1986 to exploit the unique opportunities created by the country's accession to CERN. In the last ten years an R&D line focused on the study of Space radiation environments and their effects was created and consolidated at LIP. The competences developed include all the technologies identified on ESA's roadmap for this domain: radiation environment measurement technologies; radiation environment modelling; radiation effects analysis tools; test characterization and Radiation Hardness Assurance (RHA) of EEE components.
In this presentation we will give a brief overview of LIP activities in the field of space radiation environments and effects, namely the development of a RADiation hard Electron Monitor for the JUICE ESA mission to the Jovian system (RADEM), testing of EEE components for space missions as well as the construction of the Mars Energetic Radiation Environment Models (dMEREM) simulation tool and evaluation of the effects of space radiation on crews during manned space missions. Future projects and potential interests in FAIR will be discussed.

Shock synthesis on radiation damaged samples - a new field for investigation?

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POSTERS

Non-destructive visualization of swift heavy ion induced lattice defects in apatite (Ca5(PO4)3(OH,F,Cl)) using UV-laser stimulated fluorescence.

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Ultraviolet Laser (UV-C, 266 nm) stimulated fluorescence spectroscopy establishes a novel approach to visualize and quantify defects of natural apatite Ca5(PO4)3(OH,F,Cl) in a non-destructive manner. The present study demonstrates the visualization of defects in apatite created by swift heavy ions, using UV-C laser stimulated fluorescence spectroscopy. Prior to swift heavy ion irradiation apatite crystals were annealed (100h, 400oC) in order to remove all natural spontaneous fission tracks. In addition, one natural apatite was irradiated without prior annealing. The crystals were irradiated with 197Au ions (1x106 ion/cm2, 11.1 MeV/u) at GSI Darmstadt facility. Raman and UV-C laser stimulated fluorescence spectra were determined for all apatite crystals after irradiation and for natural apatites from the same location. UV-C spectra showed that the luminescent centers of apatite are mainly represented by lanthanides and particularly by Dy+3 (bands at 484, 579, and 754nm), UO22+ (548 nm), Sm+3 (599 and 645 nm), Pr+3 (600.1 nm). In comparison, the natural non-irradiated apatite crystals exhibit higher peak intensities as the irradiated ones. The presentation will also show the UV-C laser stimulated fluorescence spectra of irradiated apatite, which have been heated for various holding times (1–4 h) and temperatures (200-800°C). Increase of temperature and holding time of temperatures lead to increasing peak intensities. The amount varies related to the emission wavelength.

Ion Sources for Focused Ion Beam Applications

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One of the most important elements of a FIB system is the ion source which has to guarantee a stable, long life working in the needed application field. Main points are the spot size, ion current and energy and also the ion species itself. At present nearly half of the periodic table can be used in FIBs to modify locally electrical, optical, mechanic or magnetic properties. Among them the Liquid Metal Ion Sources (LMIS) mostly Ga and derived for alloys LMAIS [1] are most popular.The resolution is a few nm at pA ion currents. Similar work Ionic Liquid Ion Sources (ILIS) using salts or certain compounds emitting positive or negative mono- and polyatomic ions [1,2]. The ion current limit of 100 nA restrict volume removing. ECR or RF plasma sources can overcome this using Xe ions and currents up to 2 μA [3]. Presently the Gas Field Ion Source (GFIS) was rediscovered and was the initial point of the Helium Ion Microscope [4]. The final spot size of half nm opens new prospects in ion microscopy and nano-engineering. Another modern approach is the magneto-optical trap ion source (MOTIS) successful demonstrated for Cr and Li [5]. All FIB ion sources will be compared, characterized and described with a typical application.
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Compositional analysis in the HIM

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The helium ion microscope (HIM) is well known for its imaging with spot sizes below 0.5 nm, its nano-fabrication capabilities, the small energy spread of less than 1 eV and the extremely high brightness. Contrary to electron microscopy, imaging of insulating surfaces in a HIM can be performed without any metal coating.
However, the HIM still suffers from the lack of a well integrated material analysis. Past and ongoing activities of various groups on the implementation of in situ analysis will be summarized. Recently we implemented time-of-flight spectrometry to measure the energy of backscattered helium, the mass of sputtered ions and perspectively the energy loss of transmitted particles [1]. In this contribution we will give an overview on the technical realization of the significantly improved time-of-flight SIMS setup. New results, drawbacks and drawn conclusions for the practical use of this promising technique will be presented [2]. Further we will compare our approach to another recent development that utilizes a magnetic sector field analyzer. Our setup delivers a mass resolution delta m $\leq$ 0.3 u (for m/q $\leq$ 80 u). This is sufficient for many life science applications that rely on the isotope identification of light elements. Further a lateral resolution of 8 nm has been evaluated using edge profiles and represents a world record for spatially resolved SIMS.
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Microscopic model of chemical etching of swift heavy ion tracks in olivine

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Recently developed quantitive microscopic model of wet chemical ecthing (WCE) of swift heavy ion tracks (SHI) is presented. The model consists of the (A) original Monte-Carlo TREKIS code [1] simulating the kinetics of the electron subsystem in a track as well as energy transfer into a target lattice. Application of TREKIS provides with initial conditions for (B) Molecular Dynamics simulations of the subsequent kinetics of lattice relaxation in the track. Finally, (C) transition state theory [2] is used for estimations of radial and depth dependence of material-etchant reaction rate along the trajectories. These give a 3D distribution of material-etchant reaction rates [3] which are used in the (D) model of WCE of ions tracks [3]. Thus model describes the both eching regimes controlled by reaction of etchant molecules with the damaged material and by diffusion of these molecules and reaction products to/from the etching front. The model was applied to describe experimental results [4] of etching of SHI tracks in olivine.

Electronic properties and structure modification of Al2O3 under intense excitation of electronic system

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Interactions of swift heavy ions (SHI) or free-electron laser beams with solids are characterized by extremely fast (10 – 100 fs) and intense nonequilibrium electron kinetics. Extreme excitation of the electron system [1] can change the interatomic potential causing lattice instability i.e. nonthermal structure transformations can take place in the material. Ab-initio density functional theory is applied in this work to describe changes of the band structure and density of states (DOS) of Al2O3 caused by increase of the electronic temperature above 1 eV. It is shown that the DOS shifts and modifies under such conditions, which affects interatomic potential energy surface. Car-Parrinello molecular dynamics is also used to investigate an effect of transient increase of the electron temperature on nonthermal structure instability in Al2O3. We show that the material instability occurs at ps-timescales for the electronic temperatures above ˜2 eV; a phase transition may take place within 0.5-1 ps if this temperature overcomes ˜4 eV; for material modifications to form within sub-100 fs (cooling down of an SHI track [2]), temperatures above ˜10 eV are required. The latter condition seems to preclude nonthermal melting from occurring in SHI tracks, in contrast to laser spots.
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Swift heavy ion research of condensed matter at extreme conditions

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Swift heavy ion research with condensed matter at extreme P-T conditions forces the available technologies and material properties to its limits. The Paris-Edinburgh press (PE-Press) yields a suitable technology for generating stable static pressures (10´s of GPa) on large sample volume (< 3mm3). In the past, two PE-Presses have been modified in such a way that accelerated heavy ions can reach condensed matter hold at high pressure. The specially developed anvils manufactured of tungsten carbide enclose new one-side spherical diamonds (diamond diameter = 2.7 mm). The diamond windows open the pathway for optical and spectroscopic measurements during ion irradiation. With this novel originated PE press setup, it is possible to retrieve pressure and temperature data by measuring the shift of Raman bands or fluorescence lines of standard material. The poster will provide insight into the latest technological developments. One of the PE-Presses has been modified to perform swift heavy ion irradiation of condensed matter at high pressure and medium high temperatures (<900 K). The second PE-Press will been customized to operate at medium low temperatures (>200 T <300 K). The aim of the research is to conduct experimental studies in such a way that radioactive decay and its effect to Earth mantle rocks at HT/HP-conditions can be simulated. In addition, the low temperature research aims to simulate the interaction of cosmic radiation on ice on planetary surfaces in space.

Charge exchange of highly charged ions transmitted through 2D materials

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Slow highly charged ions (HCIs), which traverse an ultra-thin solid film consisting of only a few atomic layers, do not reach their equilibrium charge state for sufficiently high incident charge states [1,2]. Hence, 2D materials serve as ultimately thin solid targets for probing the neutralisation dynamics of HCIs,- which was recently investigated for xenon ions transmitted through a single layer graphene [1,2]. A large electron current density is present upon ion impact on graphene. Thus, surprisingly short neutralisation times of only a few femtoseconds were determined. Here we want to investigate the influence of the target properties on the neutralisation dynamics of HCIs. Our measurements are extended to 2D materials beyond graphene, which exhibit different electrical properties: insulating hBN and semi-conducting MoS2. In contrast to them, graphene is a semi-metal with a very high electrical conductivity. For measuring the exit charge state distributions of transmitted HCIs, two different techniques were applied. Using an electrostatic analyser, charge states are selected and the kinetic energy loss can be determined [1]. Additionally, charge state distributions are recorded by using a setup composed of electrostatic deflector plates and a position sensitive microchannel plate, which enables the measurement of low charge states and even neutralised atoms. [1] E. Gruber et al., Nat. Commun. 7, 13948 (2016), [2] R. A. Wilhelm et al., Phys. Rev. Lett. 119, 103401 (2017).

Dynamic Measurements of Secondary Electron Emission during Plasma Immersion Ion Implantation

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Plasma based deposition processes are commonly used in industry to guarantee high quality coatings with versatile properties. Modern technologies including magnetron sputtering and HIPIMS crucially depend on the plasma and electrode properties as secondary electron emission due to impinging ions is an essential intermediate step in these PVD processes. Concurrently, sputtering of the surface by the impinging ions leads to the emission of a large quantity of neutral atoms.
Using a passive thermal probe, the emission of secondary electrons can be detected with reasonable time resolution which allows a detailed in-situ measurement of the surface state (i.e. metallic, oxidized or nitrided) and its time evolution during either sputtering of surface layers or growth of compounds by ion implantation. Thus, a dedicated investigation of the relative secondary electron emission of materials is possible. In this presentation, the time evolution of the secondary electron emission is presented as a function of ion energy using argon ions for selected metals including Al, Mg, Ag and Ti to elucidate the nature of the native oxide layer. The presented method is a versatile technique for measuring dynamic changes of the surface for materials commonly used in

PVD processes, e.g. magnetron sputtering or HiPIMS, where changes in the target or electrode composition are occurring but cannot be measured directly.

Ion beam induced surface patterns – All coefficients for the equation of motion from Monte Carlo simulations

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Theories of surface pattern formation consider the curvature dependent effects determined by the first order moments of erosion and redistribution crater functions. Smoothing of a surface is described by thermal surface diffusion or ion-induced viscous flow. The equation of motion (EOM) of the surface h(x,y,t) consists of 1st and 2nd order spatial derivatives and a 4th order term related to smoothing. Using the Monte Carlo simulation code SDTrimSP we calculate all crater function moments (erosion, redistribution and implantation) up to 4th order and derive all coefficients for the EOM up to 4th order, including the non-linear coefficients. The calculation is applicable for amorphous targets, almost any ion-target combination up to ion energies of several 10 keV, any ion incidence angle, and it may also include dynamic changes of the target stoichiometry. Higher order crater function moments give rise to a wavelength dependent contribution to the ripple propagation velocity and coefficients of the fourth derivatives, which behave similar to a diffusion term. Non-linear coefficients related to quadratic and cubic temrs of the derivatives dh/dx and dh/dy) give rise to amplitude saturation and also terrace formation. We calculate the complete set of coefficients for the EOM using SDTrimSP for several model cases, which are then used as input for a new software package that allows the rapid simulation of surface dynamics for arbitrary, nonlinear EOMs.

Ion induced surface patterns - Comparison of experiments with binary Collision Approximation Simulations

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There exist numerous experimental data on ion induced surface patterns. The interpretation of the observed surface structures and the evaluation of critical parameters like incidence angle, ion energy are often based on analytical theories using linear and non-linear equations of motion (EOM) for the evolution of a surface height profile. While the first theory of Bradley and Harper only considered ion erosion as main effect leading to surface patterns, it was later asserted that mass redistribution would be the only dominating mechanism. Meanwhile it was shown that ion implantation can give significant contribution. Input for the EOM is often obtained from time consuming molecular dynamics (MD) simulations, and it is asserted that simulations based on the binary collision approximation (BCA) are not accurate enough to yield reliable data. In this presentation we demonstrate that many experimentally observed features of ion induced surface pattern formation can be quantitatively reproduced by fast BCA simulations, taking into account erosion, mass redistribution and implantation. We will not only consider linear theories but also investigate the effect of higher order and non-linear terms in the EOM. We also treat ion induced viscous flow more realistic compared to many studies on pattern formation found in the literature. The examples studied include experiments ranging from few hundred eV up to 100 keV ion energy, include non-volatile ions and also compound target systems.

Morphology, density, and temporal evolution of topological defects in reverse epitaxy

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Low-energy ion-irradiation of semiconductors above their recrystallization temperature has been shown to induce regular nanoscale patterning of the crystalline surface. The mechanism is called reverse epitaxy in analogy to epitaxy in growth: ion-induced mobile vacancies and ad-atoms on the crystalline surface encounter the Ehrlich-Schwoebel energy barrier for crossing terrace steps and exhibit preferential diffusion along specific in-plane directions. This can lead to the formation of well-defined faceted surface structures with morphologies strongly dependent on crystalline structure and surface orientation. For instance, GaAs(001) and InAs(001) develop periodic ripple structures with a saw tooth profile. We have studied the topological defects in ion-induced patterns on GaAs(001) and InAs(001), i.e. ripple junctions, and present results from both experiments and simulations on the following aspects: - defect morphology and the influence of polar and azimuthal ion incidence angles thereon - dependence of the defect density on sample temperature and ion energy - temporal evolution of the defect density - defect motion and annihilation processes We find strong dependencies on the easily controllable external process parameters, which is crucial information when preparing ion-induced surface patterns for specific applications.

Isotopentrennung von Mangan-Radioisotopen mittels Resonanzionisations-Massenspektrometrie

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Für das MeaNCoRN-Projekt am Paul-Scherrer-Institut (PSI) werden hochreine Proben des langlebigen Radioisotops 53Mn (t1/2 = 3.7 Ma) zur Bestimmung der Lebensdauer und als Reaktionstargets für Anregungsquerschnittsmessungen benötigt. Es müssen dazu μg-Mengen (etwa 1017 Atome) des Isotops weitestgehend isotopenrein und mit möglichst hoher Effizienz in Aluminium-Targets implantiert werden und die im Überschuss vorliegenden kurzlebigen und stabilen Isotope 54,55Mn unterdrückt werden. Das hocheffiziente und selektive Verfahren der Resonanzionisations-Massenspektrometrie (RIMS) wurde am Mainzer RISIKO-Massenseparator auf Mangan adaptiert und für die effiziente Isotopenabtrennung auch bei höheren Ionenströmen im Bereich bis zu 1 [U+F06D] A Ionenstrahlstrom optimiert. Dabei wurden Effizienzen von typisch 15 % demonstriert und die anvisierte Probenmenge mit der erwarteten Reinheit erzeugt. Das Verfahren kann damit zukünftig auch die Beschleunigermassenspektrometrie (AMS) an 53Mn durch Vorunterdrückung von Nachbarisotopen und Reduktion des generellen Untergrunds unterstützen. Zum Erreichen der notwendigen extrem hohen Selektivität im Mangan im Bereich von > 1016 muss allerdings eine zusätzliche Isobarenunterdrückung (53Cr) für die AMS z.B. am 6 MV-Tandembeschleuniger am Helmholtz-Zentrum Dresden-Rossendorf über Laser-Photodetachment zum Einsatz gebracht werden kann.

Synthesis and Characterisation of Copper Nanowire Networks

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We present the synthesis and characterization of metallic copper nanowire networks by ion-track technology and electrochemical deposition. By sequential swift heavy ion irradiation of 30μm thick polycarbonate foils from four different directions, interconnected latent tracks are generated. During the subsequent chemical etching process, the ion-tracks are selectively dissolved and enlarged to form an interconnected nanochannel network. By electrochemical deposition we synthesize copper nanowires in the channels. For complete and homogeneous growth, deposition conditions and geometry are varied yielding three dimensional assemblies of embedded Cu nanowires with well defined geometrical parameters. The poster will show how network parameters such as wire diameter, wire density, interconnectivity and surface morphology are tuned by adjusting the different process steps. For a nanowire network the total surface area is two orders of magnitude higher than for a planar surface of the same size. SEM images, providing evidence on the influence of the deposition potential on the growth homogeneity of the nanowire networks will be presented on the poster. All these geometrical and crystallographic properties influence the performance of these high surface area nanostructured samples for their implementation in, e.g., catalytical or electrochemical applications.

Investigating Radiation Effects in Materials by Neutron Total Scattering

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We present neutron total scattering with pair distribution function (PDF) analysis as a new strategy for the characterization of radiation effects in materials. Key to this approach is the use of swift heavy ions with a very high penetration depth to produce sufficiently large irradiated sample mass (~150 mg). Irradiation experiments were performed at the UNILAC accelerator of the GSI Helmholtz Center with ions of specific energy of 11.4 MeV/u. The irradiated samples were characterized at the Nanoscale Ordered Materials Diffractometer (NOMAD) beamline at the Spallation Neutron Source (Oak Ridge National Laboratory). We investigated various ion-induced structural modifications, such as defect formation (CeO2 and ThO2), disordering (Er2Sn2O7), and amorphization (Dy2TiO5). Neutrons scatter strongly from low-Z elements, permitting a detailed analysis of both cation and anion defect behavior. PDF analysis elucidates the local defect structure, including changes in site occupation, coordination, and bond distance. This is particularly important for characterizing radiation effects in oxides, as structural modifications induced by ion-beam irradiation are seldom ordered over long length scales and in extreme cases result in complete loss of long-range order (i.e., amorphization). Initial results demonstrate that irradiation-induced structural modifications are much more complex than previously thought with distinct processes occurring over different length scales.

Cu2O nanowire arrays electrodeposited in etched ion-track membranes as photocathodes for solar water splitting

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Research on the synthesis and characterization of semiconductor nanowires is continuously increasing especially for applications in the field of energy conversion, such as for instance solar cells, photocatalysis, and photoelectrochemical water splitting for hydrogen production. One attractive approach to improve the efficiency of solar to hydrogen conversion is the use of nanowire architectures since they offer larger surface areas and permit to dramatically reduce the ratio of the minority carrier diffusion length over the light absorption depth. Cu2O is a promising candidate material to be applied as photocathodes for hydrogen production via water splitting. A solar-to-hydrogen conversion efficiency of 18% has been predicted for this p-type semiconductor with a band gap of 2 eV. Moreover, Cu2O has favorable band energy positions for water splitting, and is earth-abundant, scalable, non-toxic, and compatible with low-cost fabrication processes. Its limited chemical stability in aqueous solution can be potentially be improved by adding protection layers. In this poster, we discuss the fabrication and characterization of Cu2O nanowire arrays by electrodeposition in etched ion-track membranes. Nanowire diameter, length, number density, and crystallinity are adjusted in a systematic manner during the synthesis. After removal of the polymer membrane in an organic solvent, the freestanding nanowire arrays are coated by an additional electrodeposited Cu2O layer to avoid direct contact between the electrolyte and the metallic support layer. Finally, a conformal TiO2 film is applied by atomic layer deposition. Photoelectrochemical measurements on these nanowire-based electrodes will be presented, and the influence of their geometrical characteristics on their performance will be discussed.

Nanostructured Graphene/Polymer Composite Membranes for Fluid- and Gasfiltration

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Since its discovery in 2004 graphene has experienced a vast amount of interest due to its extraordinary qualities. Besides its unique electronic properties, which have often been at the center of research activities, it also displays exceptional mechanical characteristics making it suitable for novel filtering applications, in particular in areas where until now, track-etched filtering membranes are commonly used [1-2]. Our work aims at combining the advantages of both graphene, in terms of an incomparable high water and gas permeability due to negligible fluid wall interactions, and those of a flexible and mechanical stable polymer support film, resulting in a new graphene/polymer heterostructure membrane type. By irradiating the double-layer membrane with swift heavy ions (SHI) one can simultaneously induce nanometer sized pores with adjustable diameters in the graphene and a perfectly aligned latent track in the polymer. By exposing the polymer to an etching solution, macroscopic pores in the polymer are formed, right beneath the nanometer sized pores in the graphene. Hence, the efficiency and performance of processes such as protein and nanoparticle filtration can be significantly enhanced using nanostructured graphene [3].

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Fabrication of hybrid bio/polymer nanochannels

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Biological channels embedded in plasma membranes perform crucial metabolic functions and regulate the communication between each cell and its surroundings. These bio-channels exhibit highly selective and responsive ion transport. They inspire, at the same time, the biomimetic design of solid-state nanochannels for ion transport and sensing. [1] Solid state nanochannels, including the polymer etched single ion-track membranes fabricated at GSI, offer important advantages with respect to biological channels regarding durability, reproducibility, and stability. Currently, many efforts are being devoted to develop surface modification t echniques t hat confer specific s urface f unctionalities t o t hese s olid s tate n anochannels. [2-6] I n t his p oster, w e present the development of an hybrid bio/polymer nanochannel. We first f abricate s ingle polymer etched ion-tracks with high aspect-ratio, controlled dimension, and geometry, by swift heavy ion irradiation and etching. Subsequently, we assemble a synthetic biological lipid-bilayer membrane (DPhPC) on the polymer surface across the single etched channel as platform for the integration of a viral potassium channel KcvNTS. This biological channel exhibit very small sizes with only 82 aa per monomer, being quasi fully embedded across the lipid bilayer. Each assembled hybrid nanochannel is then introduced between two compartments in an electrochemical cell to investigate its ionic transport properties. The development of such hybrid nanochannel systems provides an excellent plattform to study the behavior of biological ion channels supported by the more stable polymer etched pores compared to the fragile cell membranes.

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Physics with Positrons

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The neutron induced positron source NEPOMUC at FRM II provides the world's highest intensity of 10ˆ9 moderated positrons per second [1]. Within this contribution the basic properties of positron annihilation studies will be briefly explained and the benefit of positron beam experiments will be elucidated by selected experiments. In solid state physics and surface science the positron is applied as a highly mobile nano-probe for the detection of vacancy-like defects and their chemical surrounding in a non-destructive way. Doppler broadening spectroscopy (DBS) using a scanning positron beam allows e.g. the imaging of defect distribution in metals after mechanical load [2], irradiation induced defects [3] as well as the oxygen vacancy distribution in high-Tc superconductors [4]. At the surface, the annihilation of low-energy positrons with core electrons initiates the emission of Auger-electrons primarily in the topmost atomic layer allowing the in situ observation of the surface segregation of Cu in Pd [5]. Currently, a new positron diffractometer is set up at NEPOMUC, which will enable high-precision experiments for the characterisation of surface structures [6]. Measurements of the angular correlation of the annihilation radiation (ACAR) using polarized positrons enable the spin-resolved determination of the electronic structure e.g. in Cu2MnAl [7].

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