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GSI

Buch der Abstracts

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Ion beams for photonic integrated circuits

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Ion beam technologies are today routine methods in electronic device manufacturing, e.g. the production of a modern processor needs 20-30 ion implantation steps. On the other hand, the 21st century is considered by many to be the century of light following a century of developments in electronics. Therefore, I will present several experiments for the manipulation of the optical properties of materials, thin films and nanostructures using ion beams, together with corresponding strategies for the realization of photonic integrated circuits. This will include the emission enhancement of erbium in plasmonic waveguides [Nat. Com. 14, 2719 (2023)] as well as the realization of integrated erbium-doped amplifiers [Science 376, 1309 (2022)].

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Spectroscopic Investigation of Swift Heavy Ion Induced Defects in Type Ib Diamond

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Type Ib diamonds containing ~200 ppm substitutional nitrogen were irradiated with 4.8 MeV/n swift heavy ions (^{48}Ca, ^{197}Au, ^{238}U) to investigate radiation-induced defect formation and evolution. A comprehensive spectroscopic approach combining on-line ionoluminescence, spatially resolved photoluminescence/Raman spectroscopy, UV/vis absorption, and infrared spectroscopy was employed to characterize defect dynamics across fluences from 10^9 to 2×10^{13} cm^{-2}.

Ionoluminescence spectroscopy revealed broad emission bands at ~530 nm and ~885 nm, attributed to 3H centers and NiV$^-$ centers, respectively. The integrated luminescence signal degraded rapidly, retaining only 20% of initial intensity after 2×10^{11} cm^{-2} ^{197}Au irradiation. At higher fluences ($> 10^{12}$ cm^{-2}), blue emission from 3.188 eV and 2.807 eV centers emerged.

Spatially resolved measurements with 1-2 µm resolution probed different energy loss regimes along ion trajectories. Vacancy-related GR1 centers showed maximum intensity at electronic energy loss dominated regions near the surface, while diamond lattice degradation (monitored via Raman intensity) was most pronounced at nuclear energy loss dominated end-of-range regions. The 3H center intensity peaked at vacancy densities of 4.4×10^{18} cm^{-3}, scaling with the electronic-to-nuclear energy loss ratio.

Complementary UV/vis and FT-IR absorption spectroscopy confirmed the identified defect centers and revealed direct nitrogen A/B center formation without significant aggregation.

These results demonstrate strong sensitivity of various color centers to electronic energy loss, challenging the common assumption that radiation damage in diamond is solely nuclear energy loss driven. The findings provide crucial insights for diamond detector applications in heavy ion environments and advance understanding of defect formation mechanisms under swift heavy ion irradiation.

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

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The energy deposition of ions in water generates pressure waves. These ionoacoustic signals are commonly described within the thermoacoustic approximation, where localised heating and subsequent volume expansion are considered the primary sources of wave generation. According to this model, no pressure wave should be observed at 4 ℃, a prediction confirmed in laser absorption experiments. However, when initiated by protons, the minimum of the acoustic signal shifts to significantly higher temperatures, suggesting the presence of an additional, non-thermal excitation mechanism.
We present the first experimental investigation of this effect using heavy ions (^{238}U and ^{100}Mo), conducted at the SIS-18 accelerator at GSI Darmstadt. By analysing the polarity change of the pressure wave near the water anomaly at 4 ℃, we observed distinct directional dependencies in the lateral and axial components of the acoustic signal, indicating a pronounced and unexpected directionality in the excitation process.
We developed a momentum transfer model that quantitatively describes the generation of non-thermal acoustic signals. The model aligns well with the experimental observations for heavy ions. These findings may enable novel diagnostic techniques and contribute to a broader understanding of mechanically induced radiation damage.
This work was supported by the GSI-LMU F&E cooperation LMSCH2025, DFG (491853809) and BMBF (05P21WMFA1). Results are based on an experiment in the context of FAIR Phase-0 at GSI, Darmstadt (Germany).

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News from PT-DESY

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Capturing ultrafast electron heating from single-ion impact in solids

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Low to medium energy ions in the keV regime have become a standard tool to tailor material properties, enable nanostructuring and analysis at the nanoscale. Yet, accessing the intrinsic ultrafast response of solids to a single ion impact has long been hindered by the difficulty of generating and precisely timing short, monoenergetic ion pulses in this energy regime. We present a synchronized ion-pump/laser-probe scheme that overcomes this limitation by combining femtosecond photo-ionization of a geometrically cooled gas jet with a miniaturized buncher. This approach delivers monoenergetic keV ion pulses as short as ~4 ps (FWHM) and enables direct, picosecond-resolved probing of the target system response launched by single-ion excitation. Using suspended graphene membranes as targets and a sub-work-function probe pulse in a 2PPE-like scheme, we observe a robust secondary-electron signal that appears exclusively under spatiotemporal overlap of ion and laser pulses.
Supported by first-principles calculations, analysis of the enhancement in electron yields at pump-probe correlation quantifies a transient electronic temperature of approximately 2000 K within a few picoseconds after impact, establishing a direct metric for ion-induced hot-electron heating in solids. Our results demonstrate the feasibility and diagnostic power of synchronized ultrashort ion pulses for time-resolved studies of ion–matter interactions. Looking ahead, realistic optimizations point toward sub-picosecond ion pulses (⊠0.5 ps) and broader applicability across projectile species and materials classes, opening a route to directly observe non-equilibrium electronic dynamics following ion impacts.

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Mechanical Stress Formation in Ge Films upon Ion Irradiation

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Germanium is a material widely used in various applications, especially in optoelectronic devices, due to its excellent optical and electrical properties. In these devices, germanium is typically deposited in the form of thin films. Because of the mismatch in thermal expansion coefficients between the Ge film and the substrate, the material can develop either compressive or tensile stress that affects the reliability and durability of the devices. Therefore, studying stress in such materials is essential and it plays a critical role in its fabrication. Ion irradiation offers a method for modifying the stress state of thin films. In this work, we investigate the effect of ion irradiation on the stress

state of Ge films and its correlation with the optical and structural properties. Germanium thin films were deposited by sputtering onto fused silica substrates at room temperature, followed by thermal annealing at 600 ℃ for 1 hour. The samples were then irradiated with 1.8 MeV Au+ ions with ion fluences ranging from 5e11 to 1.5e15 ions/cm². In situ stress measurements were performed during irradiation using a laser reflection technique. The results show that the samples before irradiation were tensile stressed and it decreases with increasing ion fluence up to a critical fluence of ~5e12 ions/cm². Beyond this point, the tensile stress begins to increase again. Post-irradiation characterization using X-ray diffraction revealed a structural transition from a polycrystalline to an amorphous phase with increasing fluence. Optical measurements showed a red shift in absorption, leading to a decrease in the band gap, and a decrease in reflectance as the irradiation fluence increased. These findings demonstrate that ion irradiation can effectively modify the mechanical, optical, and structural properties of germanium thin films which could be beneficial for device applications.

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Defect induced magnetic phase transition in CrSBr

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As an air-stable Van der Waals magnetic semiconductor, CrSBr is receiving great research attention due to its exceptional optical, electronic, and magnetic properties. Below the Néel temperature of 132 K, CrSBr exhibits a typical A-type antiferromagnetic order comprised of antiferromagnetically coupled ferromagnetic monolayer. This special structure makes it susceptible to external stimuli, such as defects. In this work, we present the magnetic phase transition from antiferromagnetic to ferromagnetic in CrSBr crystals irradiated by non-magnetic ions. We observe the rise and fall of the ferromagnetic phase in antiferromagnetic CrSBr with increasing the irradiation fluence, while confirm the evolution of interlayer AFM coupling. The irradiated CrSBr shows ferromagnetic critical temperature ranging from 110 to 84 K, well above liquid N2 temperature. Raman spectroscopy reveals phonon softening, suggesting the formation of defects. Structure analysis of the irradiated crystals in conjunction with density functional theory calculations suggest that the displacement of constituent atoms due to collisions with ions and the formation of interstitials favors ferromagnetic order between the layers. Increasing irradiation fluences gradually lowers the Curie temperature, reflecting the impact of crystalline degradation. This suggests that by finely tuning the irradiation parameters and employing precise lithography techniques, it is possible to selectively modulate induced ferromagnetism in CrSBr in terms of magnetization strength, critical temperature, and spatial distribution.

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Capturing ion-solid interactions on sub ps timescales

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Ion impacts trigger atomic-scale processes in solids on ultrafast timescales, yet direct experimental access to these dynamics has been limited by the lack of short, monoenergetic ion pulses. To address these challenges, we developed a novel ion source based on strong-field photoionization of a cooled gas jet. In combination with a compact buncher system, we are able of generating monoenergetic keV ion pulses with durations of only a few picoseconds. In a proof-of-principle experiment on a free-standing graphene membrane, we performed the first ion-based pump–probe measurement in the keV regime with picosecond resolution, directly probing hot electron emission following ion impact. Computer simulations indicate that ion pulses in the sub-picosecond regime are possible, highlighting the need for further instrumental improvements.

To advance this capability, we will enhance the time resolution by modifying the gas composition and redesigning the ionization chamber. We approach this challenge by a more compact and modular chamber design, improving stability and reproducibility, mitigating the sensitivity of the setup. Its modularity also increases versatility for integrating various detection technologies without affecting the remaining configuration, thus paving the way toward resolving ion–solid interaction dynamics on even shorter timescales.

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Capturing ion induced electron dynamics in 2D materials

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Ion bombardment is a powerful tool for tailoring the properties of materials, inducing structural modifications and enabling nanoscale analysis. However, understanding the fundamental response of matter to ion impact requires access to ultrafast processes that unfold on timescales ranging from femtoseconds to picoseconds. Although laser-based pump–probe techniques have long provided insight into electronic excitations and relaxation pathways, equivalent experiments involving ions have thus far been limited due to the absence of sufficiently short and precisely timed ion pulses.
To conduct such an experiment, ultra-short and precisely timed ion pulses are just as indispensable as certain requirements for the sample system. In our study, we use polymer-free, suspended graphene membranes consisting of three superimposed layers spanning circular openings with a diameter of 150 µm. Further studies will use other 2D materials, such as MoS_2, with vastly different electrical properties, as a transmission-style experiment requires minimal thickness.

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Experimental setup for swift heavy ion irradiation under high pressure and temperature using a Paris-Edinburgh Press with a large-volume toroidal Diamond Anvil Chamber

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The design of the Paris-Edinburgh Press (PEP) and large-volume diamond-anvil chambers (DAC) are designed to facilitate in-situ spectroscopic and optical measurements (e.g. Raman spectroscopy, optical observation) under high pressure and high temperature conditions, reaching up to 12 GPa and 1000 K. These setups accommodate sample sizes of 1x3mm. This setup is positioned on a motorized platform with multiple degrees of freedom allowing for high-precision positioning (~10µm). The entire system is placed into the accelerator facility for heavy ions at GSI Helmholtz Centre for Heavy Ion Research in Darmstadt (Germany), which enables unique irradiation experiments under controlled pressure and temperature conditions.

First experiments on ion-induced amorphization in $ZrSiO_4$ under pressure using swift heavy ions (U92+) reveal a linear destruction of the crystal lattice along the ion beam trajectory, along with a spatial variation in structural response. This significantly enhances the process of amorphization, making it possible to track structural modifications in real time using in-situ Raman spectroscopy. After irradiation, samples are further analyzed ex-situ using techniques such as Electron Backscatter Diffraction (EBSD), Electron Probe Microanalysis (EPMA) or Transmission Electron Microscopy (TEM) to assess microstructural and chemical changes.
Moreover, the differences in material response between pre-irradiated (already amorphous) samples and irradiated samples across different pressure and temperature conditions are systematically investigated. These insights contribute to a deeper understanding of radiation-induced transformations in complex materials and their behavior under real conditions.

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The new ion implantation chamber in the General Low Mass (GLM) area of ISOLDE.

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The General Low Mass (GLM) beamline of ISOLDE is dedicated to collecting and handling radioactive isotopes.

The currently still used ion implantation chamber is a single vacuum chamber equipped with a turbo pump capable of reaching 1E-5 mbar, often relying on the beamline vacuum pump to achieve its optimal pressure of 1E-6 mbar.

The new ion implantation chamber features a load-lock system with two sub-chambers—the implantation chamber and the sample loading/unloading chamber—connected by a DN200 gate valve, each independently evacuated by its own turbo pump (HiPace 700 and 1200 respectively). This setup allows for quick vacuuming down to 1E-6 mbar within minutes. Additionally, the implantation process is automated with computer-controlled stepper motors that (a) transfer samples between the

two sub-chambers and (b) adjust the collimator in the implantation sub-chamber, enabling optimization of the incoming radioactive ion beam, and (c) an Einzel lens that allows for the focusing of the beam downstream.

The advantages of the new ion implantation chamber are 1) the introduction of the load-lock mechanism between the two sub-chambers ensures that the implantation sub-chamber is kept at operational pressure (< 1E-6 mbar) and not vented for rapid sample change and implantation (for more frequent implantations), 2) user-friendliness, in which the automation afforded by the motors decrease the risk of user error, 3) safety, inbuilt in both hardware and software, in which minimization of mechanical contact between the GLM users and the new ion implantation chambers will lead to radiological exposition reduction."

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Superconductivity in Ga-Doped SiGe via Ion Implantation and flash lamp annealing

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Group-IV superconducting semiconductors present promising opportunities on the development of scalable hybrid platforms for quantum devices. However, achieving superconducting states in semiconductors remains challenging, particularly concerning the origin of coherent coupling and the relationship between carrier concentration and critical temperature. In this study, ion implantation and flash-lamp annealing are used to achieve hyper-doped SiGe1 alloys. We systematic investigate the tunability of the superconducting transition temperature by adjusting the Si/Ge composition and the Ga implantation fluences. As the Si concentration in SiGe increases, while maintaining identical doping fluences, the critical temperature is reduced from 550 mK to 40 mK. This is due to the lower solubility of Ga in Si than in Ge. Furthermore, as the Ga fluence decreases, the critical temperature is also reduced from 550 mK to 80 mK. All results indicate a modulation of superconductivity in diluted SiGe by carrier concentration. We establish a qualitative correlation between critical temperature and free-hole concentration, which can be tuned by varying the Ga implantation fluence and the SiGe alloy composition.

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Ion beam shaping of catalytic nanoparticles

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At the nanoscale metals exhibit catalytic properties that differ from those in the bulk phase. Gold, which is commonly regarded as inert, becomes a powerful catalyst for reactions such as the water gas shift reaction, which is an important step in the production of hydrogen. The catalytic activity depends on the size and shape of the metallic nanoparticle.

We explore the shaping of ligand-protected Au and AuCu alloy nanoparticles with ion beams and their resulting catalytic behavior, both with simulations and experimentally. SDTrimSP-3D was used to simulate the erosion of spherical nanoparticles by sputtering. Experimentally, samples of 10nm AuCu particles were irradiated with different fluences of low energy Ar ions and analyzed using atomic force microscopy. The resulting images show clusters of nanoparticles turning into single nanoparticles as the rest is sputtered away. Subsequently, these modified samples will be measured with scanning electron microscopy to determine the exact shape of the individual sputtered nanoparticles. The ion-beam-shaped particles will also be tested against the as-deposited nanoparticle shape in catalysis experiments using the water gas shift reaction.

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Surface and structural modifications in Bi nanowires induced by swift heavy ion irradiation

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The influence of swift heavy ion radiation on nanostructures has attracted increasing interest in recent years. To systematically explore size-effects on the interaction of swift heavy ions with nanowires, we have synthesized Bi nanowires with tailored diameter between 20 and 400 nm by electrodeposition in etched ion track membranes. These nanowires were irradiated at the GSI linear accelerator UNILAC with Au-ions of specific energy 8.3 MeV/u. Post-irradiation analysis with scanning electron microscopy (SEM) and transmission electron microscopy (TEM) revealed diameter dependent surface and structural modifications in the wires. In thin wires (diameter 20 to 50 nm) distinct ion tracks are visible as density contrast in TEM images. High-resolution TEM images prove complete recrystallization of the track region. Comparison between the experimental results to Molecular Dynamics (MD) simulations using the thermal spike model, allows us to assign this density contrast to hollow cavities that are formed inside the wires upon sputtering and atomic displacements. For thicker wires, above 100 nm diameter, SEM images reveal craters formed on the nanowires surface that are not present in the thinner wires.

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Electrical Modulation of Ionic Transport in Track-Etched Nanochannels

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The controlled transport of ions through nanoconfined spaces has emerged as a crucial field with applications ranging from sensing to energy storage. Ion-track technology uses swift heavy ion irra-

diation to create tracks within the materials, and chemical etching to produce well-defined nanochannels with precisely tunable dimensions and geometries [1]. This attribute makes the channels excellent model systems for studying confined ionic transport phenomena. Unlike approaches that rely on surface functionalization to introduce gating elements [2], our work uses gold-coated nanochannels as a reproducible and straightforward way to modulate ionic transport.

This study investigates the electrical addressability of single bullet-shaped nanochannels in polyethylene terephthalate (PET) membranes to regulate ionic transport. The asymmetric geometry of these nanochannels leads to ionic current rectification (ICR), exhibiting diode-like behavior with distinct "on" and "off" states under different voltage polarities. This behaviour can be tuned by external gate voltages. We systematically examine how deposited contact surfaces, nanochannel length and size influence voltage-gated ionic transport behavior in these systems.

Our findings demonstrate that external electric fields can effectively modulate ionic transport through these nanochannels, providing insight into the design of selective nanofluidic devices. This work contributes to the fundamental understanding of voltage-dependent ionic transport in confined geometries and has potential applications in nanofluidic field-effect transistors, biosensors, and energy storage systems.

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Functional Gold Nanowire Networks

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This work presents the synthesis and functional characterization of three-dimensional (3D) Au and Au–Ag alloy nanowire networks fabricated using ion-track nanotechnology. This approach allows precise control over nanowire diameter (40–200 nm), alloy composition (10–90% Ag), and network porosity (20-98%). Selective removal of Ag atoms yields hierarchical porous nanowires with tunable ligament size and interconnected geometry.
The catalytic performance of Au nanowire networks was evaluated in methanol oxidation reactions. Their 3D structure and large electrochemically active surface area resulted in peak current densities up to 200 times higher than flat electrodes, with excellent stability over repeated cycles. These results highlight the nanowire networks as robust and tunable systems for porous catalysis and direct alcohol fuel cell applications.
In addition, wettability studies revealed a transition from hydrophilic to hydrophobic behavior with increasing porosity. Super-hydrophilicity was observed at intermediate porosities, while highly porous structures displayed the rose-petal effect. Such control over wetting states opens opportunities for applications in liquid transport, microfluidics, and sensors.

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Hamiltonian of combined hyperfine interactions and its influence on the gamma-gamma angular correlations

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This work presents detailed calculations of the Hamiltonian describing the combined magnetic dipole and non-axially symmetric electric quadrupole interactions. The resulting eigenvalues and eigenvectors are incorporated into the perturbation factor G22(t) for a polycrystalline sample, as defined by time-differential perturbed angular correlation (TDPAC) theory. G22(t) spectra for the combined hyperfine interactions are generated, and some representative experimental TDPAC spectra measured for BiFeO3 are introduced to demonstrate the relevance and applicability of the theoretical model.

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Study of diameter-dependent swift heavy ion impacts in Bi nanowires using molecular dynamics simulations

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Due to growing technological and scientific interest in radiation effects on various nanomaterials, this work studies the impact of heavy ions on bismuth nanowires (NWs) using molecular dynamics simulations (MD) with "thermal spike"approximation to emulate the high-temperature zone generated by electronic excitation along the ion track. The diameter of the bismuth nanowires was systematically varied between 15 and 50 nm to investigate the influence of size effects for ions with different electronic stopping powers of between ~2 and ~5 keV/nm. The results clearly demonstrate that the effects induced by thermal spikes vary with NW diameters, ranging from perforations in the smallest NWs to cavities, craters and rims in the larger ones. In all cases, the simulations reveal that the track region fully recrystallizes. We additionally observe formation of point defects, and ejected atoms. These simulations exhibit qualitative similarities with experimental results obtained at higher stopping powers.

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RUTHELDE - A Differential Evolution Based RBS Spectra Fitting Algorithm and its Capabilities Beyond Fitting

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Recently, we applied evolutionary optimization, namely differential evolution, to fit Rutherford backscattering spectra [1]. We derived an algorithm that is capable of finding, with very high precision, the sample composition profile that best fits the experimental spectra in an autonomous manner. The robust nature of the differential evolution algorithm, especially with respect to the rather low increase of computation time with increasing number of free parameters, not only results in an excellent performance in standard fitting operation but also enables the introduction of additional fit parameters. Thanks to the stochastic nature of the optimization algorithm the code benefits well from the multi-thread/multi-core implementation.

The stochastic nature of the optimization algorithm naturally also lends itself to determining the uncertainties of the results, namely the layer areal densities, the elemental ratios and the detector calibration. Besides, it becomes feasible to predict the expected accuracy of an RBS experiment for given experimental conditions (e.g. scattering geometry, accumulated charge, etc.) prior to the actual measurement. Vice versa, the code allows us to determine what experimental conditions would be required to achieve a certain accuracy in the measurements.

Further, by adding the correction factor to the stopping cross section(s) of the projectile ions as a free fit parameter we demonstrated RUTHELDEs capabilities to derive the stopping cross sections with high precision from RBS measurements [2]. This approach opens new opportunities to determine stopping cross sections.

In our recent work, we have introduced the ability to apply non-Rutherford cross sections in RUTHELDE. This feature will broaden the applicability of the software. Besides, by making the primary ion energy a free fit parameter, it is expected that RUTHELDE will open a new opportunity to realize the energy calibration of ion accelerators by utilizing well known resonant reactions.

In this presentation we will summarize the mechanisms of the code, show certain examples of target model determination, uncertainty calculations and contributions to stopping cross section measurements [2]. We will present the corresponding open-source software package and demonstrate its capabilities, features and limitations.

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High-Pressure Phase Transitions of Nanowires

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

presents a study on the size dependence of phase transitions on nanowires under high static pressures.
High-pressure stability fields of nanomaterials can deviate significantly from their bulk counterparts, in terms of transition pressures and crystallographic structures of phases. Therefore, the investigation of size-dependent stability ranges may open up new pathways regarding the synthesis and recovery of novel materials, providing valuable insight into the impact of the sample geometry.
The present poster contribution summarizes our investigations on the size-dependent high-pressure phase transitions of bismuth nanowire networks (Bi-NWNWs) synthesized by ion track nanotechnology. The wire diameters were varied from 30 to 100 nm and the NWNWs mounted together with bulk-like microcrystals in diamond anvil cells. The samples were stepwise compressed up to 20 GPa and their crystallographic properties characterized by beams of synchrotron diffraction. Additional experimental results concerning the systematic investigation of the high-pressure behavior of Antimony NWNWs, as well as the exposure of the pressurized nanomaterials to swift heavy ion irradiation are also discussed, highlighting the various possibilities of this novel methodology.

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Heavy ion irradiation of molecular solid at high pressures

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Swift heavy ions (SHIs) are high-mass ions with high kinetic energies in the MeV–GeV range produced by large accelerator facilities. Upon traversing a material, SHIs induce various physical and chemical effects within the material, including extended defects, phase transitions, amorphization, or chemical reactions. The combination of high pressure and heavy ions is anticipated to induce unusual physical and chemical transformation in matter, such as yielding non-equilibrium phases or stabilizing high-pressure phases that are challenging to recover under ambient conditions.

We have developed an experimental setup at GSI (Helmholtzzentrum für Schwerionenforschung GmbH) in the framework of a BMBF funded project (05K22RF3). The setup is capable of simultaneously subjecting samples to high static pressures up to 100 GPa and SHI beams within diamond anvil cells (DACs). Here, we present data obtained from the initial experiments using various samples, including benzene, carbon monoxide, and carbon dioxide, demonstrating the significant effect of SHIs on the materials under high pressure.

Further research into phase transitions or chemical reactions induced by SHIs at high pressure will deepen our understanding of how SHI interacts with matter at the atomic and molecular levels in extreme conditions. Moreover, this method presents opportunities to synthesize novel materials by providing conditions that are otherwise inaccessible.

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Bond-breaking efficiency of individual MeV-GeV ions in polymer thin films: Combining studies from XPS, FTIR, and AFM-IR

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We report on the evaluation of radiation-induced chemical damage around single ion impacts on thin and ultrathin polymer films using atomic force microscopy–infrared (AFM-IR) spectroscopy and imaging. Radiation effects in polymers are known to involve complex chemical modifications of macromolecular chains, which can be strongly influenced by confinement when the material dimensions are reduced to the nanometer scale. In this work, PMMA films ranging from 2 to 100 nm, deposited on Si, Cr, and Au substrates, were irradiated with swift heavy ions (SHI) and highly charged ions (HCI). IR spectra with characteristic PMMA bands were successfully obtained for films as thin as 10 nm, whereas thinner samples provided insufficient signal for analysis. SHI impacts exhibited pronounced IR contrast, evidencing local chemical damage. However, challenges remain, particularly regarding crosstalk between chemical and topographical features and additional damage induced by the probing IR beam itself. In the case of HCI irradiation, impacts were not resolved in either topography or IR maps, most likely due to the relatively large AFM tip radius (~50 nm). A clear substrate effect was observed: films deposited on Au showed a strong enhancement of IR signal compared to Si. This highlights the critical role of substrate choice in determining signal strength and sensitivity. Overall, these findings demonstrate both the potential and limitations of AFM-IR for probing radiation effects in confined polymer systems and point to future directions for enhancing the technique's accuracy in quantifying nanoscale chemical damage.

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In-situ Raman Spectroscopy of Ion-Induced Defects in Graphene

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In recent years, two-dimensional (2D) materials and the ion-induced, tailored modification of their structural, optical and electronic properties have attracted increasing attention, driven by the potential application of modified 2D materials in optics and microelectronics. Raman spectroscopy is an established tool to characterize such ion-induced modifications, especially changes in the electronic structure. Particularly graphene, the most extensively studied 2D material, is highly sensitive to defects. However, a persistent challenge in studying ion-solid-interactions lies in distinguishing between the direct effects of ion impacts and the effects arising from the exposure of ion-induced defects to ambient conditions. For example, ex-situ analyses of irradiated graphene often show changes in doping levels, yet the processes driving these changes remain under debate.

In this contribution, we address this challenge by performing in-situ Raman spectroscopy measurements on ion-irradiated graphene under ultra-high vacuum conditions. Our portable Raman spectroscopy setup enables in-situ measurements at multiple irradiation facilities. Specifically, we present results obtained from in-situ Raman spectroscopy measurements on graphene irradiated with swift heavy ions (Au^{75+}, 945 MeV) at the CRYRING target station at GSI, and with slow, highly charged ions (Xe^{30+}, 180 keV) at the HICS beamline at the University of Duisburg-Essen. For both ion species, the Raman-active G- and D- band intensities show a linear increase of the peak area ratio A_D/A_G with fluence, consistent with defect generation. Comparison of in-situ and ex-situ Raman data reveals that changes in doping levels are primarily due to oxygen saturation of ion-induced defects upon exposure to ambient air, rather than a direct consequence of the ion irradiation itself.

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Ambipolar Transport in Phosphorus Implanted WS2 Monolayers

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The doping of two-dimensional (2D) transition metal dichalcogenides (TMDCs) by an approach compatible with circuit integration is crucial. However, ion implantation, the most commonly used method for doping semiconductors, poses significant challenges for 2D-TMDCs because of the requirement for ultra-low ion energy and the difficulty of restoring damaged 2D materials. Here, we achieve bipolar transport in intrinsic n-type WS_2 monolayers through phosphorus (P) ion implantation using commercial ion implanters. Millisecond flash lamp annealing is employed to remove ion induced defects and activate P. Experimental results show a clear change in carrier type with increasing ion fluence. Samples implanted with a fluence of 7.5 × 1012 cm-2 display ambipolar transport behavior with an on/off ratio of 4.4 ×105 and 1.6 ×106 for p- and n-branch, respectively. At the same time, the optical and structural properties of WS_2 are well preserved. All these findings not only complement the fundamental understanding of 2D-TMDCs, but also provide a possible route for hetero-integration of TMDCs into current Si-based semiconductor technologies.

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Photon Emission Induced by keV Ions Transmitted Through Single-Crystalline Si Membranes

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Ions penetrating matter cause a number of different electronic excitations in the material and in the projectile itself. The investigation of ion induced photon emission contributes to a better understanding of the exact processes taking place. We investigate the photons emitted upon transmission of keV He and Ne ions through thin single-crystalline Si membranes. The measurements were recorded with pulsed ion beams at the Time-of-Flight Medium Energy Ion Scattering (ToF-MEIS) setup at Uppsala University, which enables us to study processes with a time-resolution better than one ns. As the number of ions included in a single ion pulse is statistically well below one, we were able to perform coincidence measurements i.e. we can directly link a photon to the deexcited ion recorded up to a few 100 ns later. These coincidence measurements were performed for randomized and channeled ion trajectories while separating the charges of the transmitted ions. Our results show that the photon emission is constant for any angle relative to the surface normal if photons emitted at the rear surface of the membrane are measured. In contrast, photon emission is drastically reduced and angular dependent if the front surface is investigated instead. We can show that the behavior on the rear surface is due to the absolute majority of the recorded photons being created by electronic deexcitations of the transmitted projectile behind the surface. Therefore, for He projectiles, detection of the 2+ charge state is suppressed if the coincidence condition is applied. The excited projectiles are found to travel up to several centimeters from the surface of the sample before deexcitation. For He ions, the probability that an ion exiting in a specific charge state emits a photon remains independent of the crystal orientation. We conclude that the same processes which determine the charge state of the transmitted projectile also determine if and how the transmitted projectile is excited.

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Utilizing beams of energetic ions for measurements of kinetics in materials on the atomic scale

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Recent developments of keV and MeV ion beam analytical tools for in-situ and in-operando characterization of a number of material systems with high relevance for energy-related applications will be presented. The ion-beam based characterization was complemented by atom probe tomography, X-ray diffraction and transmission electron microscopy.

We performed high-resolution depth profiling of Li and O in thin film batteries using primary beams of He and Li at energies up to 10 MeV. By recording transmitted particles in coincidence, we could observe reversible transport of Li and quantify the material transport during charging and discharging of the battery stack [1][2][3].

Oxidized rare-earth metal hydrides can feature reversible photochromism at ambient conditions with huge potential for passive regulation of energy flow. To better understand the nature of the photochromic effect, we combined ion beam analysis with in-situ reactive growth and oxidation [4]. From this work and further complementary studies, a dual-phase nature is proposed and the photochromism is related to high residual stress levels in the films [5].

We furthermore explored the potential of ion beam analytical techniques capable of directly and indirectly sensing hydrogen in real space at a true atomic length scale. As a result, we succeeded to probe the specific lattice location and vibrational amplitude of H in crystalline matrices, specifically investigating V-based thin films and Fe/V superlattices as model systems for studying effects of proximity and dimensionality [6][7].

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Two-Temperature Modeling of Swift Heavy Ion Effects from First Principles

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The inelastic thermal spike model[1] has been widely used to describe the effects of swift heavy ions, but its theoretical suitability remains under debate[2]. The parameters for the underlying mathematical equations, the so called two-temperature model (TTM) equations, are typically obtained from

empirical fits to ion track radii. Recent computational advances now make it possible to determine these parameters from first principles using density functional theory combined with semiclassical transport theory. The TTM can be viewed as an approximation to the semiclassical electron–phonon transport equations, namely the Bloch–Boltzmann–Peierls equations. We calculate TTM parameters from first principles to construct a model directly grounded in semiclassical transport theory, and apply it to materials such as diamond, quartz, and various metals. This approach will help assess whether electron–phonon coupling alone explains ion track formation or if additional mechanisms must be invoked.

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High-Pressure Platform for Swift Heavy Ion Irradiations: Probing Structural Transformations in Extreme Radiation Environments

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Exploring the structural response and property transformations of materials under combined extreme conditions holds enormous importance across diverse, multidisciplinary, and fundamental research domains. The application of extreme pressures can induce novel phases and structures with distinctive properties. In this project, we explore the effects of exposing materials to high pressures combined with radiation conditions provided by swift heavy ions, which locally deposit extremely high energy densities (~eV/atom) on timescales as short as sub-femtoseconds, an effect that cannot be achieved by any other method.
We present an innovative experimental platform designed to simultaneously apply high-energy ion irradiation and high static pressures. This setup operates at the large-scale accelerator facility at the GSI Helmholtz Centre for Heavy Ion Research (Darmstadt, Germany). The ion accelerator provides beams of relativistic projectiles with ranges sufficient to reach samples pressurized inside diamond anvil cells (DACs). Previous work has demonstrated that the combination of pressure and ion irradiation induces structural modifications that are not observed when both extremes are applied separately [1,2]. For the irradiation experiments, the ion beam is collimated and injected through the gasket of the DAC, enabling monitoring of structural changes with increasing irradiation dose using in situ Raman spectroscopy. This presentation details the technical aspects of the experimental setup, outlines future plans, and showcases recent findings, including ion-induced phase transitions in various materials and compounds. These examples highlight the unique opportunity this approach offers to investigate materials far from equilibrium conditions and to provide new routes for achieving and stabilizing unconventional structural transformations.

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HAMSTER –a new universal 1-MV AMS facility at HZDR with ion cooler and SIMS capabilities

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The new dedicated AMS facility HAMSTER (Helmholtz Accelerator Mass Spectrometer Tracing Environmental Radionuclides) is being set up at HZDR as a universal and flexible AMS system that allows for routine measurements of nuclides across the whole chart of nuclides but has also a focus on implementing new technical developments.
HAMSTER is based on a 1-MV Pelletron accelerator (National Electrostatic Corp., NEC). It consists of three independently operating beam injection systems: two of them are high-intensity ion sources for negative ions, one coupled to an ion-cooler setup. Finally, another ion beam from a dynamic SIMS setup (CAMECA IMS 7f Auto), previously connected to the DREAMS 6-MV system (HVEE Tandetron), can be injected into the AMS beamline for Trace Element Accelerator Mass Spectrometry (TEAMS) measurements.
The high-energy side includes two magnets with the option of quasi-simultaneous measurements of up to 8 isotopes. Special focus was a setup aiming for a high measurement efficiency as well as implementing the options of full beam diagnostics at all waists with the objective to facilitate further technical developments for rare isotope detection.
A new ion cooler ILTIS (Ion Linear Trap for Isobar Suppression) had been developed in-house in collaboration with the Univ. of Vienna to utilise and explore the potential of ion-laser interaction for detection of new AMS nuclides. NEC's accelerator software will be integrated into our general EPICS-based control software, which is presently under development at HZDR.
HAMSTER is located in a dedicated new building that houses also three labs for sample handling and sample preparation, which add to the two chemistry labs already in use since about 15 years. The new facility is operated as a dedicated AMS system - with the 6-MV DREAMS facility still being used in parallel. However, HAMSTER will extend our research portfolio significantly beyond DREAMS' s primary focus on cosmogenic nuclides.

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The solid state Physics programme at ISOLDE-CERN

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ISOLDE-CERN is the worldwide reference facility for the production and delivery of radioactive ion beams of high purity. Since the late 70s the laboratory is pioneer in the use of nuclear techniques for

studying local properties of materials using high-technology equipment [1]. For instance, the brand-new ultra-high-vacuum implantation chamber called ASPIC's Ion Implantation chamber (ASCII) [2] decelerates the radioactive ion beam delivered at ISOLDE-CERN allowing to perform ultra-low energy ion implantations, and local measurements on the surface and interface of materials. The new MULTIPAC setup for Perturbed Angular Correlation Experiments in Multiferroic (and Magnetic) Materials [3] consists of a unique cryogenic magnetic system that simultaneously allows to measure local magnetic and ferroelectric properties of materials in magnetic fields up to 8.5 T. Last, but not least, the eMIL-Setup [4] is an advanced emission Mössbauer spectrometer for measurements in versatile conditions of several classes of materials, thanks to the emission Magnetic Mössbauer Analyzer (eMMA) extension [5]. This presentation introduces the new setups as powerful tools and discuss the possibilities of investigations on the frontiers of solid-state physics research.

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PACBIT —Third-Generation TDPAC Data Acquisition and Analysis

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With its unique combination of an external magnetic field of up to 8.5 tesla and the ability to heat and cool samples during measurements, the MULTIPAC Time-Differential Perturbed Angular Correlation (TDPAC) setup creates new possibilities for studying materials and their phase transitions. Building on this advanced instrumentation, the dedicated control and analysis software PACBIT enables high-performance data acquisition, streamlined experiment control, and efficient post-processing. A brief outline of the detector configuration is given, followed by an exposition on how the system increases the effective resolution beyond the 10-bit limit of the U5310A digitizer through advanced signal processing techniques. Operating in streaming mode with parallel HDF5, the data acquisition (DAQ) delivers high throughput and allows the collection of more data than in previous setups. This increased data rate enables the application of stricter coincidence selection rules while maintaining a large number of events, thereby improving statistical accuracy, reducing background noise, and enhancing measurement reliability. Post-processing features include signal smoothing, precise timestamp calculation, and automatic removal of secondary pulse signals. Finally, a coincidence search algorithm is presented that exploits the increased dataset to deliver more accurate event correlations, paving the way for better experimental results and new opportunities in high-resolution TDPAC spectroscopy.

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Magnetoelectric Decoupling in Bismuth Ferrite

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It is still an open question whether magnetoelectric coupling occurs at the atomic scale in multiferroic BiFeO3. Nuclear solid-state techniques monitor local fields at the atomic scale. Using such an approach, we show that, contrary to our own expectation, ferroelectric and magnetic ordering in bismuth ferrite (BiFeO3 or BFO) decouple at the unit-cell level. Time differential perturbed angular correlation (TDPAC) data at
temperatures below, close, and above the magnetic Néel temperature show that the coupling of the ferroelectric order to magnetization is completely absent at the bismuth site. It is common understanding that the antiferromagnetic order and the cycloidal ordering due to the Dzyaloshinskii-Moriya interaction generate a net zero magnetization of the sample canceling out any magnetoelectric effect at the macroscopic level. Our previous data show that a very large coupling of magnetic moment and electrical distortions arises on the magnetic sublattice (Fe site). The oxygen octahedra around the iron site experience a large tilt due to the onset of magnetic ordering. Nevertheless, the Bi-containing complementary sublattice carrying the largest part of ferroelectric order is practically unaffected by this large structural change in its direct vicinity. The magnetoelectric coupling thus vanishes already at the unit cell level. These experimental results agree well with an ab initio density functional theory (DFT) calculation.

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Shaping the Future of Radiobiology: Precision Ion Beams and the German Research Landscape

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Biological ion beam research in Germany stands at a decisive moment, where advances in accelerator physics, molecular biology, and clinical practice converge to define the future of radiotherapy and radiation protection. Over the next decade, the central challenge will be to understand and predict how ionizing radiation induces biological effects across scales, from nanometer-scale DNA lesions to tissue- and organism-level outcomes. Meeting this challenge requires experimental platforms that combine unprecedented spatial and temporal precision with integrative biological readouts.
In the coming years, Germany's research landscape is poised to expand in three key directions. First, precision irradiation tools such as micro- and nanobeams will enable controlled delivery of radiation at subcellular scales, allowing systematic studies of DNA damage complexity, repair mechanisms, and cell fate decisions. Second, multimodal experimental platforms that link ion irradiation with advanced imaging, omics technologies, and computational modeling will provide holistic insights into how radiation responses emerge from molecular networks. Third, the translation of knowledge to the clinic and to space exploration will demand new predictive models of biological effectiveness, grounded in mechanistic understanding rather than empirical correlations.
Germany is uniquely positioned to lead this endeavor, owing to its strong ecosystem of accelerator

facilities, clinical ion beam centers, and multidisciplinary collaborations between physicists, biologists, and clinicians. Future solutions will include next-generation microbeam lines, standardized platforms for radiobiological benchmarking, and closer integration of fundamental research with therapeutic innovation. By uniting technical excellence with biological discovery, German ion research will not only advance cancer treatment and radiation protection, but also shape the international trajectory of radiobiology in the decade to come.

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Ion microbeam for biological heavy ion research

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Cancer is one of the main causes of death worldwide, and radiotherapy (RT) is one of the prominent modalities in the fight against it. From a biological perspective, the main target of RT is the DNA of cancer cells due to its radiosensitivity. To conduct fundamental research into radiation effects at sub-cellular scales, highly precise cell irradiation with micrometer- and nanometer-sized beams is essential. The BIOMICRO project, carried out by a multidisciplinary team, aims to design and construct a new ion microbeam beamline at the 6 MV Tandetron accelerator facility of the Ion Beam Center (IBC) of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR).

The system will focus 10 MeV protons to spot sizes down to ~300 nm, delivered in microsecond bunches, enabling the simulation of heavy ion track structures (36 MeV Carbon) with high spatial and temporal precision. Advanced electrostatic and magnetic optics, together with fast pulsing electronics and real-time dosimetry, ensure sub-cellular targeting and reproducible single-particle delivery. This technical capability allows the controlled irradiation of specific cell compartments (e.g. nucleus vs. cytoplasm) to link microdosimetric track structures with biological outcomes such as DNA damage complexity, repair kinetics, and cell survival.

The project is a collaboration between HZDR, GSI Helmholtz Center for Heavy Ion Research, TUM Klinikum Rechts der Isar, and Universität der Bundeswehr München. Physicists and engineers are responsible for beamline development, including magnets, lenses, and the exit nozzle, as well as the control and analysis software, while biologists will conduct systematic experiments at this facility. Together, these efforts will provide a versatile and affordable platform for heavy ion radiobiology, advancing our understanding of radiation-induced damage at the nanoscale and contributing to the optimization of RT, radiation protection in space, and the development of new technologies.

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Construction of a proton minibeam beamline for preclinical experiments in small animals –Minibee Project

Autor Aikaterini Rousseti[1]

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Proton minibeam radiotherapy (pMBT) is a novel radiotherapy method that deploys proton beams, combined with spatial fractionation, intending to broaden the therapeutic window while protecting healthy tissues. Preclinical studies have already highlighted the potential of pMBT in sparing healthy tissues and achieving better tumor control compared to conventional proton therapy. Constructing a proton minibeam beamline for preclinical experiments (Minibee) at the Helmholtz Zentrum Berlin (HZB) will facilitate in-depth and systematic research.
The cyclotron at HZB extracts a 68 MeV proton beam, which is suitable for studies in small animals. If necessary, the beam energy can be degraded right after the cyclotron and a range shifter can further adjust the beam energy to generate a spread-out Bragg peak (SOBP). A quadrupole triplet, close to the isocenter, creates magnetically focused minibeams and scanning magnets will offer the possibility to scan a field of 50x50 mm². FLASH irradiation mode can be supported at the beam entrance in single energy mode, with an average dose rate of kGy/s and local peak dose rates up to several MGy/s. Switching times of 6 µs are needed to preserve a dose error <2%, bringing forth challenges for dose monitoring. These can be resolved by a resonant beam monitor for ultra-fast signal transmission. The beamline also includes small animal imaging, positioning tools, and a microscope, allowing live-cell imaging for 2D and 3D culture experiments. The simulation studies have shown that the proposed facility can generate minibeams with a σ of ~50µm in both directions and transmission of ~2.5%. The opening of the beamline took place last year.
The pMBT facility will intensify the research in the field while offering the opportunity to develop new technologies and better understand the underlying mechanisms.

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Optimization of stimulated outgassing for particle accelerator vacuum components

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High intensity particle accelerators suffer from outgassing of components stimulated by beam operation. This meanwhile well-understood phenomenon limits the beam intensity and / or lifetime. In recent years, a simple, yet effective method was developed for the conditioning of accelerator parts prior to their installation. In principle, the method is a specialised annealing in a UHV furnace that drives volatile gaseous species out of the material and reduces the area of grain boundaries that is most probably the dominating way of gas diffusion.
Albeit this method is fairly good established, there is still outgassing from layers close to the surface. At present, some methods for surface conditioning are under investigation, whereas the most promising ones are sputtering and ion etching in combination to thermal treatment.
In the talk, results of the last years will be given, including bulk annealing and some surface optimization techniques. Further methods such as laser polishing will be shortly discussed and the potential of tailoring technical materials for general vacuum applications including hydrogen diffusion and storage for future energy and mobility concepts will be mentioned.

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Tracing Environmental Radionuclides with the HAMSTER

Autor Stella Winkler[1]

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Accelerator Mass Spectrometry (AMS) has long been established as a prime technique to measure an array of long-lived radionuclides in the environment. Radiocarbon has been established first, and later the method has been expanded to include ^{10}Be, ^{26}Al, and ^{129}I, to name but a few. The method originally developed on large nuclear physics tandem accelerators with terminal voltages of 6MV and more, over time has been taken to ever lower energies.
The Helmholtz Accelerator Mass Spectrometer Tracing Environmental Radionuclides (HAMSTER) was incepted as a novel AMS system to detect radionuclides across the chart of nuclides. It is based on a small accelerator with 1MV terminal voltage. With its high mass resolution and background suppression of scattered interference, the system is particularly well-suited for the measurement of heavy isotopes such as the actinide nuclides. It will also feature an ion-cooler injection beam-line for laser photodetachment, a new method to do isobar separation at low energies. We will use this feature to add ^{90}Sr, ^{135}Cs, ^{137}Cs, and ^{182}Hf to our repertoire of isotopes, with many more to be tried in the future. Together with our established isotopes we will implement new applications in Astrophysics, Nuclear Physics, Geology and Environmental Physics. These includes tracing ocean currents, detecting supernova isotope signatures deposited on earth and moon, nuclear decommissioning, landscape erosion and many more. In this talk we will present the AMS methods, the new ion beam methods available at HAMSTER, and the on-going and planned applications.

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Setting-up Super-SIMS at HAMSTER

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Accelerator Mass Spectrometry (AMS) is an ultrasensitive method for detection of naturally or anthropogenically produced long-lived radionuclides in our environment.
To combine this method with the capabilities of a secondary-ion mass spectrometer (SIMS: IMS 7f-Auto from Cameca) is challenging. The idea is to use the micron-scale spatial resolution of the SIMS and the high selectivity through molecule suppression by the stripping process at an AMS system. The aim is to detect background-limited trace elements more sensitively than regular SIMS or other techniques.
After first steps at the DREsden AMS-facility (DREAMS) at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) [1] the system moved to the new compact facility HAMSTER (Helmholtz Accelerator Mass Spectrometer Tracing Environmental Radionuclides) dedicated for AMS measurements and designed to incorporate Super-SIMS capabilities. HAMSTER is based on a 1-MV tandem accelerator from NEC (National Electronics Corp.) and has dedicated instruments for tuning low current ion-beams < nA from the SIMS. In this presentation, I will highlight the current status after arrival of the HAMSTER system and future initiatives.

[1] Rugel, G., Ziegenrücker, R., Renno, A. D., Koll, D., Lachner, J., Noga, P., Vivo-Vilches, C., Wallner, A., & Wiedenbeck, M. (2022). Super-SIMS at
DREAMS: Status of a unique and complex endeavour. Nuclear Instruments and Methods in Physics

Research Section B: Beam Interactions with Materials and Atoms, 532, 52-57. https://doi.org/10.1016/j.nimb.2022.09.023

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ASCII: Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation Chamber

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The Apparatus for Surface Physics and Interfaces at CERN (ASPIC) has been installed in the solid state physics part of the ISOLDE experimental hall. Operating at ultra-high vacuum (UHV $\leq 10^{-8}$mbar) ASPIC's versatility was used to study metallic surfaces, the magnetic behavior of thin films and an interface evolution, as well as employing radioactive isotopes and a variety of surface thin film fabrication and modification techniques.

Currently under design, a new chamber called the Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation Chamber (ASCII) embodies an upgrade to ASPIC, enabling tunable ultra-low energy ($>$ 20 eV) implantation of radioisotopes in UHV $\leq 10^{-9}$mbar.
Capable of controlling implantation depth in the order of several Ångström,
precise positioning of probes including ^{111m}Cd and ^{204m}Pb in two-dimensional materials (graphene, transition-metal dichalcogenides), (multi)ferroic materials, nanoparticles and topological insulators is possible. A first successful test using ASCII to implant ^{111}Ag was conducted at the Universität of Göttingen.

While ASCII is yet to be commissioned for operational use, it will soon be available for the wide community of collaborators.
Being placed inside the ISOLDE facility, ASCII presents itself as a unique setup holding great potential for the investigation of surfaces and interfaces in nuclear condensed matter physics.

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Cosmic dust and high energy ions. What? Why? How?

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Dust is one of the fundamental players in the physical and chemical processes taking place in astrophysical and (exo)planetary environments. The composition, structure, morphology,

surface properties and optical properties of cosmic dust can dramatically change on its way from nm-sized particles in the interstellar medium to mm-sized pebbles –building blocks of planets in protoplanetary disks. These changes may influence and, in some cases, define the efficiency of physico-chemical processes involving dust.
In my talk, I will provide a brief introduction to cosmic dust and its interaction with high energy ions and will discuss experiments required to study influence of heavy ions on the optical, morphological and chemical properties of laboratory analogues of cosmic dust. Results of such a study will provide an important piece of puzzle of the evolution of cosmic dust and may have crucial industrial applications.

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Highly site-selective fragmentation of peptides induced by swift heavy ions

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The interaction of swift heavy ions (SHI) with organic matter is highly relevant for applications such as cancer therapy and the development of biomaterials based on SHI irradiation. Furthermore, the interaction of SHI with complex molecular systems such as biomolecules is interesting from a fundamental point of view in terms of the excitation mechanisms involved and how the energy deposited in the system is coupled into the molecular degrees of freedom relevant for bond breaking. SHI-induced fragmentation of peptides is an ideal model system for studying these processes due to the variety of functional groups and bonds in peptide molecules.

The study of molecular fragmentation by external stimuli, however, requires an analytical tool that does not introduce fragments itself. Therefore, we make use of Desorption/Ionization induced by Neutral SO2 Clusters (DINeC), an extremely soft desorption method [1], in combination with mass spectrometry (MS). DINeC-MS has proven to be an ideal tool for analyzing fragmentation processes. In particular, DINeC-MS was employed to investigate the fragmentation of peptides by SHI impact [2].

In this study, we examine whether the interaction of SHI with peptides can lead to bond-specific and/or selective fragmentation. We find, in addition to specific fragmentation, i.e, peptide bond cleavages restricted to the peptide backbone [2], a high site-selectivity of SHI-induced fragmentation. This means that only selected peptide bonds within the amino acid sequence are broken efficiently, while others remain intact. Furthermore, experiments with peptides in which single amino acid units were exchanged relative to a reference peptide revealed that this selectivity is independent of the amino acids present in the direct neighborhood of the cleavage site; rather, the overall peptide structure was found to be the determining factor.

[1] Gebhardt, et al., Angw. Chem. Int. Ed. 48, 4162 (2009).
[2] Schneider, et al., Sci. Rep. 12, 17975 (2022).

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Closure

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Talks / **112**

Poster Pitches

Talks / **115**

Poster Session

Talks / **80**

Structural andElectrical Response of Emerging non-volatile Memories Exposed to Heavy Ion Radiation

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Hafnium oxide- and GeSbTe-based functional layers represent promising material platforms for next-generation memory technologies. In addition to their potential for conventional computing applications, these materials are increasingly being investigated for use in radiation-harsh environments. Evaluating their resilience against ion irradiation is therefore essential to assess their suitability for future applications in emerging memory technologies, such as oxide-based, ferroelectric, and phase-change random-access memories. Radiation-induced modifications to the crystalline structure and microstructure must be carefully examined, as these changes are directly correlated with the memory states and potential failure mechanisms of these technologies
In this context, we present a comprehensive study on the effects of heavy ion irradiation in emerging memory devices based on various functional materials, specifically focusing on thin films of HfO_2, $HfZrO_2$ and GeSbTe. Our results highlight the crucial role of initial crystallinity, chemical composition, and microstructural characteristics in determining the materials' response to swift heavy ion irradiation. This integrates structural analysis via X-ray diffraction at the macroscopic scale, scanning transmission electron microscopy at the nanoscale, and electrical characterization of fully processed devices to understand how these materials interact with the radiation.
Our results demonstrate the radiation hardness of these emerging memories making them very interesting for future applications in high-dose environments.