O 5: Focus Session: Ion Beam Interaction with Surfaces and 2D Materials I

Ion beam techniques are an important tool in surface science and nanotechnology in terms of surface composition analysis as well as tailoring of surface properties. Recent important developments took place using ultra-low energy ion implantation to introduce foreign atoms into 2D material lattices or triggering self-organization mechanisms to form large-scale ordered crystalline surface structures. This focus session brings international specialists in the connecting fields of ion physics and surface science together to discuss recent progress to our fundamental understanding of ion-surface interactions as well as pathways towards new applications for emerging material classes.

Organizer: Richard Arthur Wilhelm (TU Wien)

Time: Monday 10:30–13:00 Location: GER 38

Topical Talk O 5.1 Mon 10:30 GER 38

Highly charged, slow and swift ions interacting with surfaces and 2D materials — •Marika Schleberger — Fakultät für Physik, Universität Duisburg-Essen and CENIDE

Ion beams are a proven, versatile, and efficient tool for material modification and in particular for defect engineering. An ion stores its energy in the form of kinetic (E_{kin}) and so-called potential energy (E_{pot}), the latter corresponding to the energy required to create its respective charge state. At low velocities, the energy deposition is based on elastic collisions leading to linear sputtering cascades or collision peaks in the volume of the material, and ultimately to the emission of atoms. At higher kinetic energy, electronic excitations and ionizations are dominant. The release of potential energy again occurs via electronic processes that can also lead to the emission of atoms from the target material. By adjusting these two parameters, E_{pot} and E_{kin}, one can in principle fine-tune the nature of the interaction and thus the corresponding material changes. However, the basic mechanisms of defect formation through electronic excitation have not yet been clarified. We have introduced 2D materials as target material for the study of ion-solid-interactions. Due to their well-defined thickness, the flexible preparation and last but not least the wide range of available materials, they are an ideal target material for our task. We have studied the interaction of ions of different types with surfaces and 2D materials and I will present key results.

O 5.2 Mon 11:00 GER 38

Model for Nanopore Formation in Two-Dimensional Materials by Impact of Highly Charged Ions — •A. S. Grossek, A. Niggas, R. A. Wilhelm, F. Aumayr, and C. Lemell — TU Wien

Experiments of highly charged ions (HCI) on 2D-materials have shown that HCIs extract numerous electrons from the 2D target. This interaction has shown to lead to nanopore formation in materials such as monolayer MoS_2 while single layer graphene remains structurally intact. One hypothesis proposed for the cause of nanostructuring of these materials is charge build up by hole charges in the target, which -depending on material charge conductivity- may sustain sufficiently long in order to lead to structural damage of the target atoms. We study this hypothesis of nanostructuring by HCI impact on 2D-materials via molecular dynamics simulations. The charge transfer from target to HCI is well described by the classical-over-the-barrier model, of which a simplified version is implemented into the simulation. Charge conduction in the target is modelled by charge hopping with a hopping time t_h between lattice sites. Our 2D lattice is simulated by a Stillinger-Weber potential with parameters fitted to reproduce graphene. We study different materials by respectively adjusting the hopping time t_h (conductivity) of the graphene lattice in the simulation. After the simulation kinetic and potential energies of the individual target atoms are evaluated to determine if a pore has formed. Our simulation is able to qualitatively reproduce experimental results showing pore formation efficiencies and pore sizes to be dependent on initial HCI charge state and conductivity of the material.

O 5.3 Mon 11:15 GER 38

Charge-state-enhanced ion sputtering of metallic gold nano islands — •Gabriel L. Szabo[1], Benedykt R. Jany[2], Helmut Muckenhuber[1], Anna Niggas[1], Markus Lehner[1], Arkadiusz Janas[2], Paul S. Szabo[3], Antony George[4], Ziyang Gan[4], Andrey Turchanin[4], Franciszek Krok[2], and Richard A. Wilhelm[1] — [1]TU Wien, Institute of Applied Phyiscs, 1040 Vienna, Austria, EU — [2]Jagiellonian University, Institute of Physics, 30-348 Kraków, Poland, EU — [3]University of California, Space Sciences Laboratory, Berkeley 94720, USA — [4]Friedrich Schiller University Jena, Institute of Physical Chemistry, 07743 Jena, Germany, EU

Irradiation of certain targets with slow highly charged ions (HCIs) can trigger phase transitions or nano-structure formation. The main driving force for these processes is the electronic excitation of the target's electronic sub-system in close proximity of the impact triggered by the ion neutralization. Subsequent electron-phonon coupling mediates lattice heating of the target. So far charge state dependent erosion of metallic surfaces was not unambiguously shown. The potential energy stored in the HCI dissipates quickly before a transfer to the target's atomic lattice can take place. By reducing the size of the target down to the nanometer regime, geometric confinement might prevent free electrons of the target to dissipate the electronic excitations on the fs time-scale. In this work we irradiated gold nano islands with Xe^{q+} (q=1,18,25,32,40) with a constant kinetic energy of 180 keV, which results in an erosion of the islands that is strongly enhanced by the potential energy deposition.

Topical Talk O 5.4 Mon 11:30 GER 38

A contactless single-step process for simultaneous nanoscale patterning and cleaning of large-area graphene — •Tuan Tran — Department of Physics and Astronomy, Uppsala University, Sweden

In this talk, we will present a contactless single-step process for structuring self-supporting graphene with customizable patterns and over large areas. Using energetic ions passing through a suspended mask with through-hole nanopatterns, we can deterministically structure the graphene with a minimum feature size down to 15 nm, comparable to what can be achieved with focused ion beam techniques. Our process, however, instead uses a broad parallel beam with no stringent requirement on the beam focusing, and hence enables a contactless approach. Neither, any chemicals and coating layers are necessary, substantially reducing the amount of contamination which might otherwise occur using other lithographic methods. In addition to the structuring capability, we found that the method can simultaneously render the graphene cleaner. The areas surrounding the direct ion impacts are significantly cleaned from the initial contamination which commonly are remnants from the transferring process of the graphene. We will explain the mechanism leading to such cleaning effect. Finally, selective area electron diffraction were used for detailed characterization of the graphene lattice after ion irradiation with and without the mask at different doses and temperatures. These diffraction data are necessary for understanding the creation and annihilation of defects and the possible role of the contamination on self-healing and stabilization of the graphene lattice.

O 5.5 Mon 12:00 GER 38

chemical etching of 2D materials — •Mitisha Jain, Silvan Kretschmer, and Arkady Krasheninnikov — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

Transmission electron microscopes are used for imaging 2D materials to the resolution of single atoms. On the other hand, the imaged material gets damaged (modified by the beam) quite easily. Hence, the information about the damage done by the beam are important for proper imaging. Different channels of damage construction such as knock-on, ionization (excitation), chemical etching (e.g. adatoms) have been determined. In this study, the knock-on threshold energies for graphene (C), h-BN (B and N) and MoS2 (S) materials in the presence of adsorbed adatoms (H, C, N, O) on the surface are calculated in the framework of spin-polarized density functional theory. From the preliminary results, we found that when an adatom is adsorbed,

the threshold energies are reduced by 2-3 eV compared to pristine systems. Further, we consider the additional effect of electronic excitation on the threshold energies in combination with adsorbed adatoms. The displacement cross-section under the electron beam are assessed employing the McKinley-Feshbach formalism allowing to compare different channels of damage creation.

O 5.6 Mon 12:15 GER 38

Influence of the swift heavy ions' charge state on pore creation in single-layer MoS_2 — •Yossarian Liebsch[1], Lukas Madauss[1], Henning Lebius[2], Abdenacer Benyagoub[2], Clara Grygiel[2], Radia Rahali[2], Rajendra Singh[3], Jani Kotakoski[3], and Marika Schleberger[1] — [1]University Duisburg-Essen, Duisburg, Germany — [2]CIMAP/GANIL, Caen, France — [3]University Vienna, Vienna, Austria

The initial charge state of a swift heavy ion is usually of no special interest when discussing the interaction of the ion with a bulk target. This is due to the potential energy being small in comparison to the kinetic energy of the ion and due to the equilibrium charge the ion accumulates within a few nanometers after it enters the material. However, in single-layer materials the travelling distance is less than the typical distance needed to establish the equilibrium charge state. Hence, we try to investigate the influence of the charge state of the ions on the defect formation in MoS_2. This is done by irradiating single-layers with swift heavy ions of different charge states. For this experiment we chose 6.6 MeV/u Xe ions with charge states ranging from +41 to +48. Evaluation of the effect on the material is done by analyzing the pore radii and creation efficiencies with STEM-HAADF. With this experiment we aim to shed light onto the fundamental processes and interactions between ultra thin materials and swift heavy ions as well as quantifying the influence of the charge state on the stopping power in single-layered materials.

O 5.7 Mon 12:30 GER 38

Spectroscopic and microscopic analysis of ion-induced modifications in 2D materials — •Carolin Frank[1], Lucia Skopinski[1], Lars Breuer[1], Jennifer Schmeink[1], Lukas Kalkhoff[1], Stephan Sleziona[1], Ulrich Hagemann[2], and Marika Schleberger[1] — [1]University of Duisburg-Essen, Faculty of Physics and CENIDE, 47057 Duisburg, Germany — [2]University of Duisburg-Essen, CENIDE, ICAN, 47057 Duisburg, Germany

In this contribution we present results concerning modifications induced by xenon- and gold-ions in two-dimensional molybdenum disulfide exfoliated on gold including Raman spectroscopy, X-ray photoelectron spectroscopy and friction force microscopy. Irradiations at the target station HICS, located at the University of Duisburg-Essen, as well as at the target stations MSS@CRYRING and M1-Branch, both located at the GSI Helmholtzzentrum für Schwerionenforschung, were implemented with slow, highly charged ions as well as with swift heavy ions, which differ from each other regarding their charge state and their kinetic energy.

A focus will be given to the impact of both the kinetic and potential energy of the ions on modifications of the molybdenum disulfide and also on the size of ion-induced defects. Based on the results of friction force microscopy it is shown for the first time that the impact of the potential energy of the swift ions regarding generation of defects in 2D materials is significantly larger than the impact of the kinetic energy. Additionally, results regarding interaction between the gold substrate and the molybdenum disulfide will be discussed.

O 5.8 Mon 12:45 GER 38

Manipulation of the electrical and memory properties of MoS_2 field-effect transistors by highly charged ion irradiation — •Stephan Sleziona[1], Aniello Pelella[2], Enver Faella[2], Osamah Kharsah[1], Lucia Skopinski[1], André Maas[1], Yossarian Liebsch[1], Antonio Di Bartolomeo[2], and Marika Schleberger[1] — [1]Fakultät für Physik und Cenide, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg — [2]Physics Department, University of Salerno, 84084 Fisciano, Salerno, Italy

Molybdenum disulfide (MoS_2) is a semiconductor that develops a direct bandgap of 1,8 eV when its thickness is reduced to the monolayer limit and is therefore a suitable 2D material for applications in optoelectronic devices. MoS_2 field-effect transistors (FET) in particular exhibit a hysteresis in their transfer characteristics, which can be utilized to realize a 2D memory device. This hysteresis is generally attributed to adsorbates or defects either in the MoS_2 lattice or in the underlying substrate. We fabricated MoS_2 FETs on SiO_2/Si substrates and irradiated these devices with Xe^{28+} ions at a kinetic energy of 180 keV to deliberately introduce defects and modify their electrical and hysteretic properties. We evaluate different electrical properties before and after the irradiation and find clear influences of the irradiation e.g., on the conductivity and charge carrier mobility of the devices. Significantly reduced n-doping and a well-developed hysteresis can be measured after irradiation. We utilize this hysteresis to demonstrate the use of the MoS_2 FET as a memory device, which has remarkably longer relaxation times (≈ minutes) compared to previous works.