DS 2: Focus Session: Ion Beam Induced Surface Patterns I

Low energy ion irradiation of surfaces is known to induce self-organized nanoscale surface dot or ripple patterns. During the last years several novel experimental and theoretical advances have been accomplished, contributing to a better understanding of the pattern formation mechanisms and allowing fabrication of tailored patterns or very smooth surfaces. Several possible applications of self-organized nanopatterned surfaces for optical and magnetic devices were presented. A variety of systematic experimental data is now available, allowing a profound test of recent theoretical models for pattern formation. This focus session will highlight the recent developments in self-organized pattern formation and new analysis techniques to determine in particular the dynamic behavior of ion-induced surface patterns. (Organizer: Hans Hofsäss, University Göttingen)

Time: Monday 9:30–12:45 Location: H32

Topical Talk DS 2.1 Mon 9:30 H32
Mechanisms of ion beam induced surface pattern formation — •Thomas Michely — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln

Related to three different material classes - metals, elemental semiconductors and epitaxial graphene - three different pattern formation mechanisms will be presented. At sufficiently high temperatures ion induced pattern formation on metals may be considered as the inverse of homepitaxial growth and is determined by anisotropies of diffusion related to the crystalline structure. Elemental semiconductors like Si and Ge amorphize under the ion beam at ambient conditions and form patterns most readily in the presence of silicide forming impurities. Finally, ion beam induced pattern formation in epitaxial graphene can originate from an inhomogeneous interaction of graphene with its substrate, driving vacancies into an ordered array of vacancy clusters.

Topical Talk DS 2.2 Mon 10:00 H32
Mechanisms of surface pattern formation under irradiation with heavy ions — •Karl-Heinz Heinig[1], Bartosz Liedke[1], Herbert Urbassek[2], Christian Anders[2], Lothar Bischoff[1], and Roman Böttger[1,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, POB 51 01 19, 01314 Dresden — [2]Physics Department and Research Center OPTIMAS, University Kaiserslautern, Erwin-Schrödinger-Straße, 67663 Kaiserslautern — [3]Technische Universität Dresden, 01062 Dresden

The driving force for surface pattern formation under ion irradiation has been under discussion for many years. Bradley and Harper suggested that curvature dependent sputtering is the source for the surface instability. Later on, Carter and Vishnyakov concluded that the transfer of the ion momentum to atoms causes a mass drift which smoothes the surface but destabilizes it at large off-normal impact angles. Thus, no pattern formation is expected for normal incidence on elemental semiconductors. However, very recently we found that normal incidence irradiation of Ge with ultraheavy ions (Bi_3^{++} , Bi_2^{+}, 10...20 keV/atom) leads to very pronounced, hexagonally ordered dot pattern [1]. This pattern form if the energy density deposited close to the surface in a single ion impact exceeds a threshold, which can be achieved by ultraheavy ions or by substrate heating [2]. A model of pattern formation based on transient melt pool formation with local surface minimization will be presented. [1] L. Bischoff, K.-H. Heinig, B. Schmidt, S. Facsko, W. Pilz, NIMB 272 (2012) 198; [2] R. Böttger, L. Bischoff, K.-H. Heinig, W. Pilz, B. Schmidt, JVST B30 (2012) 06FF12.

Topical Talk DS 2.3 Mon 10:30 H32
Interaction of energetic ultraheavy ions with surfaces — •Lothar Bischoff, Roman Böttger, and Karl-Heinz Heinig — Helmholtz-Zentrum Dresden-Rossendorf, Germany

Energetic ultraheavy polyatomic ions like Bi_3^{++} and Bi_2^{+} produce very dense collision cascades in surface layers. Compared to monatomic ion impacts, which do not overlap in space and time within the heat relaxation time, the simultaneous impact of a few atoms in the same point can cause very different effects. Here, we report on FIB irradiation with fluences up to 10^{17} cm^{-2} using a liquid metal ion source. Using ultraheavy ions, a significantly increased sputter yield of Ge has been found, which can be attributed to thermal processes. Another, more striking feature is the dramatic difference in the surface morphologies caused by monatomic and ultraheavy ion irradiation. For instance, the well-known spongy surface layer forms on Ge upon 20 keV Bi^{+} irradiation, whereas normal incidence Bi_3^{++} irradiation with the same energy per atom results in hexagonally ordered dot pattern having an aspect ratio of about one. Similar pattern have been found on Si by ultraheavy ion irradiation, but only under substantial substrate heating. And, in hot Ge substrates, normal incidence monatomic Bi^{+} ions produce no longer Ge sponge but also dot pattern. A crude thermal analysis of the experiments shows that the considered dot pattern formation is associated with a critical energy density deposited by an ion close to the surface. A more comprehensive model on this pattern formation will be presented in a subsequent talk by K.-H. Heinig.
R. Böttger, L. Bischoff, K.-H. Heinig, et al. JVST B30 (2012)06FF12

Coffee break (15 min)

Invited Talk DS 2.4 Mon 11:15 H32
Quantitative analysis of nanoripple patterns by GISAXS 3D mapping — •David Babonneau, Elliot Vandenhecke, Mathieu Garel, Sophie Camelio, and Sophie Rousselet — Institut Pprime, CNRS, Poitiers, France

3D reciprocal space mapping in the grazing incidence small-angle x-ray scattering (GISAXS) geometry was used to obtain accurate morphological characteristics of nanoripple patterns prepared by low energy (500-1500 eV) Xe^{+} ion sputtering of Al_2O_3 and Si_3N_4 amorphous thin films at oblique incidence. We will show that appropriate modeling in the distorted wave-Born approximation makes it possible to determine unambiguously the average 3D shape of the ripples (width, height, length, and asymmetry) along with the degree of ordering of the pattern, which strongly depend on the experimental conditions of sputtering such as ion energy, angle of incidence, temperature, ion flux, and total fluence. In addition, we will show that the lateral order of the nanoripple patterns can be transferred to arrays of noble metal nanoparticles (Ag or Au) or magnetic nanowires (FePt) by subsequent ion-beam sputtering deposition at glancing incidence. GISAXS experiments clearly demonstrate that (i) the rippled surfaces are selectively decorated by the nanoparticles/nanowires on the facets that face the incoming atomic flux, and (ii) the growth of an additional capping layer proceeds conformal with respect to the modulation of the prepatterned buffer layer.

Invited Talk DS 2.5 Mon 11:45 H32
Movement of a ripple pattern by ion beam irradiation — •Paul Alkemade — Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands

When a beam of energetic ions bombards a material, atoms are being sputtered from the material's surface. Even if the surface is initially smooth, the bombardment might induce surface roughness, often in a more or less regular pattern. These patterns can be a nuisance in sputter deposition or 3-dimensional materials analysis, but are also potentially beneficial, e.g. as anti-reflection layers.

Depending on the material's bulk and surface composition, the temperature, and the type, energy and angle of the ion beam different pattern types might evolve. A very common one is a ripple pattern, evolving under off-normal incidence on amorphous surfaces.

Various physical mechanisms can determine the pattern evolution. So far almost all experimental and theoretical studies address the growth or decay of the ripple amplitude. However, study of the lateral movement of the ripples can reveal crucial details of the mechanisms.

The angular dependence of the sputter rate predicts that at off-normal incidence ripples move against the ion beam direction, but recent experiments show otherwise. In this talk I will show that beam-driven viscous flow and relaxation of beam-induced stress can explain the observed direction of the moving ripples.

Topical Talk DS 2.6 Mon 12:15 H32

Redeposition during ion-beam erosion — Nils Anspach, Christian Diddens, Marc Osthues, and •Stefan Linz — Institut für Theoretische Physik, WWU Münster

Redeposition, i.e. the effect that eroded target particles generated by ion-beam erosion processes can, at least partially, attach to the target surface again, has been scarcely studied in the past. This inherently non-local effect can have substantial impact on the nano-scale evolution of the surface morphology of the eroded target. Using an appropriately tailored one-dimensional solid-on-solid model [1] and a two-dimensional continuum formulation [2] for redeposition processes, we investigate their generic physical properties on the nanoscale. Most significantly, by combining the redeposition model with standard models for erosion, we are able to verify that redeposition can potentially stabilize well-ordered hexagonal nanostructures, as also detected in low-energy ion-beam erosion experiments on semiconductors.

[1] N Anspach, S Linz, J. Stat. Mech. 2012, P06012; 2010, P06023
[2] C Diddens, S Linz, in preparation