# DS 21: Micro- and nanopatterning (jointly with O)

Time: Wednesday 11:45–13:45 Location: H 0111

DS 21.1 Wed 11:45 H 0111

**Investigation of the Fe incorporation in ion-beam induced patterning on Si (100)** — •Behnam Khanbabaee[1], Andreas Biermanns[1], Marina Cornejo[2], Dietmar Hirsch[2], Frank Frost[2], and Ullrich Pietsch[1] — [1]Universität Siegen, Festkörperphysik,Siegen, Germany — [2]Leibniz-Institut für Oberflächenmodifizierung e. V. (IOM), Leipzig, Germany

Ion beam erosion of semiconductor surfaces can modify the surface and depends on main sputtering parameters; different surface topographies such as ripple or dot like pattern are fabricated on the surface. Recent experiments have shown that the incorporation of foreign metallic atoms during the sputtering process plays a crucial role in pattern formation on surfaces. In the result of investigation we report on the depth profile of Fe atoms incorporated in sputtering process on Si (100) with low energy Kr ion beam. X-ray reflectivity (XRR) measurements determine the concentration profile of Fe atoms. X-ray absorption near edge spectroscopy (XANES) at the Fe K-edge (7112 eV) shows the formation of Fe rich silicide near surface region. X-ray photoelectron spectroscopy (XPS) shows a shift in the binding energy of Si2p levels at the surface compared top bulk confirming the formation of different phases of Fe-silicide on top and below the surface. The depth profiles obtained by XRR are compared to results obtained by complementary secondary-ion mass spectrometry (SIMS).

DS 21.2 Wed 12:00 H 0111

**Threshold sputter depth for nanopattern formation and "zero" sputter yield ion beam irradiation of amorphous carbon** — •Omar Bobes, Kun Zhang, and Hans Hofsäss — II. Phys. Institut, Uni Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

The question whether sputtering is actually needed for pattern formation by ion beam erosion is still under debate. Therefore, we investigate the minimal required sputter depth which corresponds to the transition from a flat surface to a nanostructured surface for ion energies up to 10 keV. Especially, we chose ion beam irradiation under conditions where the sputter yield approaches zero. This can be achieved by using a light substrate materials such as carbon and heavy ions with energies not exceeding 100 eV, e.g., for 100 eV $Xe^+$-ions at 60° angle of incidence the sputter yield is to 0.002. In order to distinguish between sputter effect and the effect of displacement of recoil atoms for the pattern formation, low energy $He^+$-ion irradiation has been used and compared with $Xe^+$-ion irradiation. $He^+$-ions are unique, because they provide a small and almost constant sputter yield in the energy region between 500 eV and 1200 eV for amorphous carbon, but the displacement yield changes by a factor of two. One can choose the energies of $Xe^+$- and $He^+$-ions in such a way, either resulting in similar sputter yields or in similar displacement yield. The first results of such experiments will be presented.

DS 21.3 Wed 12:15 H 0111

**Is silicide formation the decisive factor in impurity induced ion beam pattern formation?** — Sven Müller[1], •Martin Engler[1], Frank Frost[2], and Thomas Michely[1] — [1]II. Physikalisches Institut, Universität zu Köln, Cologne, Germany — [2]Leibniz-Institut für Oberflächenmodifizierung e.V., Leipzig, Germany

Metal co-deposition during ion beam erosion of Si induces nanoscale patterns. Here we present the results of a comparative study of Pd and Ag co-deposition during 2 keV $Kr^+$ ion irradition of Si(001) at normal incidence. Co-deposition was conducted by e-beam evaporation and by sputter deposition from an adjacent target, which was hit by the eroding ion beam simultaneously with the Si surface.

The collision kinetics of Ag and Pd are almost identical due to their similar atomic masses (Ag: 107.9 amu, Pd: 106.4 amu) and nuclear charges (Ag: Z = 47, Pd: Z = 46). There should be differences in pattern formation If chemistry is of relevance it, since Ag is almost insoluble in Si and forms no silicides, while Pd forms a number of silicides with substantial enthalpy of formation.

We find that for Ag co-deposition no patterns are formed while a sequence of patterns forms for Pd co-deposition which depends strongly on the flux ratio of arriving Pd atoms to $Kr^+$ ions.

Most surprising, pattern formation with Pd not only ceases for low, but also for high flux ratios. We therefore speculate that under the conditions used, phase separation through spinodal decomposition triggers the formation of the most pronounced patterns.

DS 21.4 Wed 12:30 H 0111

**Innovative FIB specific Nanopatterning Strategies for Optimized Photonic Crystal Nanofabrication** — •Frank Nouvertne and Achim Nadzeyka — Raith GmbH, Konrad Adenauer Allee 8, D-44263 Dortmund, Germany

The physical interactions underlying ion beam lithography (IBL) are quite complex as it brings in both sputtering and redeposition effects. Sputtering, the key mechanism for focused ion beam milling, is a complex process that depends on several factors, such as crystal orientation, surface topography, surface diffusion, ion implantation, and the stoichiometry of the solid. Redeposition is a less desirable mechanism that is ubiquitous in focused ion beam milling and has a similar complexity as sputtering. These additional physical complexities associated with the IBL technique call for more flexible beam deflection strategies than are typically available for EBL.

This talk will focus on the optimization of a photonic crystal fabricated by a FIB milling process, controlled by ELPHY MultiBeam, a new generation of nanofabrication pattern generators (PG). This newly developed PG allows for a huge variety of different directional and repetitive patterning strategies, which - in combination with a dedicated automatic drift compensation functionality - enables the required, most precise pattern placement accuracy and highest stability for this long term photonic crystal nanofabrication process over several hours.

DS 21.5 Wed 12:45 H 0111

**Photonic Crystal Gratings for High-Speed Energy-Efficient Laser Sources** — •Philip Wolf[1], Werner Hofmann[1], Norbert Grote[2], and Dieter Bimberg[1] — [1]IFKP & Center of Nanophotonics, TU Berlin — [2]Heinrich Hertz Institute, Fraunhofer, Berlin

Recently, VCSELs with highest modulation speeds [1] and highest energy efficiencies have been demonstrated [2]. Furthermore, a novel nano-photonic element, the so-called sub-wavelength or high-contrast grating (HCG) has been successfully applied in various VCSEL structures [3-5]. This special photonic crystal can be understood as a multi-mode Fabry-Pérot interferometer being able to replace a thick distributed Bragg-mirror [3]. It has been demonstrated that a HCG can improve the modal behavior of this type of lasers [4]. We expect that this technology will enable us to demonstrate VCSEL of superior bandwidth and energy efficiency. The challenge is to implement this technology into cutting-edge high-speed device designs. Here, we like to show our new concept and present recent breakthroughs in fabrication of these photonic crystals using electron beam lithography and dry-etching with our ICP-reactor.

[1] Hofmann, W. et al.: "44 Gb/s VCSEL for optical interconnects," OFC 2011, PDPC5, 2011. [2] Moser, P. et al.: "81 fJ/bit energy-to-data ratio of 850 nm VCSEL for optical interconnects," APL, 98, 2011. [3] Chang-Hasnain, C.J. et al.: "High-Contrast Grating VCSELs," IEEE J. Sel. Top. Quantum Electron., 15, 2009. [4] Hofmann, W. et al.: "Long-Wavelength High-Contrast Grating VCSEL," IEEE Photon. J., 2, 2010. [5] Il-Sung Chung et al., IEEE PTL, 20, pp. 105, 2008.

DS 21.6 Wed 13:00 H 0111

**Nanopatterning by molecular polygons** — •Stefan-Sven Jester, Eva Sigmund, Natalia Shabelina, Stephan M. Le Blanc, and Sigurd Höger — Rheinische Friedrich-Wilhelms-Universität Bonn, Kekulé-Institut für Organische Chemie und Biochemie, Gerhard-Domagk-Str. 1, 53121 Bonn, Germany

Self-assembly of rigid molecules at the solution/solid interface interface allows an efficient approach towards two-dimensional supramolecular crystalline surface patterns. In-situ scanning tunneling microscopy yields a submolecularly resolved insight into the adlayer structures and thus a conclusion on the driving forces for their formation. Of particular interest is how the nanoscale architectures depends on the symmetry and dimensions of the molecular building blocks and their substituents. One approach to tailored adlayers is based on the adsorption of shape-persistent arylene-alkynylene macrocycles at the interface of 1,2,4-trichlorobenzene and HOPG. The molecules are ac-

cessible from organic synthesis and can be widely substituted with functional groups. Recent work has focused on macrocycles involving dithiophene corner building blocks connected via linear phenylene-ethynylene-butadiynylene units that can be viewed as molecular polygons of distinct symmetry (i.e. triangles, squares, pentagons, and hexagons), so that concepts of discrete geometry can be applied to design tailorable nanoscale surface patterns. The results gain insight into the 2D crystallization of nanoscale pentagons, binary mixtures of triangles and hexagons, and how large periodicities of several 10 nm may become accessible.

DS 21.7 Wed 13:15 H 0111

**Rapid Prototyping of Hierarchical Gecko-Mimicking Nano- and Microstructures using Multiphoton Absorption** — •Michael Röhrig[1], Michael Thiel[2], Matthias Worgull[1], and Hendrik Hölscher[1] — [1]Karlsruhe Institute of Technology, P.O. Box 3640, 76021 Karlsruhe, Germany — [2]Nanoscribe GmbH, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopolds., Germany

Applying 3D direct laser writing, we designed hierarchical gecko-type structures which match the elastic modulus and the relevant length scale of the gecko's setae very closely. These setae, delicate hairs covering the gecko's toes, originate the famous ability of geckos to climb effortlessly walls and ceilings. The setae are consisting of beta-keratine, a stiff material with Young's modulus of around 1 - 4 GPa. Due to their hierarchical design, they are very compliant and can achieve a very high real contact area even to rough substrates. Thus, the van der Waals forces cause high adhesion that enables geckos to stick to nearly every surface. Mimicking the gecko-effect is therefore pursued by groups all over the world. However, such structures are mostly based on soft materials that usually have some drawbacks, like degradation or rapid contamination. Hence, we used 3D direct laser writing to structure stiff materials. 3D direct laser writing is a rapid prototyping method based on multiphoton absorption that allows for the fabrication of arbitrary three-dimensional structures down to the nanometer scale. Measuring the adhesion by using atomic force microscopy, we could show that hierarchy is indeed favorable for artificial gecko-inspired structures made of stiff materials on the nanometer scale.

DS 21.8 Wed 13:30 H 0111

**Time and space resolved pump-probe investigations on induced ablation of thin films with femtosecond laser pulses** — •Stephan Rapp, Matthias Domke, and Heinz P. Huber — Munich University of Applied Sciences

An about 500 nm thin molybdenum film acts as p-contact for CIGS thin film solar cells, which has to be separated to serially interconnect the sub cells of a solar panel. The Mo can be structured either by irradiating the Mo from the front side or from the glass substrate side, resulting in a selective removal or a lift-off of an intact Mo cap, respectively. To investigate the underlying physical effects, a pump-probe setup is used for time- and space resolved microscopy. Several series of pictures are taken with time delays between femto- and microseconds, showing the complete temporal evolution of laser ablation (lift-off). The front side irradiation with fluences up to 5.0 J/cm$^2$ leads to thermal effects after a few picoseconds and after 100 ps ring systems appear. This suggests a bulging of the material. After 3 ns a shock wave crosses the sample with velocities from 675 to 3950 m/s. The substrate side irradiation with fluences up to 1.0 J/cm$^2$ initiates a decrease of the sample reflectivity due to heating for delay times up to 10 ps. Ring systems are formed after 4 ns and a model was created to determine the bulging height by analyzing these Newton′s rings. After the bulging a lift-off of an intact Mo cap can be observed at times between 10 and 40 ns for fluences above the ablation threshold which was determined to 0,6 J/cm$^2$.