DS 29: Lithography III: Lithography and Structuring (joint session KFM/DS)

While high-resolution 2D lithography and structuring is relatively mature and also widely applied in industrial processes, work on its 3D variant is mostly focusing on fundamental aspects and process development. At the lower edge of possible 3D feature dimensions, certainly methods such as electron beam induced deposition, non-linear multi-photon-laser lithography and thermal scanning probe lithography techniques are required. This session discusses most of these dedicated 3D methods in detail. For the fabrication of complex 2D and 2.5D patterns, advanced electron beam and X-ray methods are continuously developed further. In addition, new methods such as high resolution Talbot lithography for relatively large areas are already entering industrial maturity. This session also discusses some of the latest developments in this field of binary lithography.

Organizer: Robert Kirchner - Technische Universität Dresden

Time: Thursday 9:30–12:50 Location: EMH 025

Invited Talk DS 29.1 Thu 9:30 EMH 025

3D Nanoprinting via Focused Electron Beams — •Harald Plank[1,2], Robert Winkler[1,2], Jason Fowlkes[3,4], and Philip Rack[3,4] — [1]Institute for Electron Microscopy and Nanoanalysis Graz University of Technology, 8010 Graz, Austria — [2]Graz Centre for Electron Microscopy, 8010 Graz, Austria — [3]Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA — [4]Department of Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee 37996, USA

3D-printing of functional structures has emerged to an important technology in research and development. While being reliable on the micro and sub-micron scale, it becomes very challenging when aiming for nano-sized geometries. Among the very few direct-write techniques on that scale, Focused Electron Beam Induced Deposition is one of the promising candidates as this technology has recently done tremendous steps forward. In particular, this technology allows additive fabrication of complex, freestanding 3D nano-architectures on almost any material and surface morphology, which enables entirely new 3D nano-applications (e.g. plasmonics, artificial spin-ice or nano-probes). The contribution starts with an introduction of FEBID and sheds light on recent progress, which leverages this technology from a scientifically oriented fabrication tool into the status of a reliable and predictable 3D-nanoprinter. In the following, several applications are discussed to demonstrate the new possibilities of this generic fabrication technology. Finally, the talk gives an overview of ongoing activities together with future perspectives beyond current limitations.

DS 29.2 Thu 10:00 EMH 025

3D printing at the diffraction limit: sample injection for time-resolved serial crystallography — •Michael Heymann — MPI of Biochemistry, Am Klopferspitz 18, 82152 Martinsried

Continuous injection using the Gas Dynamic Virtual Nozzle (GDVN) is a proven sample delivery method for biological imaging using X-ray free-electron lasers. However, many important aspects of GDVN functionality have yet to be thoroughly understood and/or refined due to fabrication limitations. We report the application of 2-photon polymerization as a form of high-resolution 3D printing to fabricate GDVNs with submicron resolution. This allows rapid prototyping of a wide range of nozzle designs from standard CAD drawings to iteratively optimize crucial dimensions for optimal performance. To understand enzyme catalysis and protein conformational changes at the atomic scale, we pioneered mixing-injectors for time-resolved structural biology to record molecular movies of substrate turn-over. We experimentally validate 3D print accuracy, as well as fluid mixing dynamics using X-ray tomographic imaging. We developed mixing-injectors to mix nanocrystals with substrate and to subsequently deliver them into the X-ray interaction region just milliseconds after mixing. This method can determine the structures of transient states and thereby kinetic mechanisms. In a proof of principle experiment, we could follow the catalytic reaction of the M. tuberculosis β-lactamase with the 3rd generation antibiotic ceftriaxone by time-resolved serial crystallography with millisecond to second time resolution at 2Å spatial resolution.

DS 29.3 Thu 10:20 EMH 025

Fabrication of superior 2D and 3D nano-devices using NanoFrazor lithography — Colin Rawlings[1], Armin Knoll[2], Felix Holzner[1], and •Zhengming Wu[1] — [1]SwissLitho AG, Zurich, Switzerland — [2]IBM Zurich, Switherland

Thermal scanning probe lithography (t-SPL) has recently entered the lithography market as first true alternative or extension to electron beam lithography (EBL). The first dedicated t-SPL systems, called NanoFrazor, have been installed at research facilities in Europe, America, Asia and Australia by the company SwissLitho.

The application range for this new nanofabrication capability is broad and will be demonstrated with the discussion of a selection of examples. Applications that are enabled by the nm-precise 3D patterning include 3D phase plates and finely tuned coupled Gaussian optical microcavities. Furthermore, 3D shaped nanofluidic confinements have been used to precisely control the movement of nanoparticles and nanowires. The high resolution 2D capability was applied e.g. to shape complex plasmonic structures. Furthermore, several superior nanoelectronic devices will be shown. Such devices are predominantly made from randomly dispersed nanowires or 2D materials. Therefore, they benefit strongly from the unique markerless overlay capability of the NanoFrazor lithography, but also from the fact that actually no charged particle beam is used during lithography, which can often damage sensitive materials. Finally, a few examples are shown, how the heated tips are also used for direct modification of surfaces by triggering of a local phase change or a chemical reaction.

DS 29.4 Thu 10:40 EMH 025

Innovations in photoresists and photopolymers for 2D / 3D micro and nano fabrication — •Anja Voigt, Christine Schuster, Jan Klein, Arne Schleunitz, and Gabi Grützner — micro resist technology GmbH, Koepenicker Str. 325, 12555 Berlin, Germany

Different methods for the manufacture of high resolution 2D and 3D features require a wide range of material solutions based on innovative photoresists and photopolymers. As a commercial resist supplier, micro resist technology aims at providing such solutions tailored for diverse lithography processes, comprising both materials and technology support. The following highlights will be presented:

E-beam lithography is a versatile patterning method for the generation of high resolution nano-patterns. Combining stepwise greyscale exposure and pattern reflow with a positive tone resist results in greyscale patterns of small dimensions.

Greyscale UV lithography of up to 100 micron thick resist films, either by direct laser writing or by conventional mask aligner exposure and a greyscale mask, can generate very deep greyscale micro-patterns. Both very thick films, and considerably smaller pattern features including sharp tips have been successfully fabricated using this technique.

Laser interference lithography is another method which allows the manufacture of nanoscale patterns * periodic patterns even on very large substrates. Whereas two photon absorption (2PA) allows the generation of real 3D patterns at micro and nanoscale.

The development of photoresist and photopolymer materials tailored to meet the requirements of the specific technologies will be presented.

20 min. break

Invited Talk DS 29.5 Thu 11:20 EMH 025

Diffractive X-ray Optics for Synchrotrons and Free Electron Lasers - a challenge from the lithographer's point of view — •Christian David — Paul Scherrer Institut, Villigen, Switzerland

X-rays are excellent probes for the investigation of matter using scattering, imaging and spectroscopic techniques, offering high penetration capability, spatial and temporal resolution, along with elemental and chemical sensitivity. Accelerator-based photon sources play a key role in these analytical techniques as they offer beams with unique brilliance.

This presentation will give an overview on developments of x-ray instrumentation and experimental techniques based on diffractive optics. These optical elements are designed for short wavelength radiation ranging from the vacuum ultraviolet to hard x-rays and play a key role in the shaping, direction, and detection for a variety of experiments. The key challenges lie in the fabrication of the diffractive structures by advanced nanolithography techniques, as they need to provide dimensions and placement accuracies down to the nanometer scale.

Many applications of these devices include x-ray imaging techniques. The x-ray optics developed at PSI provide spatial resolution down to the 10 nm range, and are designed exploit phase contrast mechanisms or spectroscopic information. Moreover, recent developments of optics for beam splitting and the manipulation of x-ray wave fronts open up new opportunities for time resolved measurements of ultra-fast processes at x-ray lasers.

DS 29.6 Thu 11:50 EMH 025

A high contrast multilayer process for electron beam lithography using different developers — •Philip Trempler[1], Frank Heyroth[2], Matthias Schirmer[3], Christian Kaiser[3], Tobias Mai[3], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther Universität Halle-Wittenberg, 06099 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther Universität Halle-Wittenberg 06099 Halle (Saale), Germany — [3]ALLRESIST GmbH, Am Biotop 14, 15344 Strausberg, Germany

We have developed a new multilayer resist system for the fabrication of three-dimensional nanostructures in a one-step electron beam exposure. The multilayer resist consists of three layers with different sensitivity and different process chemistry. The sensitivity of the three layers to different respective developers allows a very large controllable undercut in the middle layer. The low sensitivity bottom layer can be patterned in high detail almost independent from the pattern exposed in the two layers on top. At acceleration voltage of 30 kV the resist is ideally suited for the fabrication of for example T-gate structures by lift-off in a high reliability process with a very large process window.

DS 29.7 Thu 12:10 EMH 025

Fabrication of metal nanostructures with focused X-rays — •Andreas Späth, Florian Vollnhals, Fan Tu, Hubertus Marbach, and Rainer H. Fink — Lehrstuhl für Physikalische Chemie II, Friedrich-Alexander Universität Erlangen-Nürnberg, Egerlandstr. 3, D-91058, Erlangen, Germany

Focused X-ray beam induced deposition (FXBID) is a novel technique for the fabrication of metallic nanostructures by illuminating gas phase precursors with focused soft X-rays in a zone plate based scanning transmission X-ray microscope (STXM). With this technique we have been able to produce localized Co and Mn nanostructures with growth rates and purity competitive with electron beam induced deposition (EBID) [1,2]. We demonstrate that our approach exhibits significant selectivity with respect to incident photon energy leading to enhanced deposition for resonant excitation of the precursor molecule. This finding opens a new field of photon energy selective deposition from precursor mixtures and deposition from various precursors within one production cycle. The impact of several deposition parameters on the growth rate, such as illumination time and precursor pressure are discussed with respect to a deeper understanding of deposition processes and optimization of the procedure. Furthermore, we discuss routes to the formation of magnetic deposits by in-situ cleaning techniques (e.g., co-dosing of reactive gases or annealing). The project is funded by the BMBF (05K16WED).

[1] A. Späth et al., RSC Advances, 2016, 6, 98344.
[2] F. Tu et al., J. Vac. Sci. Technol. B, 2017, 35(3), 031601.

DS 29.8 Thu 12:30 EMH 025

Printing Uniform Periodic Structures over Large Areas with Displacement Talbot Lithography — •Harun Solak — EULITHA AG, 5416 Kirchdorf, Switzerland

High-resolution periodic patterns such as linear gratings or two-dimensional arrays are required in many applications. This is especially true in photonics, where optimized interaction of light with periodic nanostructures enables creation of new or higher performance devices such as LEDs, lasers, photovoltaic cells, sensors and LCD screens. In such applications, patterns with periodicity approximately in the 0.1-1micrometer-range need to be printed on device surfaces. Current lithographic methods face significant challenges in terms of technical feasibility or cost in meeting the requirements. The recently introduced Displacement Talbot Lithography (DTL) method allows uniform printing of periodic patterns in a non-contact, proximity scheme [1]. The technique enables patterning on non-flat surfaces and in thick photoresist films up to the highest resolution possible at a given exposure wavelength. Photolithography systems specially designed to perform DTL exposures are now available and they find increasing use in various academic and industrial applications [2-3]. The capabilities of this new tool will be introduced with examples of applications. 1. H. Solak, C. Dais, F. Clube, Optics Express, Vol. 19, p. 10866 (2011). 2. H. Le-The, et al, Adv. Mater. Technol. 2017, 2, 1600238. 3. P. M. Coulon, et al Phys. Status Solidi B, 1700445.