KFM 7: Focus: High-resolution Lithography and 3D Patterning

While high-resolution 2D lithography and structuring is relatively matured 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 focused electron beam induced deposition (FEBID), non-linear multi-photon-laser lithography and thermal scanning probe lithography techniques are required. This session will discuss 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 will also discuss some of the latest developments in this field of binary lithography.

Chair: Dr. Frank Heyroth (Martin-Luther-Universität Halle)

Time: Wednesday 9:00–12:35 Location: POT 51

Invited Talk KFM 7.1 Wed 9:00 POT 51

Novel device integration – combining bottom-up and top-down approaches — •Artur Erbe — Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — TU Dresden, Germany

Scaling electronic devices to smallest structure sizes well below 10nm will require novel developments for the fabrication of single components. Smallest functional devices can be assembled using chemical methods leading to, e.g., single molecules with electronic functionalities. Reliable contacting of single molecules using metallic contacts is, however, an extremely challenging task that has not been solved so far. We have therefore developed techniques that use self-assembly to create conducting nanostructures to create small, self-assembled circuits that can then be contacted reliably using standard lithographic methods. In this talk, we will show how DNA Origamis can be used for the self-assembly of metallic nanowires, which are contacted using electron beam lithography and electrically characterized. Self-assembly can be used to integrate semiconducting nanoparticles or single molecules for building nanodevices. Further integration of such nanostructures into standard silicon electronics may for example be achieved by connecting these nanodevices to silicon nanowires or transistors based on 2-dimensional materials. We have therefore developed reconfigurable transistors based on these materials using electron beam lithography and further processing (i.e. using a classical top-down approach), which are reconfigurable. With the combination of these transistors with self-assembled nanostructures, a large variety of electronic nanocircuits can be constructed in future applications.

KFM 7.2 Wed 9:30 POT 51

Optical properties of photoresists for femtosecond 3D printing: Refractive index, extinction, luminescence - dose dependence, aging, heat treatment and comparison between 1-photon and 2-photon exposure — •Michael Schmid, Dominik Ludescher, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Femtosecond 3D printing has emerged as an important technology for manufacturing nano- and microscopic optical devices and elements. Detailed knowledge of the dispersion in the visible and near-infrared spectral range is crucial for the design of these optical elements. Here, we provide refractive index measurements for different UV-doses, aging times, heat treatment and 2-photon exposed structures for the photoresists IP-S, IP-Dip, IP-L, OrmoComp, IP-Visio, and IP-n162. We use a modified and automized Pulfrich refractometer setup, utilizing critical angles of total internal reflection with an accuracy of 5*10^-4 in the visible and near-infrared spectral range. We compare Cauchy and Sellmeier fits to the dispersion curves and also give Abbe numbers and Schott Catalog numbers of the almost entirely polymerized resists. Additionally, we provide quantitative extinction and luminescence measurements for all photoresists.

KFM 7.3 Wed 9:50 POT 51

3D direct laser writing of miniature optical apertures with highly absorptive photoresist — •Michael Schmid[1,2], Andrea Toulouse[2,3], Simon Thiele[2,3,4], Simon Mangold[1,2], Alois Herkommer[2,3], and Harald Giessen[1,2] — [1]4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Institute of Applied Optics (ITO), University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany — [4]Printoptix GmbH, Johannesstraße 11, 70176 Stuttgart

In recent years, 3D direct laser writing and its possible application developed rapidly. Different complex micro-optical systems have been demonstrated, such as multi-lens objectives. However, it is still challenging to integrate microscopic apertures to these systems. We present a novel approach to create 3D direct laser written apertures using an opaque material suitable for 2-photon lithography. This way, it is possible to integrate microscopic apertures into 3D printed micro-optical systems improving the imaging quality. We demonstrate this potential by combining 3D printed black apertures with singlet lenses made of the commonly used photoresist IP-S. A significant contrast improvement of the imaging is achieved. Furthermore, due to the absorption coefficient, it is possible to create thin lenses with the black material enabling the fabrication of optical lens and aperture in one step.

KFM 7.4 Wed 10:10 POT 51

Self-Folding micro cubes of laser-cut templates — •Pierre Lorenz[1], Ye Yu[2], Ronald Franz[3], Joachim Zajadacz[1], Martin Ehrhardt[1], Robert Kirchner[2], Gregory Lecrivain[3], and Klaus Zimmer[1] — [1]Leibniz Institute of Surface Engineering, Permoserstr. 15, Leipzig, 04318, Germany — [2]Institute of Semiconductor and Microsystems, TU Dresden, Nöthnitzer Straße 64, Dresden, 01187, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Institut für Fluiddynamik, Bautzner Landstraße 400, Dresden, 01328, Germany

3D microstructures exhibit manifold applications with compact system integration in mind. Especially self-folding processes of laser-cut 2D templates allow for fast, flexible, and cost-effective fabrication of 3D structures. A UV ps laser was used for the laser cut of polyimide foil-based 2D templates. Two different folding concepts were tested: water-droplet self-folding and vacuum micro forming (VMF). The VMF concept is based on an array of cavities in a Teflon plate, which work similarly to deep drawing as a guide for the VMF of the 2D templates. In the water-droplet concept, a water droplet was added by a tweezer with a defined volume resulting in self-folding due to the surface tension. Both concepts allow the well-defined folding of sub-mm cubes after optimization of the 2D template geometry. Especially the VMF allows a parallelization and miniaturization of the folding process, which was monitored and analyzed by high-speed imaging.

KFM 7.5 Wed 10:30 POT 51

High resolution and process stability tests on new HSQ based resists — •Nicolas Kunzfeld and Axel Rudzinski — Raith GmbH, Konrad-Adenauer-Allee 8, 44263 Dortmund, Germany

Many new resist providers for hydrogen silsesquioxane (HSQ) based high resolution e-Beam-resist emerged on the market in the last few years.

Until now, the experience with these new resists regarding resolution capabilities, process stability and long term behaviour is very limited.

To expand the experience with these resist, further testing based on statistical methods like a process capability evaluation based on the CpK-Value is required.

This work presents the latest high resolution, process capability and long term stability tests of these HSQ-based resists provided by different resist suppliers.

We achieved isolated single pixel lines with sub 6 nm line width with a CpK-Value of 1 and were also able to get a first impression about the resist behaviour over a time frame of almost 30 days.

15 min. break

Invited Talk KFM 7.6 Wed 11:05 POT 51

4D meso-scale electronics for next generation medical tools and electronic skins — •Daniil Karnauschenko — Research Center MAIN, Technical University Chemnitz, Rosenbergstr. 6, 09126 Chemnitz, Germany

State-of-art mesoscale systems for IoT, e-skins or smart-dust applications, medical or commercial products are essentially 3D architectures, whose geometry plays vital role when providing communication, sensing, actuation and power management functions. Conventional components carrying electronic functions are static, functionally heterogeneous and spatially separated requiring nontrivial sequential assembly and packaging procedures, which hinder further miniaturization and development of next generation mesoscale systems. 3D self-assembled architectures are envisioned to become a driving force for 3D electronic devices designed, microfabricated and self-assembled from planar thin-film structures and self-organized electronic components. Dynamic (4D) parallel assembly operating at mesoscale (1 um - 1 mm) allows offers improved performance while reducing overall manufacturing complexity of devices and components by harnessing the relative ease in which it can produce mesoscopic 3D geometries i.e. origami folded structures and "Swiss-roll" architectures. These architectures and benefits will lead to tighter a system integration e.g. electronic skins and medical tools made out of electronic components including active matrix, capacitors, power sources, coils, sensors, actuators and antennas with reduced costs fabricated from a single wafer.

KFM 7.7 Wed 11:35 POT 51

Two-Photon Polymerization Lithography Structures Characterized via Raman Spectroscopy and Nanoindentation — •Severin Schweiger[1,2], Tim Schulze[1,2], Peter Reinig[1], Simon Schlipf[3], and Harald Schenk[1,2] — [1]Fraunhofer Institute for Photonic Microsystems, Maria-Reiche-Str. 2, Dresden, Germany, 01109 — [2]Brandenburg University of Technology, Platz der Deutschen Einheit 1, Cottbus, Germany, 03046 — [3]Fraunhofer Institute for Ceramic Technologies and Systems, Maria-Reiche-Str. 2, Dresden, Germany, 01109

Additive manufacturing using two-photon polymerization (TPP) lithography has gathered interest in industry and research. Parameter sweeps of cuboid structures fabricated using TPP lithography were investigated to find dependent mechanical material properties across the parameters of the laser power and scan speed. Raman spectroscopy and micro- or nanoindentation were used on the cuboids to find the degree of conversion (DC) of monomer to polymer and the Youngs modulus (E), respectively. The DC and E found for the photoresist IP-Dip was 20 % to 45 % and 1 to 2.1 GPa, respectively. These results were compared to reports found in the literature. The DC and E found for the photoresist IP-Q, was 53 % to 80 % and 0.5 to 1.3 GPa, respectively. The properties found for IP-Q are the current state of knowledge for this photoresist. Many structures fabricated via TPP and based on IP-Q can benefit from this knowledge and the customizability of the material. Examples are evaluated and discussed in the presentation.

KFM 7.8 Wed 11:55 POT 51

Dry film resists: A promising material class for micro-/acoustofluidic chip fabrication — •Andreas Winkler — Group "Acoustic Microsystems", IFW Dresden, Helmholtz str. 20, 01069 Dresden, Germany

Dry film resists (DFRs) promise low-cost and greener microfabrication, and can partly replace conventional technologies for microstructure fabrication being associated with high-energy demands and intense use of toxic and climate-active chemicals. Due to their mechanical stability and superior film thickness homogeneity, DFRs also outperform spin-on resists, such as SU-8, as structural materials, especially when high-resoluted two- and three-dimensional architectures are required such as the case in acoustofluidic chip devices. We investigated various dry film resists in the recent years for their suitability in micro-/acoustofluidic applications. While in general their performance was found to be highly promising and also allowed completely new solutions, properties of commercially available DFRs can vary strongly between individual products and even product charges, and literature on - as well as description of - these materials is still scarce. Here, we introduce this relatively young material class and present selected results regarding technically important effects and limitations, optical properties and performance in acoustofluidic cell separation and aerosol generation.

KFM 7.9 Wed 12:15 POT 51

Artificial Intelligence for high resolution multi-photon lithography — •Julian Hering-Stratemeier[1], Sven Enns[1,2], Nicolas Lang[1], and Georg von Freymann[1,2,3] — [1]Physics Department and State Research Centre OPTIMAS, TUK, 67663 Kaiserslautern, Germany — [2]Opti-Cal GmbH, 67663 Kaiserslautern, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

Multi-photon lithography, a.k.a. direct laser writing (DLW), is one of today's most flexible high resolution 3D additive manufacturing technologies. Nevertheless, there are fundamental restrictions, limiting its resolution and structure-conformity: First, the shape of the polymerization-triggering laser focus limits the minimal volume that gets solidified (voxel). Hence, laser focus shape distorting optical aberrations within the beam path worsen the quality of the 3D printed outcome. Second, the physico-chemical properties of the photo resins influence the sharpness and extensions of single voxels, and, therefore, the 3D printed structure quality and resolution as well. Here, we show very first steps (i) towards a fast algorithm for predicting those error-loaded structures. Moreover, we use artificial intelligence (ii) to correct for optical aberrations within the beam path and (iii) to pre-compensate for the photo resin's outcome-worsening properties. Especially correcting aberrations is crucial for, e.g., extending DLW to high resolution STED-inspired DLW which is analogue to the well-known and Nobel price warded STED-microscopy.