Symposium Nanostructuring Beyond Conventional Lithography (SYNS)

jointly organized by
the Microprobes Division (MI),
with the Thin Films Division (DS),
the Dielectric Solids Division (DF),
the Semiconductor Physics Division (HL),
the Metal and Material Physics Division (MM),
and the Vacuum Science and Technology Division (VA)

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Since a long time, the development of silicon microelectronics is the main driving force of the progress in high-resolution lithography. Currently, industry is approaching the 14 nm node, and technology for the 10 nm node is under development. In parallel, the increasing storage density in hard disk drives has initiated additional needs for very regular but ultra-high resolution lithography processes for patterned media. At the moment, silicon integration still favors optical lithography processes enhancing the resolution by double patterning techniques and aims at introducing extreme UV technology. This strategy still works, however, the increasing costs have led to several attempts to introduce electron beam lithography into production. The requirements for patterned media, however, might allow the introduction of nanoimprint lithography or self-organization processes using the demixing of blockcopolymers. In addition, academic research on quantum effects, spintronics, plasmonics metamaterials or molecular electronics has given rise to the development of other lithography methods, based for example on scanning probe methods which are also able to reach the sub 10 nm regime. This symposium aims at showing the current state of the art of ultra-high resolution lithography. On one hand the state-of-the-art of ultra high resolution electron beam lithography will be discussed. On the other hand other methods will be presented which are less common, but which are able to achieve the same resolution and precision as electron beam methods. These methods include scanning probe methods, selforganization on prepatterned surfaces and direct patterning by ion beams. The symposium should demonstrate that substantial progress in recent years, not only with regards to size resolution, but also in the portfolio of reliable structuring methods has been achieved. Limitations, such as high costs, resolution, and poor compatibility with materials other than silicon (e. g. soft matter, ceramics) have been addressed. Interesting is as well the coupling of advanced structuring techniques with new concepts of in-situ analysis. The symposium aims at a broad interdisciplinary field with major contributions as well from basic research as well from industry application.

Overview of Invited Talks and Sessions

(Lecture room HSZ 02)

Invited Talks

SYNS 1.1	Wed	15:00–15:30	HSZ 02	**The Limits to Lithography: How Electron-Beams Interact with Materials at the Smallest Length Scales** — •Karl K. Berggren
SYNS 1.2	Wed	15:30–16:00	HSZ 02	**High precision fabrication for light management at nanoscale** — •Saulius Juodkazis, Armandas Balcytis
SYNS 1.3	Wed	16:00–16:30	HSZ 02	**Directed self-assembly of performance materials** — •Paul Nealey
SYNS 1.4	Wed	16:45–17:15	HSZ 02	**Nanometer accurate topography patterning using thermal Scanning Probe Lithography** — •Armin W. Knoll
SYNS 1.5	Wed	17:15–17:45	HSZ 02	**High resolution 3D nanoimprint lithography** — •Hartmut Hillmer

Sessions

SYNS 1.1–1.5	Wed	15:00–17:45	HSZ 02	**Symposium Nanostructuring Beyond Conventional Lithography (MI with DS, DF, HL, MM and VA)**

SYNS 1: Symposium Nanostructuring Beyond Conventional Lithography (MI with DS, DF, HL, MM and VA)

Time: Wednesday 15:00–17:45 Location: HSZ 02

Invited Talk SYNS 1.1 Wed 15:00 HSZ 02
The Limits to Lithography: How Electron-Beams Interact with Materials at the Smallest Length Scales — •Karl K. Berggren — Massachusetts Institute of Technology (MIT), 77 Massachusetts Ave., Cambridge, MA, USA

Electron-beam lithography is a ubiquitous tool required by the modern industry and research enterprise. The semiconductor industry relies on it for mask making, while researchers use it for prototyping advanced device concepts and structuring materials to achieve desired form and function. However, surprisingly the impact of the underlying physics of the interaction of electrons with radiolytic materials such as photoresist has been somewhat neglected in describing the limits of lithography. It has been known for some time that, lithographic systems suffer from spatial blurring due to the creation of secondary electrons and the propagation of these secondary electrons in space. What was not as well understood was the role of electro-galvanic effects–plasmons–in the limiting the performance of sub-10-nanometer lithography.

In this talk, I will describe efforts to improve the resolution and performance of sub-10-nm lithographic systems based on enhancement of resist processing. I will then point out the role plasmons (primarily in the bulk) play in limiting the resolution of lithography at the sub-10-nm scale. Finally, I will present some key applications of lithographic patterning at this length scale, and discuss the future implications of the work to related fields such as optical lithography, microscopy, and electromagnetic radiation generation.

Invited Talk SYNS 1.2 Wed 15:30 HSZ 02
High precision fabrication for light management at nanoscale — •Saulius Juodkazis[1,2] and Armandas Balcytis[1] — [1]Swinburne University of Technology, Melbourne, Australia — [2]Melbourne Center for Nanofabrication, Melbourne, Australia

For control of light-matter interactions occurring on molecular level we need to develop tools with nanoscale precision via nano-fabrication. Recent advances in high precision nanofabrication using 3D approaches and combining standard cleanroom tools with laser direct writing capabilities will be presented. Combination of electron beam lithography (EBL) with post-processing of nanoparticles with Ga-ion milling opens a possibility of sub-20 nm direct write of nano-inscriptions on nanoparticles. Arrays of identical chiral nanoparticles were fabricated with high fidelity and with uniform nano-features. Controlled resizing of ion-milled nanopores over the range of sizes from 100 nm to several nanometers in nano-membranes is achieved using electron beam scanning. Surface charging which is a common problem in applications of ion milling and electron imaging is resolved with co-illumination of deep UV light whose photons have energy larger than the electron work function for a given material. EBL and IBL can be both optimized for a high throughput for simple sample geometries. 3D laser fabrication of micro-optical elements and nano-textured surfaces adds new applications in lab-on-chip and sensing.

Invited Talk SYNS 1.3 Wed 16:00 HSZ 02
Directed self-assembly of performance materials — •Paul Nealey — University of Chicago and Argonne National Laboratory, Chicago, IL USA

Directed self-assembly (DSA) is arguably the most promising strategy for high-volume cost-effective manufacturing at the nanoscale. Over the past decades, manufacturing techniques have been developed with such remarkable efficiency that it is now possible to engineer complex systems of heterogeneous materials at the scale of a few tens of nanometers. Further evolution of these techniques, however, is faced with difficult challenges in terms of feasibility of implementation at the scale of 10 nm and below, and prohibitively high capital equipment costs. Materials that self-assemble, on the other hand, spontaneously form nanostructures down to length scales at the molecular scale, but the micrometer areas or volumes over which the materials self-assemble with adequate perfection in structure is incommensurate with the macroscopic dimensions of devices and systems of devices of industrial relevance. Directed self-assembly (DSA) refers to the integration of self-assembling materials with traditional manufacturing processes to enhance and augment capabilities. Here I will discuss the use of lithographically-defined chemically patterned surfaces to direct the assembly of block copolymer films for semiconductor manufacturing and ion-conducting membranes, liquid crystal based systems for optoelectronics, and nanoparticles for applications in nanophotonics.

15 min. break

Invited Talk SYNS 1.4 Wed 16:45 HSZ 02
Nanometer accurate topography patterning using thermal Scanning Probe Lithography — •Armin W. Knoll — IBM Research - Zurich, Switzerland

In thermal Scanning Probe Lithography (t-SPL) [1-5] a heated tip with an apex radius of less than 5 nanometers is used to locally evaporate organic resists and thereby create well defined patterns. Key features of t-SPL are linear patterning speeds of up to 20 mm/s [3] and a resolution of $<$ 10 nm half pitch in resist and $<$ 15 nm after pattern transfer to the substrate [4]. High precision device fabrication is possible due to overlay accuracies of $<$ 5 nm [5]. In addition, 3D topography patterning with ~1 nm (1 sigma) depth accuracy was demonstrated [2].

Examples of unique devices fabricated by t-SPL will be discussed, such as Gaussian shaped mesas in optical micro-cavities for light confinement and Brownian motors for transport and separation of nanoparticles in fluids.

References:
[1] D. Pires et al. Science, 328, 732-735 (2010).
[2] R. Garcia et al. Nature Nanotechnology 9, 577-587 (2014).
[3] P. Paul et al. Nanotechnology, 22, 275306 (2011).
[4] H. Wolf et al. J. Vac. Sci. Technol. B, 33, 02B102 (2015).
[5] C. Rawlings et al. ACS Nano, 9, 6188-6195 (2015).

Invited Talk SYNS 1.5 Wed 17:15 HSZ 02
High resolution 3D nanoimprint lithography — •Hartmut Hillmer — Institute of Nanostructure Technologies and Analytics (INA), University of Kassel, Germany

2D nanoimprint technologies have been widely investigated and are well established today, although huge research and development tasks have to be tackled in future since many scientific problems are not yet fully solved. In contrary, studies dealing with 3D nanoimprint technologies are still rare. This talk presents imprints of 3D structures:

1) 3D structures on substrates with very high spatial resolution in the vertical direction on substrates. Mesa arrays of laterally arbitrary shape with nominally perpendicular side walls towards the vertical direction have been fabricated by Substrate Conformal Imprint Lithography (SCIL). The height differences between the mesas are in the range of 2-3 nm and is some cases in the sub-nm range. These structures are embedded between Distributed Bragg Reflectors (DBRs) and define the cavities. These arrays of Fabry-Pérot Filters are applied as spectrometers. Since the entire different cavity heights are implemented by a single nanoimprint step, we label the device a nanospectrometer. The 3D templates have been fabricated using digital lithography. Applications of the imprinted nanospectrometer are demonstrated in food monitoring.

2) Released full 3D micro and 3D nano particles with arbitrary shape have been fabricated using our Self-Aligned NanoShaping (SANS) technology. The technological process involves a dual mold "waffle iron" principle. The novel SANS nanoimprint technology allows arbitrarily shaped 3D nanoparticles with precise size and shape control. Applications are intended in the field of pulmonal drug application in future.

References:
S. Schudy, M. Smolarczyk, H. Hillmer, N. Worpattrakul, F. Pilger, Patent application DE 10 2011 054 789.4
A. Albrecht, X. Wang, H.H. Mai, T. Schotzko, I. Memon, M. Bartels, M. Hornung and H. Hillmer, Nonlinear Optics and Quantum Optics 43, 339-353 (2012).