Field-Emission Scanning Probe Lithography, Low Energy EBID and Correlative Microscopy with AFMinSEM

Ivo W. Rangelow[1], Mathias Holz[1,2], Claudia Lenk[1], Marcus Kaestner[1], Martin Hofmann[1], Ahmad Ahmad[1,2], Tzvetan Ivanov[1], Steve Lenk[1], Christoph Reuter[2], Alexander Reum[1,2] Elshad Guliyev[1]

[1]Technische Universität Ilmenau, MNES, IMNE, Gustav-Kirchhoff-Straße1, 98693 Ilmenau, Deutschland
[2]Nanoanalytik GmbH, Ehrenbergstr. 1, 98693 Ilmenau, Deutschland

ivo.rangelow@tu-ilmenau.de

Nanofabrication techniques have revolutionized the electronic manufacturing and information technology as they offer the possibility for reproducible mass-fabrication of devices with complex geometries and functionalities. Tip-based nanolithography or so called scanning probe lithography (SPL) is a rapidly growing alternative to many cost-intensive lithography techniques. In this talk, we present results using our AFMinSEM tool for nanofabrication.
Our AFMinSEM consists of a specially designed atomic force microscopy (AFM) module which was integrated into a conventional dual beam system combining a scanning electron microscopy (SEM) and a focussed ion beam (FIB). The newest generation of this module enables AFM as well as field-emission scanning probe lithography (FE-SPL) in vacuum but also in ambient conditions.
In FE-SPL, a probe is in close proximity to a surface and used as an electronic field emitter to expose a thin resist film. Besides high-resolution capability, overlay alignment accuracy, and reliability the combination of FE-SPL with other lithographic methods (*mix-and-match*) opens new horizons for cost-effective nano-manufacturing [2]. Positive tone as well as negative tone writing can be obtained for calixarene resist with FE-SPL at ambient conditions [1]. In contrast to these results, we found out that in vacuum only negative tone is possible.
Another viable way to meet the demand for high resolution nanofabrication is through electron beam induced deposition (EBID), which allows deposition of structures in the nanometer scale. The theoretically possible nanometer scale has been demonstrated already experimentally [3]. A new opportunity to improve the resolution and reproducibility is to use low-energetic electrons (< 50 eV) in the EBID process. We will present a first study of EBID using these low-energy electrons, which has been carried out using the AFMinSEM tool.
Besides nanofabrication characterization at the nanoscale is as important as the fabrication. The AFMinSEM based on small active cantilevers can take the quintessence information of a sample without going to different analytic instruments. Correlative microscopy gives global solution and all-in-one workflows. AFMinSEM combines electron, ion and X-Ray microscopes without any modification of the main instrument offering high speed correlative analysis at sub-nm resolution. The AFM with 0.1 nm resolution in z-direction enables the direct correlation for 3D-imaging with the other sample analysis methods.

[1] M. Kaestner, M. Hofer and I.W. Rangelow, Advanced Lithography, Proc. SPIE - Int. Soc. Opt. Eng. 2013, Vol. 8680, 868019-1

[2] I.W. Rangelow, et al. JVST (B) 35, 06G101 (2017)

[3] Z. A.K. Durrani, M. E. Jones, C. Wang, M. Scotuzzi, C. W. Hagen, Nanotechnology (2017)

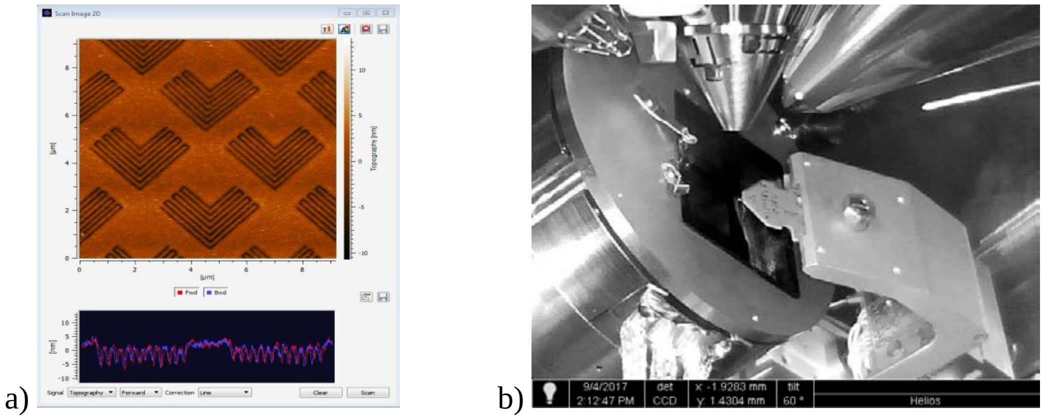

Fig. 1. (a) Features in 15 nm calixarene resist generated with FE-SPL; (b) AFMinSEM set-up combining various patterning and analysing methods in the smallest space.

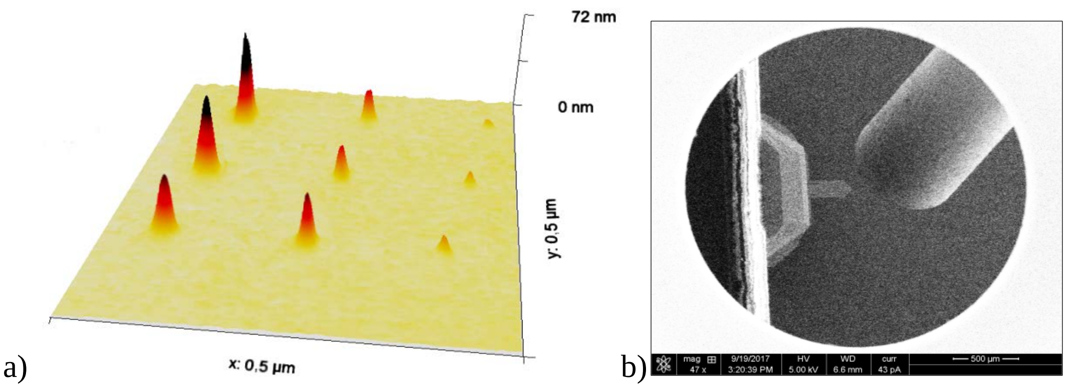

Fig. 2. (a) Generation of sub-10 nm platinum features using field-emitted low-energy electrons (< 50 eV) in the EBID process; (b) View of the AFM set-up and gas-injector of trimethyl (methylcyclopentadienyl) platinum.

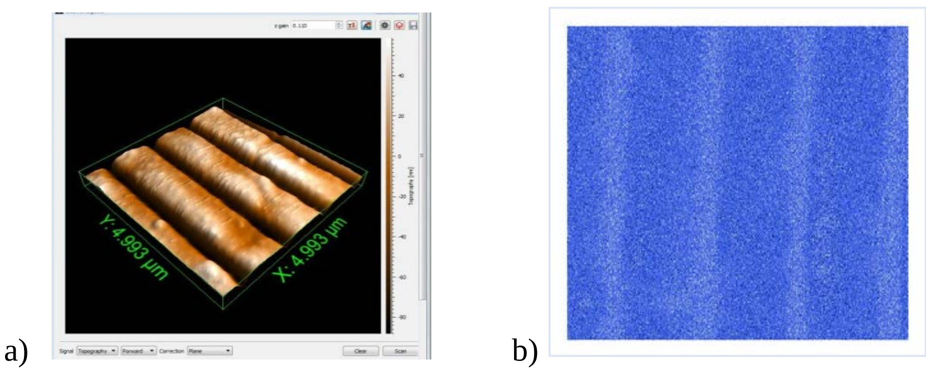

Fig. 3. Correlative microscopy with AFMinSEM. a) 3D-AFM image of not-fully developed polymer structures on Si, b) EDAX image giving information on the chemical composition of the sample, in that case the oxygen KLL elemental map.