Experimental study of Field Emission from sharp Silicon, Diamond and Tungsten tips used for Field Emission Scanning Probe Lithography

[1]C. Lenk, [1]S. Lenk, [2]M. Holz, [1]E. Guliyev, [1]M. Hofmann, [1]T. Ivanov, and [1]I. W. Rangelow
[1]TU Ilmenau, Gustav-Kirchhoff-Straße 1, 98693 Ilmenau,
[2]Nanoanalytik GmbH, Ehrenbergstraße 1, 98693 Ilmenau, Germany

claudia.lenk@tu-ilmenau.de

The patterning process in field-emission scanning probe lithography (FE-SPL), a high-resolution and cost-effective method for nanofabrication, is based on the field emission of electrons from ultra-sharp tips in close proximity to a sample (distances below 100 nm). Thereby, the emitted electrons expose directly an ultrathin resist film. The field enhancement at the tip apex is crucial for the field emission current, which follows the Fowler-Nordheim theory.
Despite the success of FE-SPL in nanofabrication, systematic experimental studies of the field-emission process for these small tip-to-sample distances and different tip materials are lacking. Furthermore, with a recently developed numerical model [1, 2] it could be shown that current analytical models for the field enhancement at the tip cannot describe its dependence on the ratio of tip-to-sample distance divided by the tip radius for the full range.
To resolve this issue, we performed experimental measurements of the field-emission current for tip-sample proximity distances below 500 nm. For this purpose, we use our developed AFMinSEM system [3], which enables us to monitor the tip-sample distance with a high accuracy using SEM while simultaneously recording the field-emission current.
We will present experimental results of the dependence of the field-emission current on the tip shape, tip material, applied voltage and tip-sample distance. Therefore, the emission characteristics of silicon, diamond and tungsten tips of various tip radii and opening angles will be shown and the field enhancement extracted. The experimental results will be compared to the theoretical model.

The knowledge about the field-emission process for small tip-to-sample distances will help to understand and improve the current FE-SPL. Optimal ranges for tip radius and opening angle can be determined from this study as well as the advantages and disadvantages of the different materials for the field-emission process.

[1] S. Lenk et al, "*2D Simulation of Fowler-Nordheim Electron Emission in Scanning Probe Lithography*", J. Nanomater. Mol. Nanotechnol. **5:6** (2016).
[2] S. Lenk, C. Lenk, I.W. Rangelow, "*Calculation of the enhancement factor for field-emission scanning probe Lithography*", submitted
[3] T. Angelov et al., "*Six-axis AFM in SEM with self-sensing and self-transduced cantilever for high speed analysis and nanolithography"*, JVST B **34**, 06KB01 (2016)

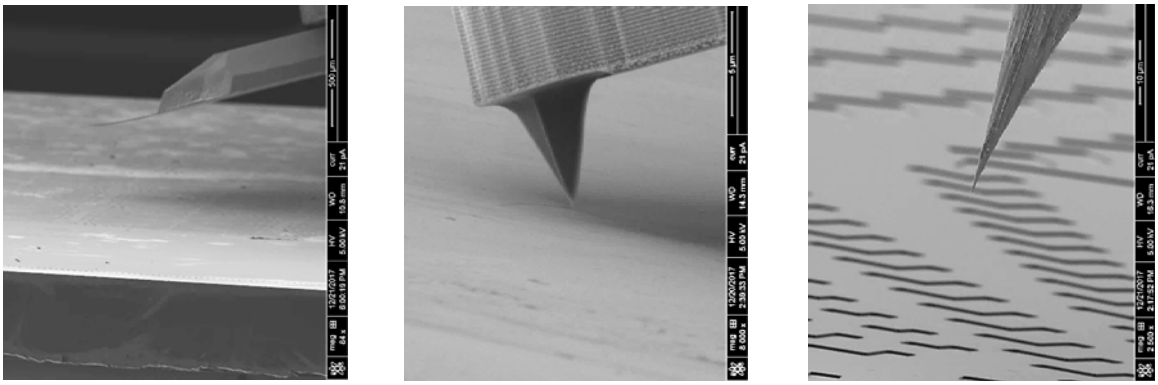

Figure 1: SEM image of active cantilever with silicon tip (left: large view, middle: close-up for tip-sample distance determination) or tungsten tip (right) in front of sample

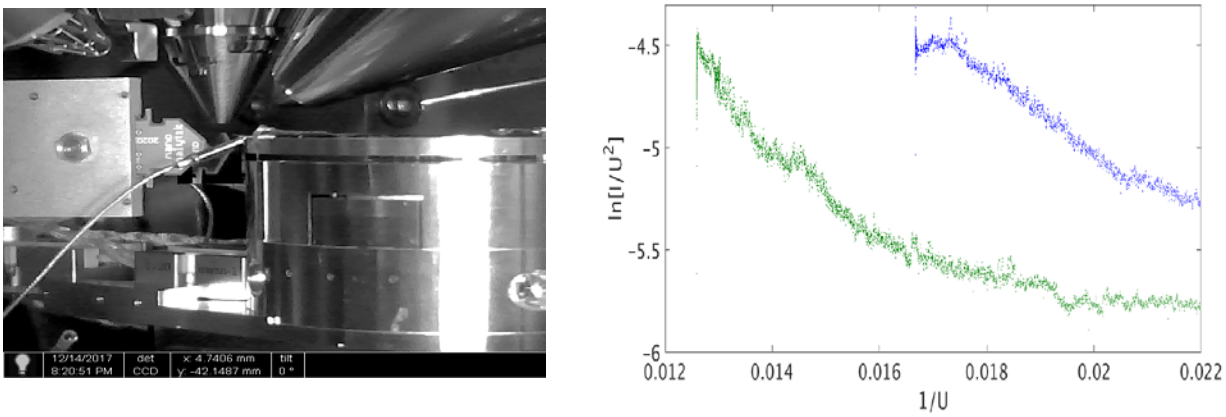

Figure 2: Left Image of AFMinSEM (Nanoanalytik Gmbh) system showing the active cantilever and the SEM column; *Right* Fowler-Nordheim-plots of the field emission from a diamond tip for two different tip-to-sample distances.