Scanning Proximal Probe Lithography (SPPL) with sub-10nm resolution on Calix[4]resorcinarene

M. Kästner and I.W. Rangelow
MNES, Institute of Micro- and Nanoelectronics, Faculty of Electrical Engineering and Information Technology, Ilmenau University of Technology, Gustav-Kirchhoff-Str.1, 98684 Ilmenau, Germany

marcus.kaestner@tu-ilmenau.de

High resolution scanning probe-based methods for surface modification and lithography are an emerging and powerful method to face the critical nanomanufacturing challenges for next generation sub-10nm lithography. Moreover, it's a key technology which can enable ways to reach Single Nanometer Lithography (SNL)[1].

In this study, we have demonstrated a maskless nanoscale lithography method based on patterning of 10 to 50nm thick spin-coated molecular resist material, especially calix[4]resorcinarene, by extreme spatial confined electric-field-induced interactions. The high, nonuniform electric fields created between biased nanoprobe and sample leads to a localized field emission current and in-situ removal of resist material. In marked contrast to electron beam lithography and EUV lithography the calixarene derivative shows a positive-tone self-developing manner with ultra-high resolution.

Within our studies we have used a modified ambient air STM at room temperature to demonstrate a wide patterning range from sub-10nm features with sub-15nm half pitches to micrometer-sized structures and multiple-tip-effect structures. The results offer a significant higher resolution compared to resist exposure with low energy electrons[2] and the sidewalls are practically vertical. The patterning characteristic and obtained feature size depends on the applied bias voltage, bias-polarity, field emission current, tip-form and sharpness, tip velocity, resist thickness and material properties of the calixarene derivative.

The dry nature of the entire patterning process eliminates solvent-related problems such as swelling-induced instability or capillary forces which can cause pattern collapse in the wet development. Furthermore, due to low energy operation proximity effects and substrate damage are avoidable and the contactless method prevents tip wear and increase patterning speed and reproducibility. Moreover this technology offers excellent overlay alignment accuracy. However, the scale-up process by self-actuated piezoresistive cantilever arrays can overcome throughput limitations[3] and organic/inorganic hybrid resist-systems can lead to direct inorganic nanopatterning.

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[1] I. W. Rangelow et al. Proc. SPIE, 7637 (2010)
[2] K. Wilder et al. Appl. Phys. Lett. 73, 2527 (1998)
[3] K. Ivanova et al. J. Vac. Sci. Technol. B 26(6), (2008)

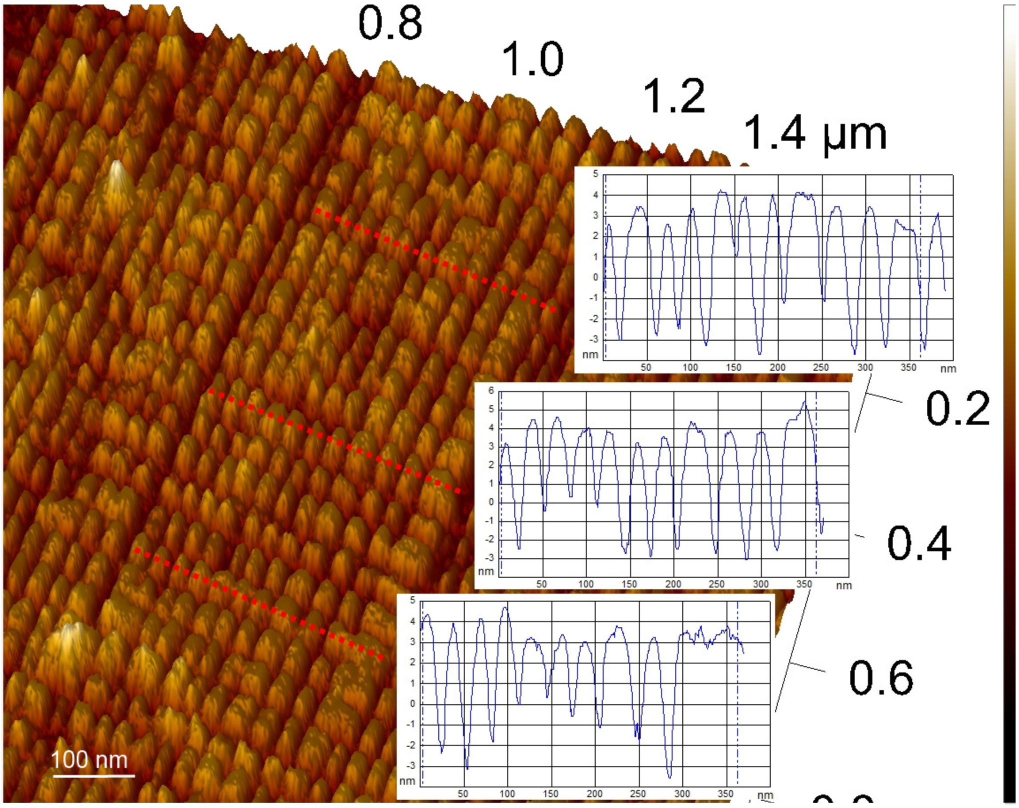
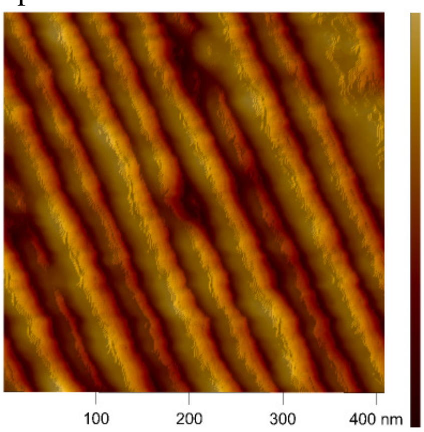


Figure 1: Topographic tapping mode AFM image of a structured 10nm thick calix[4]resorcinarene layer by modified ambient air, room temperature STM at +20V bias voltage, 200pA field emission current and 2µm/s tip velocity. The sub-10nm wide crossed lines at a half-pitch of 15nm are the result of spatial confined material removal by a biased nanoprobe.



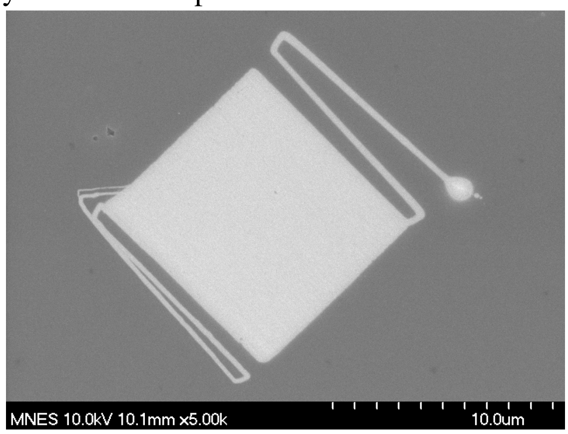


Figure 2(left): Topographic tapping mode AFM image of patterned sub-10nm lines with a half-pitch of 25nm and
Figure 3(right): SEM image of patterned area of 10x10µm, where the whole resist material was entirely removed. Both structures were written at
Fig. 2: +20V, *Fig. 3:* +30V bias voltage, 200pA field emission current and a tip velocity of 1µm/s.