Investigation of Line Edge Roughness in Field-Emission Scanning Probe Lithography

Sertac Guneri Yazgi[a], Tzvetan Ivanov[b], Mathias Holz[c], B. Erdem Alaca[a,d], Ivo W. Rangelow[c]

[a]*Department of Mechanical Engineering, Koc University, Istanbul, 34450, Turkey*
[b]*Dept. of Micro- and Nanoelectronic Systems, TU Ilmenau, Ilmenau, 98693, Germany*
[c]*nano analytik GmbH, 98693, Ilmenau, Germany*
[d]*Koc University Surface Technologies Research Center (KUYTAM), Koc University, Istanbul, 34450, Turkey*

syazgi16@ku.edu.tr

Recently, maintaining the shrinkage trends in the Single Digit Nanometer Regime together with high yield and cost-effectiveness becomes a challenge [1]. At this point, field-emission scanning probe lithography (Fig. 1) with active probes [2] is a candidate technology for fabrication of Single Electron Devices [3] devices, photonic resonators [4] or high precision NIL templates [5]. This versatile nature of the active scanning probes makes them an irreplaceable tool in many nanofabrication, positioning, overlay and characterization applications. Sub 10-nm features are patterned using a field emission, current controlled scanning probe lithography (FE-CC-SPL) on molecular glass resist calixarene [6]. As the feature size of transistors decline from microns to nanometers, line edge roughness (LER) becomes a more and more important parameter because it does not scale with the decreasing feature size. Line edge roughness has a direct effect on critical dimension of the printed features; thereupon, the speed and functionality of the devices. In the literature, Kaestner et. al presented the negative and direct positive tone patterning of calixarene [7]. In this study, for the first time a novel development method is utilized to shift between negative and positive tone patterning in molecular glass resist calixarene. Several lines with same exposure dose (-25nC/cm) and 200nm pitch are patterned using an FE-CC-SPL relying on a self-actuating and self-sensing cantilever technology. Set of images of the lines seen in Fig. 2 to Fig. 3 with different pixel size and length are obtained using the same tip for SPL-exposure and imaging in non-contact AFM mode.

In this work, a total of 50 AFM images before and after development of negative tone exposure are analyzed for LER and other related properties via MetroLER software (Fractilia, LLC) using Fractilia's unbiased roughness measurements. The utilized model in this study enables the detection of edges in a high noise environment without using filters, so that measurement noise can be removed from the LER [8]. A preliminary study conducted on a 1024px latent AFM image with a feature length of 1µm along with 4 features and 8 edges (Fig. 2) indicates 11.91nm unbiased LER and 13.72nm LWR with an 81.77nm mean line CD and 200.78nm mean pitch.

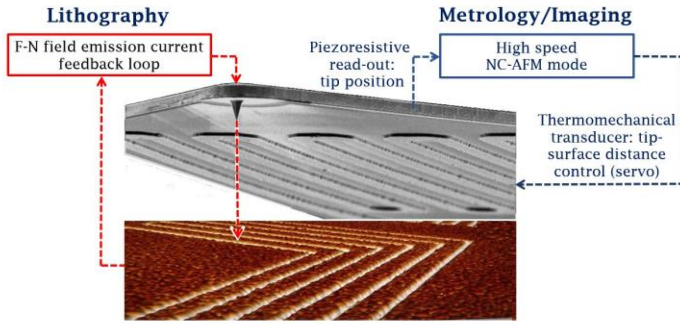

Fig. 1: Principle setup of the SPL system incorporating an electron field-emission current feedback loop for SPL and a force feedback loop for AFM imaging. Fast switching between either mode (imaging and lithography) is employed. Thus, the same nanoprobe is used for both direct writing of nanofeatures and AFM-imaging for pre and post-inspection, as well as for pattern overlay alignment.

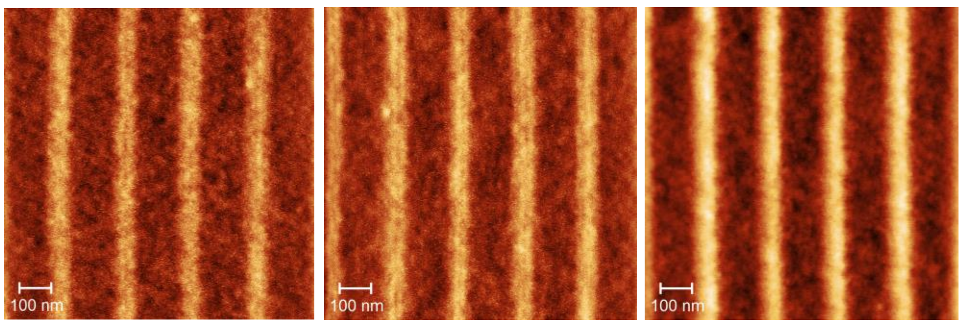

Fig. 2: 1x1µm 1024x1024px latent AFM images of the features (negative-exposure dose).

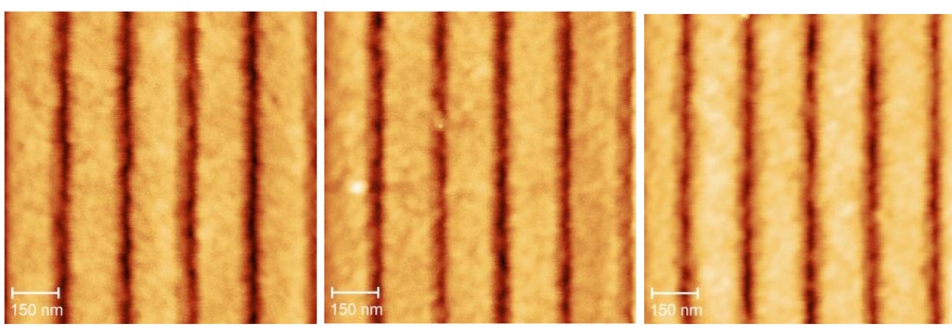

Fig. 3: 1x1µm 1024x1024px AFM images of the features after 5 secs. positive tone development.

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