In-situ characterization of exposed e-beam resist using novel AFM technique

Pushing the size of e-beam lithography pattern to the nanometer range opens up new challenges for lithography apparatus and procedures. In order to achieve highest resolutions, a better understanding and control of the processes taking place on the nanometer scale in e-beam resists is crucial. In this application note, the impact of e-beam exposure on PMMA (poly-methyl methacrylate) is characterized by an in-situ application of atto**cube**'s attoAFM III in a Raith eLINE electron beam lithography system (EBL).

Fig. 1 shows the tuning-fork based attoAFM III in the configuration as used for these experiments. The setup is designed to fit into all standard SEM/EBL systems available and allows an operation in conditions ranging from ambient pressure to ultra-high vacuum ($1x10^{-9}$ mbar). A small tilt angle of the AFM tip with respect to the e-beam allows imaging every location on the surface with both AFM and SEM microsopes simultaneously.

In the experiment described, 60 nm thick PMMA A2 resist was spun onto a silicon substrate. Line-and-spaces pattern were subsequently exposed at different electron doses while keeping the acceleration voltage constant at 20 keV. Fig. 2a) and 2b) show AFM phase and topography images of the resist as exposed to a 1 µm/2 µm line-and-spaces pattern at a dose of 190 µC/cm², indicating the shrinkage in resist thickness at exposed locations. In this specific example, exposed areas show a shrinkage of 0.45 nm compared to unexposed locations on the same resist. To demonstrate the vertical resolution/noise limit of the AFM apparatus, we have subtracted two neighboring topographic line cuts yielding a vertical noise figure of only 40 pm, see Fig. 2c). In a separate set of experiments, the dependance of exposure dose on resist shrinkage was investigated. As can be seen in Fig. 3, an increase in exposure dose yields an increase in resist shrinkage, with a roughly linear depenance between both figures (not shown).

In this application note, we have demonstrated a novel technique which allows the in-situ characterization of exposure processes of e-beam lithography processes, allowing a step-wise proximity correction and a reexposure of underexposed spots. Instead of the traditional approach of imaging the post-processed resist in a scanning electron microscope (SEM) as shown in Fig. 1a), we have used an in-situ AFM to deliver more physically valuable information, such as polymer grain size and distribution.

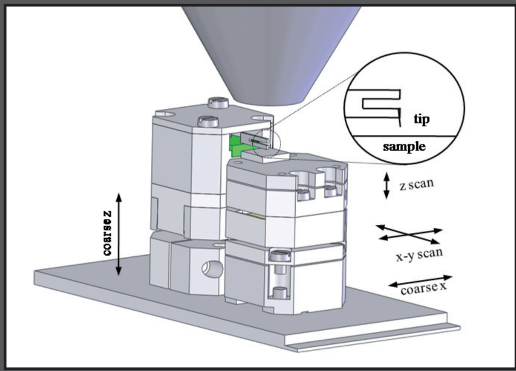

Fig. 1: Schematic drawing of the tuning fork-based attoAFM III as used inside a Raith eLINE EBL system. The system allows the in-situ characterization of the the quality of exposed ebeam resist without the need of a development process.

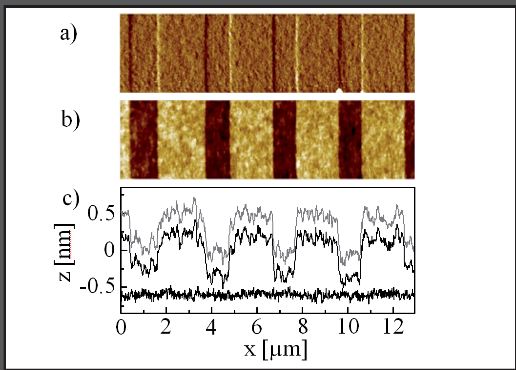

Fig. 2: Phase and topography image of an undeveloped resist measured in-situ by AFM. The topographic profiles of 2 neighboring lines cuts are shows in c). The two line cuts are shifted vertically for better visualization. The bottom graph shows the subtraction of the (non-shifted) line cuts, demonstrating a vertical noise of order 40pm rms.

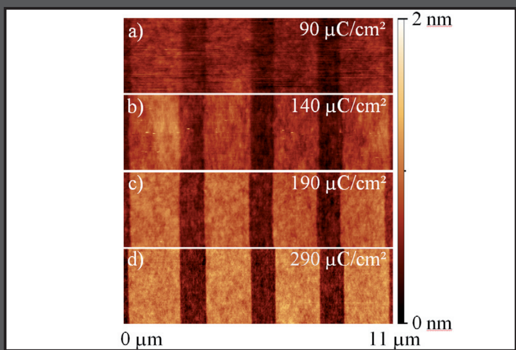

Fig. 3: Topographic images of undeveloped resist, exposed to doses ranging from 90 µC/cm² up to 290 µC/cm². The dark areas are corresponding to exposed regions, where shrinkage of the PMMA has taken place.

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atto**cube** systems AG, Königinstrasse 11 A (Rgb), D-80539 München, Germany, www.attocube.com, Tel. +49 (0)89 2877 809-0, Fax. +49 (0)89 2877 809-19.