Greyscale E-Beam Lithography Revisited: Dynamic Range and Roughness of Patterns on Silicon

Ivan I. Kravchenko and Nickolay V. Lavrik
Center for Nanophase Materials Sciences, Oak Ridge National Laboratory
Oak Ridge, TN, USA lavriknv@ornl.gov

Abhijeet Gujrati and Tevis D. B. Jacobs
Mechanical Engineering & Materials Science, University of Pittsburgh
Pittsburgh, PA, USA tjacobs@pitt.edu

Dose-modulated e-beam lithographic (EBL) patterning, commonly referred to as greyscale EBL, is uniquely suitable for creating surface topographies of high complexity with nanoscale precision. Continued refinements in greyscale EBL are of great interest due to many emerging applications [1] and basic science research that benefit from 3D nanopatterning.

This study focuses on critical remaining challenges in greyscale EBL: out-of-plane accuracy; dynamic range; and surface roughness of patterned topologies. This effort focused on grayscale patterns in silicon, created using a combination of EBL and dry etching, and is driven by our interest in asymmetric nanotextures with a topological bias [2] as well as random patterns that can mimic surfaces of typical engineered and naturally occurring materials. Our main goal is to identify processing protocols that result in 3D topologies with the highest fidelity. Our analysis of artifacts and additional surface roughness introduced by each of the processing steps involved in greyscale EBL is presented.

8-bit greyscale images were generated and converted into the format compatible with a Jeol 9300FS EBL tool. Our test images included harmonically modulated and staircase greyscales as well as pseudo-random patterns. The bitmaps were up to 9 megapixels with one pixel corresponding to a 50 nm x 50 nm area on the substrate. The resulting surface topologies were characterized using optical interferometric profilometry and scanning probe microscopy (SPM) on the micro- and nano- scales, respectively. The profilometry and SPM data were analyzed both in real space and spatial frequency domain. With a PMMA 495 A4 resist spun at 2000 rpm, the optimal based doze was 350 μCcm^{-2} with the dose modulation of -50%. Peak-to-peak roughness as small as 2.5 nm was achieved on 12 μm x 12 μm flat field areas when 3D patterns in the e-beam resist were transferred on silicon using a mixed SF_6 : Ar plasma etching. The characterization of the final pattern enabled the assessment of out-of-plane accuracy, dynamic range and surface roughness and demonstrated their dependence on input patterns and parameters.

1. Schleunitz, A., *et al.* Novel 3D micro- and nanofabrication method using thermally activated selective topography equilibration (TASTE) of polymers. *Nano Convergence* (2014) 1,7.
2. Agapov *at al.* Asymmetric Wettability of Nanostructures Directs Leidenfrost Droplets. *ACS Nano* 2014, 8, 1, 860-867.