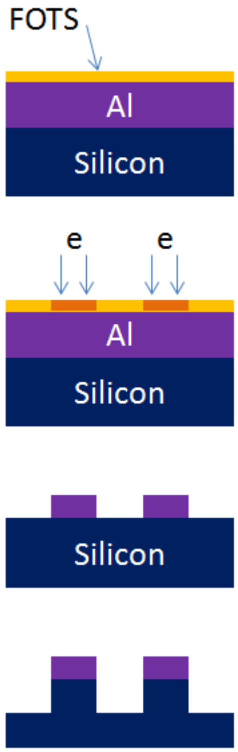
Benchtop fabrication method on non-planar surface using SAM as e-beam resist

Alanoud Alshammari, Celal Con, Mustafa Yavuz and Bo Cui
Waterloo Institute for Nanotechnology (WIN), University of Waterloo
200 University Ave. West, Waterloo, ON, N2L 3G1,
bcui@uwaterloo.ca

Conventional electron beam lithography (EBL) using spin-coated resist is a planar process. In contrast, dry evaporated resist, such as polystyrene [1-2], ice [3] and sterol-based resist [4], can be coated on virtually any surface to be patterned. Similar to vacuum evaporation, self assembled monolayer (SAM) can also be coated onto irregular surface, provided that the substrate material is compatible with the self-assembling process. Previously SAM has been reported as resist with a high resolution of ~10 nm. However, since the SAM is extremely thin, pattern transfer to the substrate or sub-layer is challenging. Moreover, all previous studies used either aliphatic or aromatic SAM. Here we show that perfluoro SAM, 1H,1H,2H,2H-Perfluorooctyltrichlorosilane (FOTS), can also be used as an electron beam resist. FOTS is best known for its application as anti-adhesion layer for nanoimprint mold. In addition, we coated FOTS on Al that can be deposited on any surface. After EBL and pattern transfer to Al by wet etching, the current pattern transfer process may be used to pattern many substrate/sub-layer materials by anisotropic dry etching since Al is a good etch mask. More importantly, since both Al deposition and SAM coating can be applied to arbitrary surface, our process is capable of patterning on irregular surfaces such as the end of an optical fiber or AFM cantilever.

As a proof of concept for this pattern transfer process, 10 nm Al was coated on bare silicon wafer (see Figure 1 for the process steps). Then the Al surface was cleaned by a short exposure to oxygen plasma, followed by FOTS silane treatment in a vacuum container for >10 hours. EBL was carried out at 5 keV using Raith 150^{TWO} system. Unlike previous studies with aliphatic SAM and UV-Ozone development, no development was conducted. Instead, after exposure, the sample was directly dipped into PAN solution to etch the Al underneath at room temperature. Finally, the pattern was transferred to the silicon substrate using SF6/C4F8 ICP-RIE that etches silicon ~100× faster than Al. Figure 1 shows the SEM image of an array of squares each 5 μm × 5 μm, with exposure dose increasing exponentially from lower left to upper right. Here the FOTS behaved as a negative resist, and the dose needed to well define the square was about 2550 $\mu C/cm^2$. At lower dose and shorter PAN etching (thus Al not completed etched at the unexposed area), FOTS was also found to behave as a positive resist (not shown). Figure 2 shows pillar array etched into silicon using this process. Nanofabrication on non-planar surface is currently under study and will be presented.

[1] J. Zhang , C. Con and B. Cui, ACS Nano, revised manuscript submitted.
[2] C. Con, J. Zhang and B. Cui, Nanotechnology, revised manuscript submitted.
[3] A. Han, A. Kuan, J. Golovchenko and D. Branton, Nano Letts. 12 (2012), 1018.
[4] P. S. Kelkar, et. al, J. Vac. Sci. Technol. A, 22 (2004), 743.



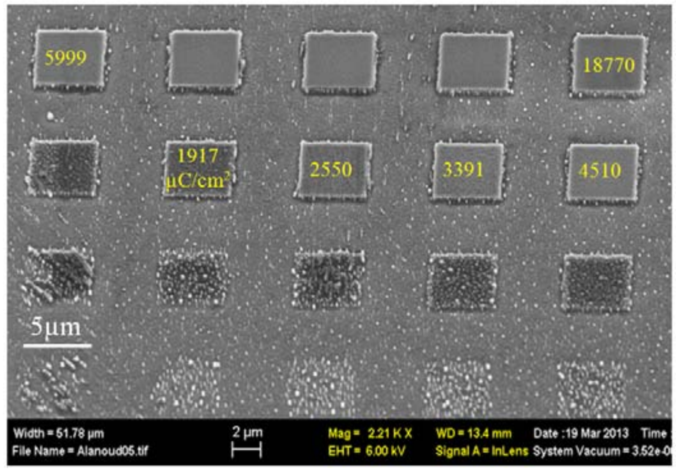


Figure 1 (left) Schematic process for the fabrication of silicon structures using FOTS SAM as (here negative) resist and Al as pattern transfer layer. (right) SEM image of an array of silicon square patterns exposed at exponentially increasing doses from lower left to upper right. The exposure dose is indicated on some squares. Roughly 2550 $\mu C/cm^2$ is needed to well define the structure. Wafer tilted 45 degree during SEM imaging.

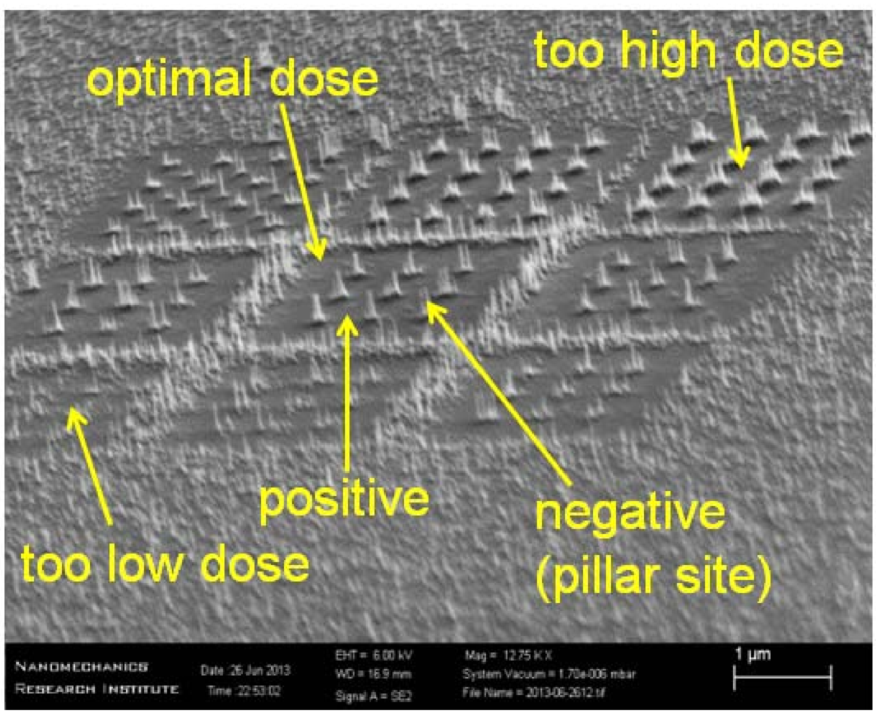


Figure 2. Array of silicon pillars with ~100 nm diameter and 400 nm height. The dose increases exponentially from the lower left region to the upper right one, with the region in the center having the optimal dose. The directly exposed area (pillar site) showed a negative tone, whereas the area in-between the pillars were exposed by proximity effect with low dose, thus positive tone. The pillars could be better defined by improving the coverage of the FOTS SAM.