# Helium ion beam lithography of thick HSQ resists

Paul F.A. Alkemade, Anja K. van Langen-Suurling, Emile van der Drift
*Kavli Institute of Nanoscience, Delft University of Technology*
*Delft, the Netherlands*
*p.f.a.alkemade@tudelft.nl*

Emile van Veldhoven, Diederik J. Maas
*TNO*
*Delft, the Netherlands*

The effectiveness of lithography depends on the interaction -mainly energy loss- of the impinging beam with resist material. Electron beam lithography (EBL) has been studied for over two decades. Recently, scanning helium ion beam lithography (SHIBL) evolved as a viable alternative to EBL. Because the interaction of ions with matter is very different from that of electrons of the same energy, new investigations are required for process optimization. The energy loss of helium ions in resists materials is not constant over the thickness of the resist, but decreases with depth. Furthermore, as a consequence of small-angle scattering, the width of the (focused) beam increases and, hence, the density of the energy deposition decreases with depth. For these two reasons one expects that thicker resist layers need higher dose than thinner layers.

In this work we study the resist thickness dependence of SHIBL in negative tone hydrogen silsesquioxane (HSQ) resist. The ion beam used is a 30 keV focused $He^+$ beam of an OrionPlus helium ion microscope. The structures made are dots, single and multiple lines, and squares. The resist thickness is varied between 4 and 162 nm. The substrate is silicon.

We found that thicker layers indeed require higher dose. Furthermore, the width of the structures increases with depth, especially in case of overexposure. In Figure 1a, the line width at the top is 19±3 nm and at the feet 48±4 nm. In Figure 1b –with overexposure– the line widths are 24±3 nm and 90±5 nm, respectively. Line detachment is a failure mode when the beam dose is deficient, see Figure 1c. Detachment from the substrate is the consequence of insufficient exposure due to the low density of energy deposition at larger depths. The lines in Figure 1d –made at a pitch of 50 nm– lean over, thus decreasing the pitch to 45 nm.

The observations are compared to results of TRIM simulation of the ion penetration plus calculations of ranges of the secondary electrons.

The consequences of depth-dependent exposure for negative and positive tone ion beam lithography will be discussed.

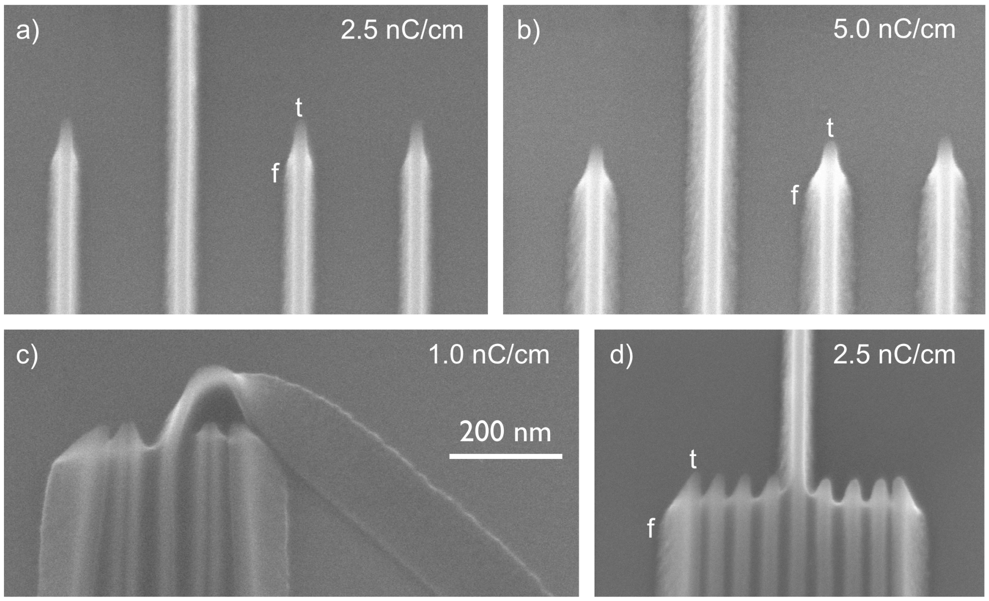


*Figure 1: Lines made in HSQ by scanning helium ion lithography at various doses.* (SEM images at a sample tilt of 30°.) The original HSQ resist layer was 162 nm thick. 'f': foot of the lines; 't': top of the lines.
a) optimal dose for single lines
b) overexposure: the width at the foot of the lines is increased
c) underexposure: the single line is detached from the substrate and curls over
d) optimal dose: the lines lean over toward each other; the pitch at the top is 45 nm, whereas 50 nm at the feet.