Large area scanning-helium-ion-beam lithography

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Scanning-helium-ion-beam lithography (SHIBL) is an emerging fabrication technique[1,2]. Using a beam of helium ions, rather than an electron beam, provides a significant reduction in beam scattering, increased resist sensitivity and possibly increased resolution. Additionally, the small helium-ion-beam divergence leads to a long depth of field, and hence a large focus tolerance in nanofabrication. Here we use SHIBL to pattern large area gratings (up to 100µm x 100µm) of high density and high resolution (< 20 nm) without any proximity corrections. Moreover, we exploit the large depth of field and pattern on tilted surfaces without dynamic focus corrections, demonstrating that SHIBL can be used to pattern surfaces with curves and/or trenches. The patterns were fabricated on silicon wafers using the negative-tone resist hydrogen silsequioxane (HSQ) and high-contrast salty development. The thickness of the HSQ was approximately 30 nm.

Helium ions, relative to electrons, scatter less in materials due to their higher mass. To show the significant reduction in beam scattering, 1 µm x 1 µm squares were exposed in HSQ while leaving four small windows open in the middle of the square (see Figure 1(a)). Figure 1(b) and 1(c) shows SEM images of the developed structures, indicating that long-range scattering is minimal. This is of key importance when fabricating high-density, high-resolution periodic structures without proximity corrections. A 50 µm x 50 µm grating is presented in Figure 2. The lines were defined as rectangles (i.e. not as single pixel lines) with a width of 16 nm. The pitch was 50 nm. The measured width was 17 ± 1 nm, and the pitch was 50 ± 1 nm. Figure 3 shows the four corners of a grating patterned while having the sample tilted at 45 degrees. The depth of field, which in theory can reach several mm, was increased by deliberately defocusing the beam and increasing the working distance. Within the 100 µm x 50 µm field patterned, the width of the single-pixel lines is found to be 26 ± 2 nm. Such a large area pattern would be extremely hard to realize using electron beam lithography without dynamic focus corrections.

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[1] D. Winston et al, *Scanning-helium-ion-beam-lithography with hydrogen silsequioxane resist*, J. Vac. Sci. Technol. B, 27; 2702-2706, 2009
[2] X. Shi et al, *Helium ion beam lithography on fullerene molecular resists for sub-10 nm patterning*, Microelectronic Engineering, 155; 74-78, 2016

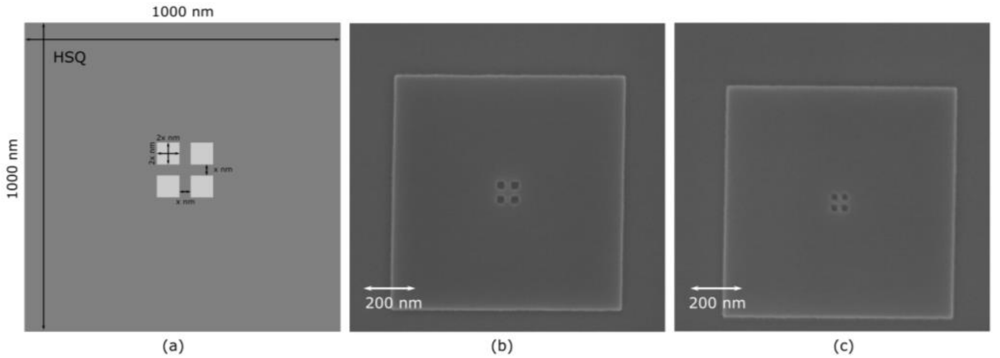

Figure 1: 1 µm x 1 µm patterned area in HSQ with four small unexposed windows in the center. (a) Design; the width of the unexposed windows is defined as 2x, while the edge-to-edge distance is defined as x. (b) and (c) SEM images. (b) 2x was set to 40 nm and measured to be 37 ± 2 nm and x was set to be 20 nm and was found to be 19 ± 2 nm. (c) 2x was set to be 30 nm and was measured to be 26 ±2 nm and x was set to be 15 nm and was found to be 14 ± 2 nm.

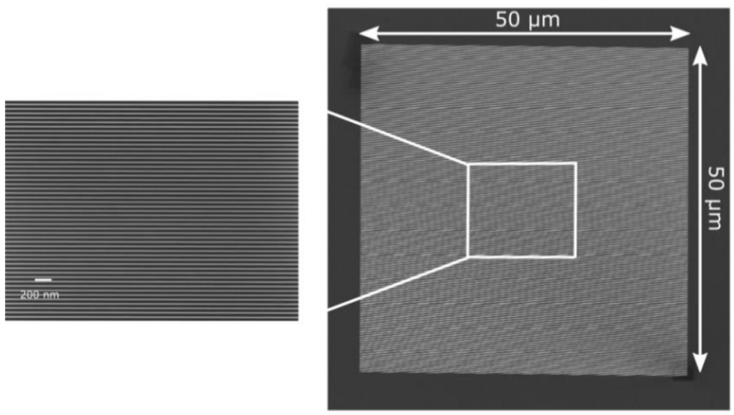

Figure 2: Large area exposure using SHIBL. SEM images of a HSQ grating patterned using SHIBL. The lines were defined as rectangles with a width of 16 nm and a length of 50 µm, and a pitch of 50 nm. The measured width was 17 ± 1 nm, and the pitch was 50 ± 1 nm.

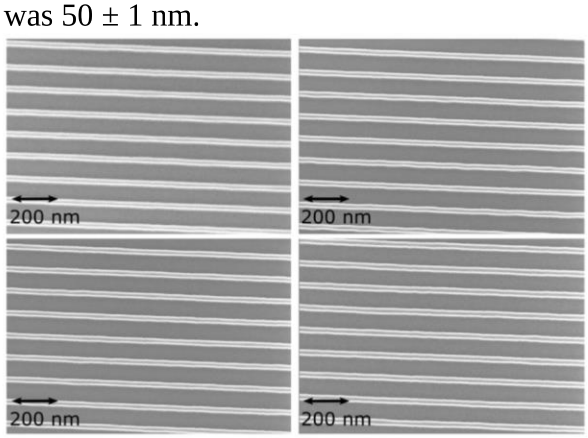

Figure 3: 45^o tilted exposure. SEM images of the four corners in a 50 µm x 100 µm HSQ grating fabricated with a 45^o tilt. The lines were found to be 26 ± 2 nm.