Helium-ion Lithography with Hydrogen Silsesquioxane Resist

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Focused-ion-beam lithography[1] is not as widely practiced as scanning-electron-beam lithography for resist patterning, in part due to resolution constraints and in part due to substrate sputtering. However, helium ions in particular may enable nanostructure fabrication with higher resolution than electrons. The over three orders of magnitude higher mass of helium ions relative to electrons should reduce lateral scattering in the resist, thus conceivably enabling patterning of small features at higher density than is possible with electron-beam lithography. Helium ions achieved ~ 200 nm lithographic resolution as early as twenty years ago[2], but only recently has a scanning-helium-ion-beam column been engineered with a focused spot size on par with electron beam columns[3] --- the specified spot size of this commercial system is below 1 nm. We have used a Zeiss Orion* scanning helium ion microscope to demonstrate lithography of hydrogen silsesquioxane (HSQ) on silicon. HSQ is already used as a high-resolution electron-beam resist[4], and it permits high-resolution inspection after development in a scanning-electron microscope without requiring pattern transfer.

To form patterns consisting of lines and dots, densely-packed and isolated, at a variety of doses, we processed samples in a sequence of steps. First, we spun ~ 30 nm of HSQ on silicon. Next, we switched control of helium-ion-beam steering and blanking from the helium ion microscope's internal electronics to a pattern generation system connected to a computer with CAD software (NPGS, Nabity), using apparatus we built. Finally, samples were developed in a 1% NaOH, 4% NaCl aqueous solution[4] and inspected in a scanning-electron microscope. Dot doses ranged from 0.018 to 15.5 fC, with ~ 0.15 fC (or ~ 1000 ions) being the minimum dot dose to print. Line doses for nested-"L" patterns (see one such pattern in Figure 1a) ranged from 0.01 to 7.2 nC/cm, with ~ 0.075 nC/cm (or ~ 50 ions/nm) being the minimum line dose to print. We note that acceleration voltage, on this instrument equal to the extraction voltage, varied between 26 kV and 30 kV depending on the formation of the sharp-tipped emitter, which required occasional rebuilding. As shown in Figure 1, feature sizes of 10 nm were achieved.

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[1] For a review of past work, see J. Melngailis, *Nucl. Instrum. Meth. B*, **80-1**, 1271-1280 (1993).
[2] K. Horiuchi, T. Itakura and H. Ishikawa, *J. Vac. Sci. & Tech. B*, **6**, 241-244 (1988).
[3] B. W. Ward, J. A. Notte and N. P. Economou, *J. Vac. Sci. & Tech. B*, **24**, 2871-2874 (2006).
[4] J. K. W. Yang and K. K. Berggren, *J. Vac. Sci. & Tech. B*, **25**, 2025-2029 (2007).

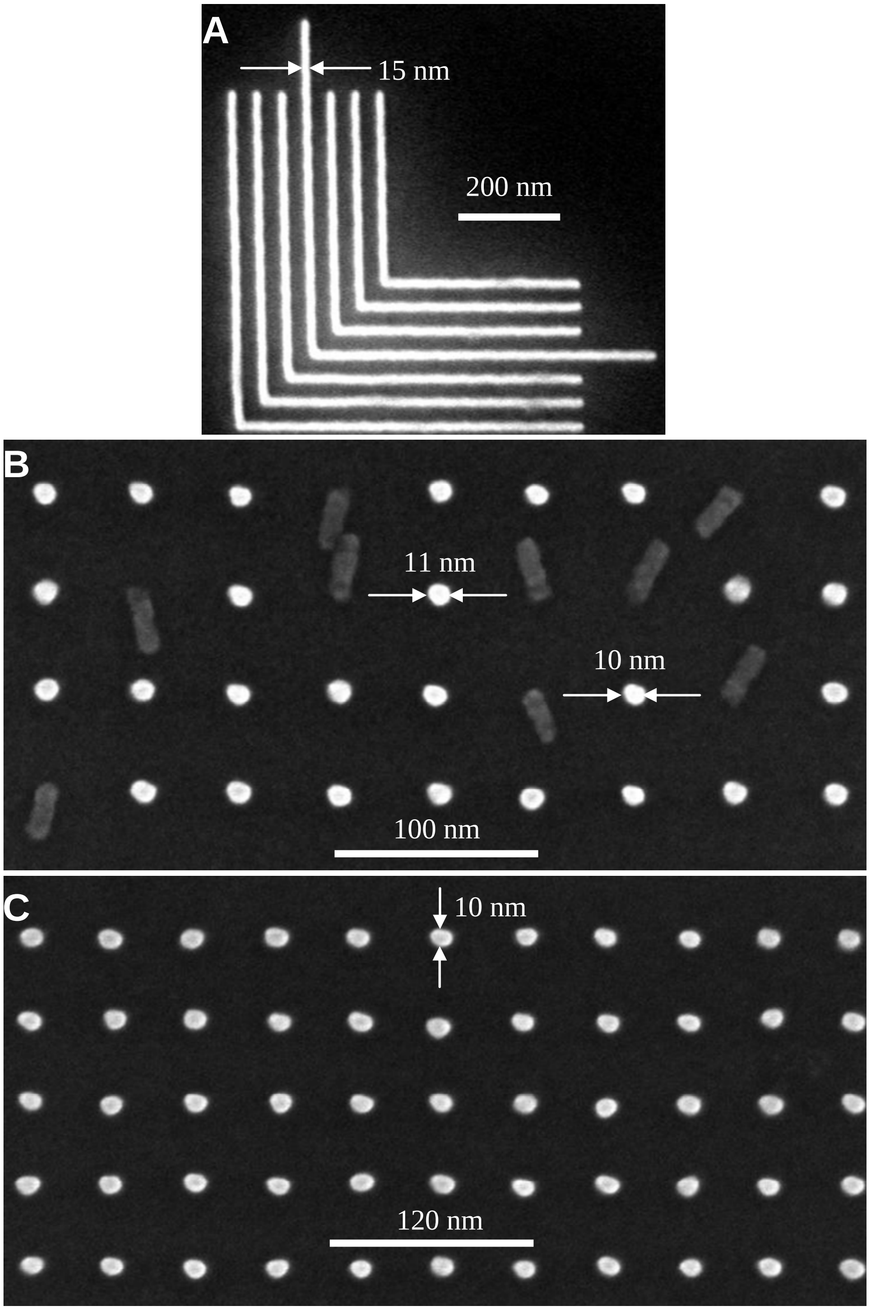

Fig 1: Scanning-electron micrographs of HSQ on silicon, exposed with helium ions; **(a)** a 46-nm-pitch nested “L” pattern; **(b)** a 46-nm-pitch “pillar” array chosen here to show the pillars’ 3:1 aspect ratio and good edge profiles, as some of them have fallen; **(c)** a 46-nm-pitch pillar array of higher dose than in (b), resulting in fewer pillar collapses.

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