Challenges and Possibilities of Aberration-Corrected Electron-Beam Lithography on non-Electron-Transparent Substrates

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Aberration-corrected electron-beam lithography (ACEBL) has achieved single-digit nanometer resolution in popular electron beam resists deposited on electron-transparent membranes.[1-3] ACEBL's implementation on thick, non-electron-transparent substrates is appealing to overcome the fragility of thin membranes during device fabrication processes such as multistep stacking of exfoliated 2D materials or for quantum devices requiring a global backgate. This study presents experimental measurement of point spread function (PSF) of a 200 keV aberration-corrected scanning transmission electron microscope (AC-STEM) by defining both positive and negative patterns in poly (methyl methacrylate) (PMMA) spin-coated on thick SiO_2/Si substrates. The PSF data ranges over four orders of magnitude down to ~ 4-5 nm hole radii and its trend suggests that hole radii smaller than 4 nm could be attained. We present the practical problems encountered in achieving smaller hole diameters and discuss methods to overcome this difficulty. In addition, applying some of these methods, we printed arrays of holes in PMMA with pitches around 26 nm on SiN_x/Si substrates with incrementally increasing Si layer thickness and observed that, even up to a thickness of ~200 μm, the effect of the substrate on the pattern quality is minimal.

[1] V. R. Manfrinato, A. Stein, L. Zhang, C.-Y. Nam, K. G. Yager, E. A. Stach, and C. T. Black, Nano Lett. **17,** 4562 (2017).
[2] F. E. Camino, V.R. Manfrinato, A. Stein, L. Zhang, M. Lu, E. A. Stach, and C. T. Black, J. Vis. Exp. **139,** e58272 (2018).
[3] V. R. Manfrinato, F. E. Camino, A. Stein, L. Zhang, M. Lu, E. A. Stach, and C. T. Black, Adv. Funct. Mater. **29,** 1903429 (2019).

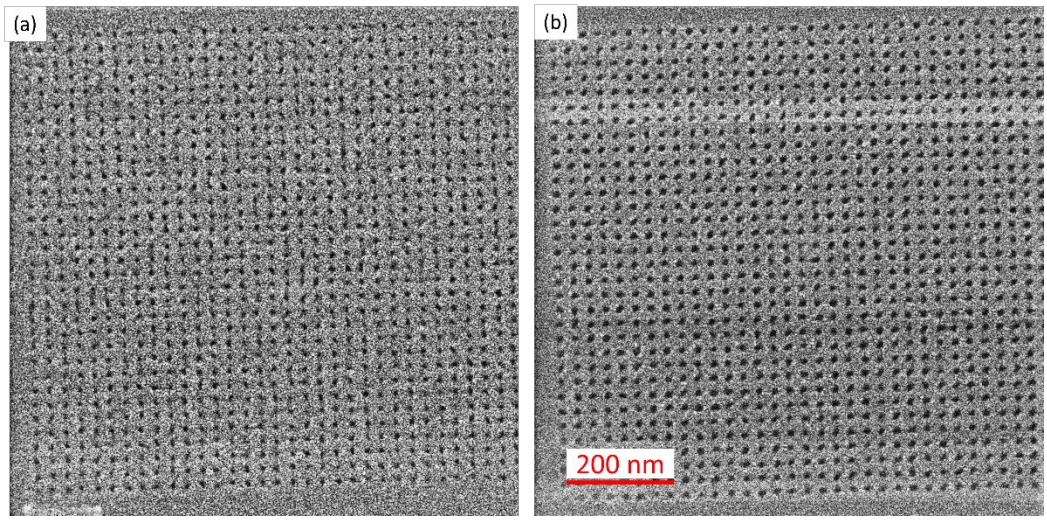

Figure 1: ACEBL-defined array of holes on 30 nm-thick PMMA spin-coated on substrates of different thicknesses: (a) PMMA over 50 nm thick SiN_X membrane. (b) Same as in (a), but with an additional ~200 µm thick Si layer. Both results present the same pitch of 28 nm. The effect of the substrate seems to be responsible for an increase of the average hole radius from 5.5 nm to 6.7 nm. Both images were obtained with the secondary electron detector of the same tool used for lithography. A 3 nm thick Cr coating was deposited over PMMA to reduce charging during imaging. The scale bar is the same for both images.