Fabrication and characterization of 10-nm-diameter nanopore arrays for applications in mask-based metastable atom-beam lithography

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Large-scale pattern generation with resolution on the 1-nm length scale remains an open challenge for the nanofabrication community. While techniques such as EUV lithography come close to meeting this challenge, EUV lithography still has fundamental obstacles to overcome, such as the secondary electron blur problem that can limit the ultimate resolution of the technique.[1] The secondary electron blur problem arises due to the production of energetic photoelectrons when EUV photons are absorbed by the resist. These photoelectrons can migrate laterally in the resist resulting in undesired lithographic exposure some distance from the point of photo absorption. Lithography with metastable helium (He*) atoms may provide an alternate route to avoid this issue by utilizing He* atoms that carry potential energies equivalent to < 25% of EUV photon energies. Consequently, the energy deposited by a He* is a small fraction of that deposited by an EUV photon and crucially, a room temperature He* atom also has a de Broglie wavelength < 0.1 nm affording a diffraction limit suited to nanoscale pattern generation.

Recently, holographic mask-based He* beam lithography has emerged as a route to large-scale pattern generation with nanometer resolution.[2,3,4,5] Holographic mask-based He* lithography involves He* atoms passing through nanoscale holes in dielectric membranes generating near field patterns on a proximal substrate. Here, the interaction between atom and mask material becomes important due to dispersion forces, which can result in significant reduction of effective hole diameter.[6] Therefore, a good understanding of the composition of the mask material (especially at hole edges), hole size distribution, hole placement accuracy and stability of nanoholes is necessary for the intended application. Previous reports related to nanopore devices for molecular sensing have explored stability

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investigations of nanopores in SiN_x/Si and SiN_x/SiO_2/Si membranes.[7] The size of these nanopores were observed to increase after storage in various electrolyte solutions at a rate of up to 3 nm/day.

Here, we report the nanofabrication and electron microscopy characterization of nanohole arrays in 10-nm-thick low-stress SiN_x membranes. Nanohole arrays having hole diameters of 10-20 nm at center-to-center pitches of 40 or 50 nm were prepared by electron-beam lithography using a PMMA resist. Resist patterns were transferred to the SiN_x membrane using CF_4/O_2 reactive ion etching. A scanning electron microscopy (SEM) image acquired at 1 keV for a nanohole array containing holes at 40 nm pitch etched in SiN_x membrane is displayed in figure 1(a). The size distribution of these holes plotted in figure 1(b) shows the measured 1/e diameter values with a mean diameter of 10.49 ± 0.24 nm. SEM images were also processed to determine hole placement error and a placement error of about 0.5 nm was observed in patterns. The atomic distribution of Si, N, O, C and F at the edges of the etched holes was investigated by energy dispersive x-ray (EDX) analysis and electron energy-loss spectroscopy (EELS). The finding outlined in this report could serve as a significant resource for advancing pattern generation using atom beam lithography.

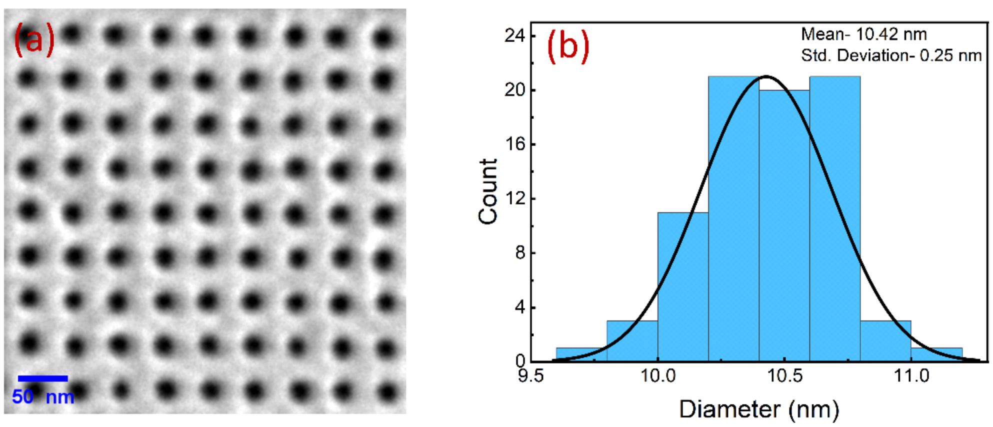

Figure 1: (a) Scanning electron microscope Image of nanopore arrays at 40 nm pitch fabricated in 10 nm thin low stressed SiN membrane. The EBL patterned SiN membrane was etched by CF_4 plasma using reactive Ion etching. (b) The size distribution of nanopores depicts a 1/e mean diameter of 10.49 nm with 0.24 nm standard deviation.

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