Hard Mask Fabrication from Block Copolymer Templates and Atomic Layer Deposition

CNF Fellows Project

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Primary CNF Tools Used: Oxford FlexAL ALD, Zeiss SEM, Oxford Cobra etcher, YES Asher

Abstract:

Block copolymer (BCP) lithography enables facile self-assembly of nanostructures at size scales inaccessible by optical lithography. We demonstrate tone-reversal and hard mask creation from BCP templates by utilizing the conformal nature of atomic layer deposition (ALD) of alumina. The alumina enables creation of hard masks that possess high etch selectivity. We demonstrate the utility of this process by fabricating high-aspect-ratio silicon nanowires with 30 nm lateral dimensions and 180 nm vertical dimensions.

Summary of Research:

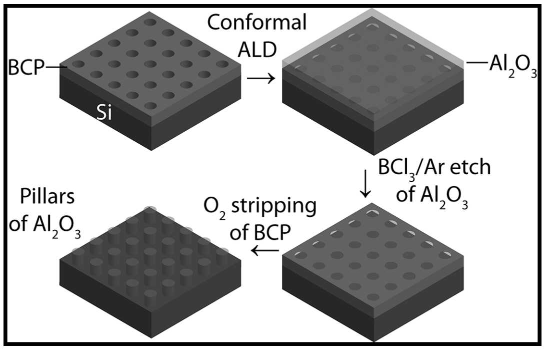

Figure 1: Process flow for hard mask creation from block copolymer templates.

Block copolymer (BCP) resists create nanoscale features through phase segregation of dissimilar polymer blocks. A variety of morphologies including pores, pillars, and lines have been demonstrated through choosing appropriate copolymer blends [1]. A challenge for the community is design of resists that possess high selectivity during etching and thermal processes. One approach is to incorporate silicon-containing compounds into the resist, such as polystyrene-polydimethylsiloxane (PS-PDMS) blends. Our approach, however, is to convert the resist pattern into a hard mask using conformal atomic layer deposition (ALD). This approach enables tone-reversal of substrate patterns and offers a broad palate of materials for the mask creation. The versatility of this approach enables device engineers to choose a hard mask with the desired etch properties.

The process flow for creating of hard masks from BCP templates is outlined in Figure 1. A BCP blend of polystyrene and poly-methylmethacrylate (PS-PMMA) is used as a template. The PS-PMMA ratio chosen produces a morphology of pores in the resist. Low-temperature ALD of alumina conformally coats the features and self-planarizes by over-filling the pores. Directional etching of the over-filled alumina produces a pattern of alumina-filled pores in the BCP template. Finally, the BCP resist is stripped in a downstream oxygen plasma, leaving behind alumina pillars.

The process was characterized through visual inspection in the scanning electron microscope (SEM). Figure 2 (top) shows the formation of the pores in the BCP resist. Typical pore sizes range between 25-30 nm. The total resist thickness is comparable to the pore size. The bottom micrograph in Figure 2 shows the wafer decorated with the remaining alumina pillars.

Optimization of the alumina etching time is essential to avoid eroding the mask. The results presented are 300 cycles of ALD alumina (nominal thickness 30 nm) and an alumina etching time of 1.5 minutes at 25 nm per minute. A slight over-etch guarantees that all of the over-filled alumina has been removed, while still remaining safely within the process window for the alumina pillar.

To demonstrate the utility and etch resistance of the alumina masks, we fabricate arrays of silicon nanowires

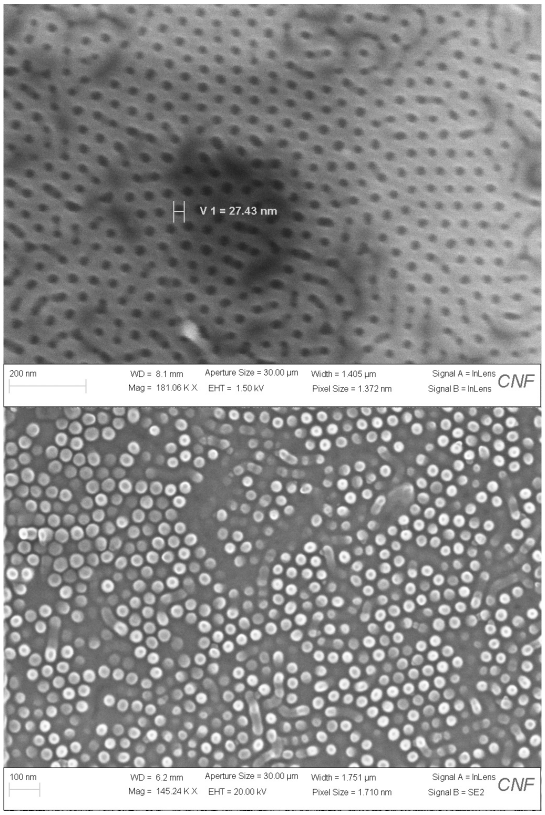

Figure 2: Scanning electron micrographs (SEMs) of the BCP tone reversal process.

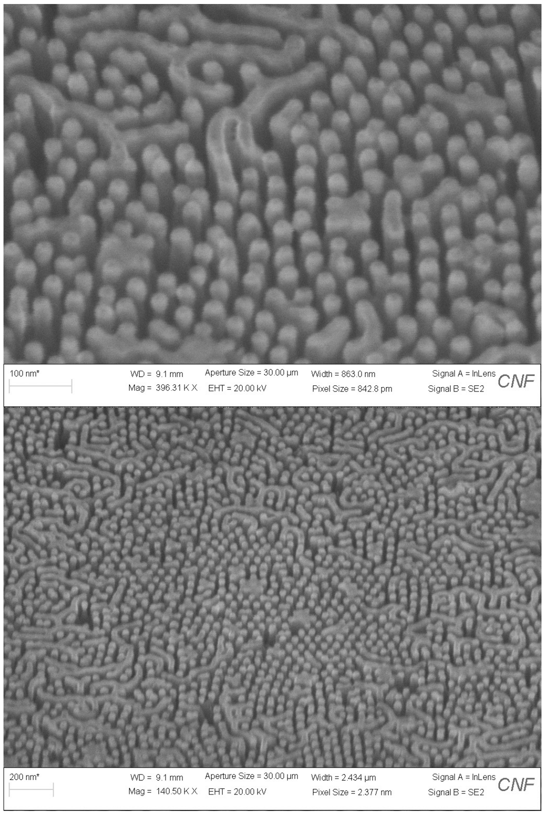

Figure 3: SEMs of high-aspect-ratio silicon nanowires fabricated from alumina masks.

by etching in an HBr/Ar plasma. Figure 3 shows successful fabrication of silicon nanowires with 30 nm diameters and heights approaching 180 nm. Pattern transfer is uniform across large areas, and is only limited by the defect density in the BCP resist. Many lithographic approaches toward vertical nanowire fabrication involve costly electron-beam lithography steps, while this approach is facile, versatile, and enables high aspect ratios. Optimization of the nanowire etch could further increase achievable aspect ratios in this system.

The ease of fabrication of silicon nanowires with high aspect ratios inspires device concepts and applications. The fabricated structures have dimensions and packing densities smaller than visible optical wavelengths. The reflectance therefore approaches zero, as there are no smooth surfaces for reflection of light. Therefore, by doping the top layer of silicon, vertical *p-n* junction solar cells can be fabricated that do not suffer from reflection losses.

References:

[1] Jeong, Seong-Jun, Ju Young Kim, Bong Hoon Kim, Hyoung-Seok Moon, and Sang Ouk Kim. “Directed Self-Assembly of Block Copolymers for next Generation Nanolithography.” Materials Today 16, no. 12 (December 1, 2013): 468-76. https://doi.org/10.1016/j.mattod.2013.11.002.