Controlled self-assembly of linear structures for nanoscale device fabrication

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Electron-beam lithography (EBL) has sub-10-nm patterning performance with good pattern registration. However, it is slow and not economical for patterning dense structures over large areas. Alternatively, block-copolymer (BCP) self-assembly can form nanostructures economically and in parallel over large areas, but lacks global registration. Fortunately, EBL can be combined with BCP self-assembly to overcome their collective shortcomings. The result is a nano-manufacturing approach that achieves high resolution, registration accuracy, and throughput. This approach was demonstrated before using sparse arrays of EBL-patterned templates to guide BCPs into ordered periodic structures.[1,2,3] However, periodic structures have limited utility, and one needs controlled but arbitrary patterns in device fabrication.

Here, we controlled cylindrical morphology BCP into line structures that resembled integrated-circuit interconnects and dense nanowire arrays. In addition to achieving long-range order, we were also able to direct the local orientation of individual BCP microdomains into various geometries. In the examples shown here, the structures were made with an effective increase in throughput, as the EBL exposed only a fraction of the patterns and the BCP completed the missing structures.

Figure 1A shows a scanning electron micrograph (SEM) of an un-guided cylindrical morphology polystyrene-polydimethylsiloxane (PS-PDMS) BCP that formed line structures with a natural spacing of 35 nm on a Si substrate. Without a guiding template, the lines were locally ordered but globally disordered. To achieve global ordering, we used a template consisting of a sparse array of posts fabricated by EBL patterning of hydrogen silsesquioxane HSQ resist.[4] Figure 1B shows the resulting template, consisting of posts that were 10 nm in diameter and 35 nm tall. As shown in Fig. 1C-G, these posts guided a subsequently applied film of PS-PDMS BCP into well-ordered lines. The different orientations of the lines were achieved simply by varying the distances between posts in the template.

To achieve arbitrary pattern formation, we broke the symmetry of the template using "dash" structures instead of circular posts, and strategic positioning of the posts. Figure 2A shows that an array of dashes was able to guide the BCP into accurately-positioned bends. Furthermore, as shown in Fig. 2C, we were able to locally control individual BCP microdomains into meandering lines by strategic positioning of posts.

The resulting well-controlled linear structures have potential for use in the fabrication of integrated circuit interconnects and dense nanowire arrays.

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[1] I. Bita, J.K.W. Yang, Y.S. Jung et al., Science 321 (5891), 939 (2008).
[2] R. Ruiz, H.M. Kang, F.A. Detcheverry et al., Science 321 (5891), 936 (2008).
[3] J.Y. Cheng, C.T. Rettner, D.P. Sanders et al., Advanced Materials 20 (16), 3155 (2008).
[4] J.K.W. Yang and K.K. Berggren, Journal of Vacuum Science & Technology 25 (6), 2025 (2007).

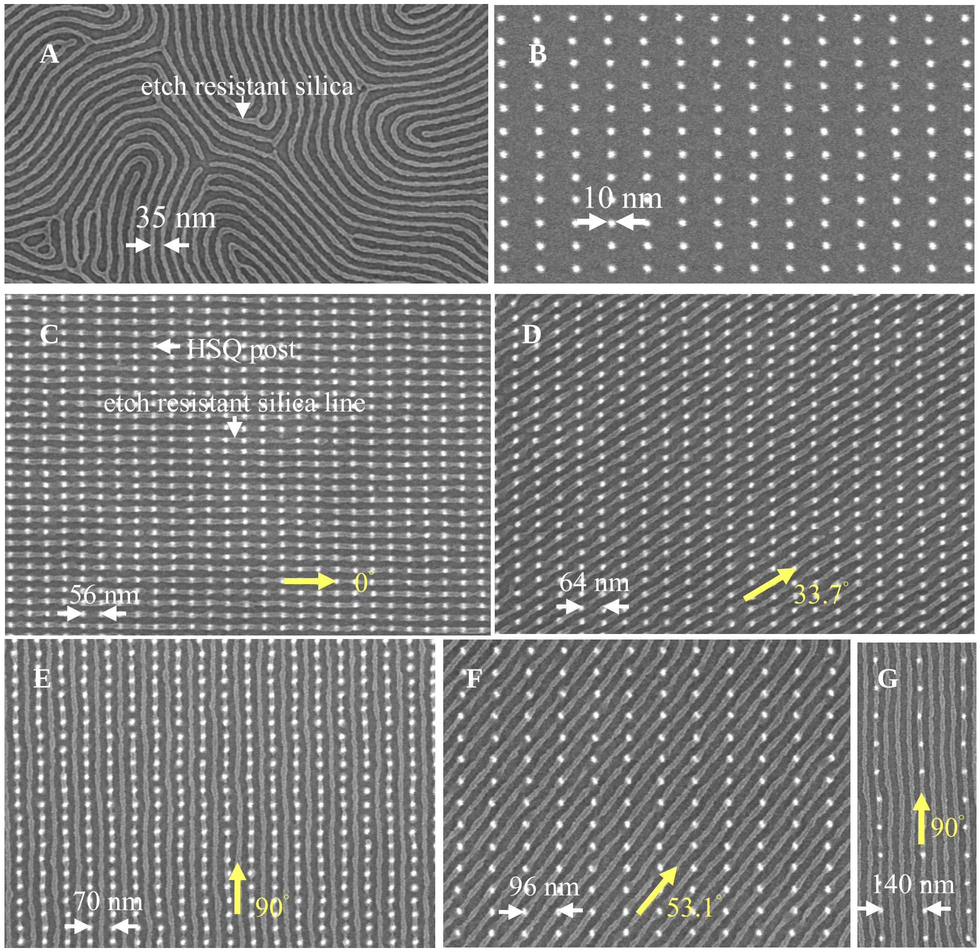

Figure 1. (A) SEM image showing an untemplated cylindrical phase polystyrene-polydimethylsiloxane (PS-PDMS) BCP after selective removal of PS, leaving etch resistant silica material from oxidized PDMS. (B) SEM image of a template consisting of posts 10 nm in diameter and 35 nm tall. (C)-(G) BCP self-assembled on the template forming ordered grating of lines that can be oriented at different directions as indicated by the arrows by changing the spacing of the template spacing. Notice in (C)-(G) that the template orientation was unchanged.

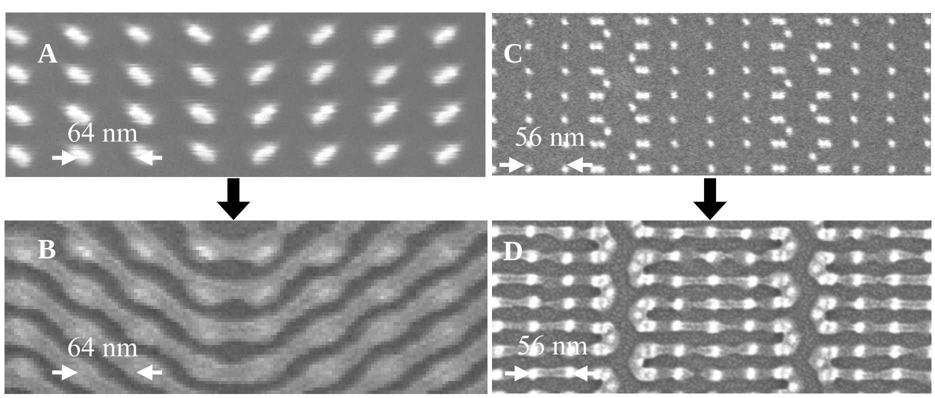

Figure 2. (A) SEM of a template consisting of dashes arranged such that the BCP that aligns along the dashes will form bends as shown in (B). (C) SEM of a template consisting of an arrangement of posts designed to guide the BCP into an array of meandering structures as shown in (D).