# Using Self-Assembled Block Copolymer Patterns to Template Ultra–Fine Bilayer Mesh Structures

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Mesh-shaped (or gridded) patterns are needed for applications such as metamaterials and next-generation IC architecture in which high throughput of dense features will be required. Our previous studies[1] showed that by using arrays of majority-functionalized posts fabricated by electron-beam lithography (EBL), we controlled bilayers of block copolymer (BCP) cylindrical microdomains and fabricated a variety of complicated structures including mesh-shaped patterns. This work required arrays of EBL-fabricated posts, which is impractical in a large-area manufacturing process. Furthermore the generated patterns were of primarily square symmetry because top and bottom layers were made from the same BCP. In the following study we investigated an EBL-free process for fabricating bilayer mesh structures. Majority-functionalized BCP patterns were used as templates to self-assemble another BCP layer of the same or different molecular weight, the latter on top of the former.

Figure 1 describes the main steps of the fabrication process. In the first step poly(styrene-dimethylsiloxane) (PS-PDMS) BCP was spin-coated on the surface of a silicon substrate. Thermal or solvent annealing was used to promote microphase separation forming a monolayer of parallel cylinders. A reactive ion etch (RIE) process was used to remove the top PDMS surface and PS block matrix and leave the oxidized-PDMS (ox-PDMS) patterns on the substrate. Then the patterns were functionalized using majority-block brush (PS brush). Next the second layer of PS-PDMS BCP was spin-coated on the patterns and self-assembled with thermal or solvent annealing. Finally, RIE was used to remove the top PDMS layer and PS matrix and leave a mesh-shaped bilayer cylinder structure on top of the substrate.

Figure 2 (c) shows one of the results of the described process. In this figure, a bilayer rectangular mesh-shaped structure was formed using a 53 kg $mol^{-1}$ PS-PDMS (Figure 2(b)) on top of a 16 kg $mol^{-1}$ PS-PDMS (Figure 2(a)). In other systems, BCPs have been shown to orient perpendicular to underlying periodic patterns because the free energy for perpendicular orientation of the second BCP to the bottom pattern is lower than parallel orientation[2]. The layers in Figure 2(c) are not orthogonal all across the substrate because the bottom BCP pattern was poorly oriented. In order for the mesh to be orthogonal, the bottom BCP pattern can be templated, e.g. using topographical trenches. Figure 3(c) shows a dense, ultra-fine, mesh-shaped structure ($9\times9$ $nm^2$, period=18 nm) in which both layers had the same molecular weight (16 kg $mol^{-1}$) (Figure 3(a)).

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[1] A. Tavakkoli K. G., et al., *Science* 2012, 336, 1294.
[2] Hong, Sung Woo, et al., *Proceedings of the National Academy of Sciences* 109.5 (2012): 1402.

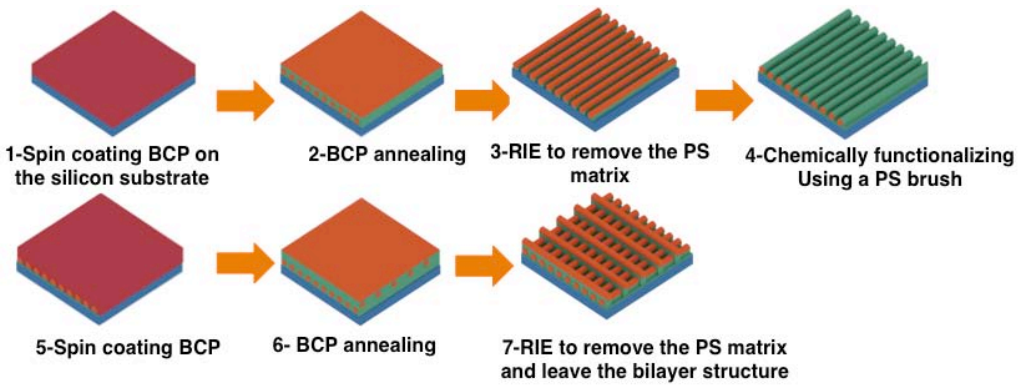


**Figure 1:** The major steps of bilayer mesh-shaped structure fabrication.

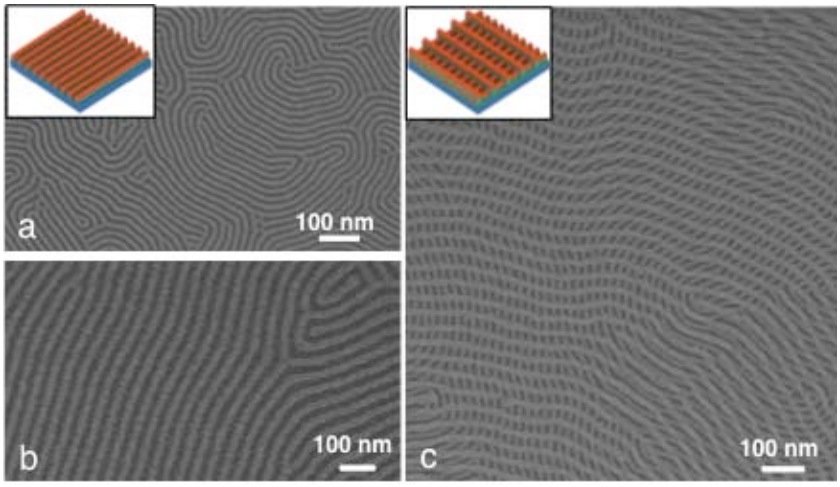


**Figure 2:** SEM images of (a) a single layer of cylinders from a 16 kg $mol^{-1}$ PS-PDMS BCP on top of a silicon substrate, (b) a single layer of cylinders from a 53 kg $mol^{-1}$ PS-PDMS BCP on top of a silicon substrate, (c) a bilayer of 53 kg $mol^{-1}$ PS-PDMS on top of 16 kg $mol^{-1}$ PS-PDMS cylinders.

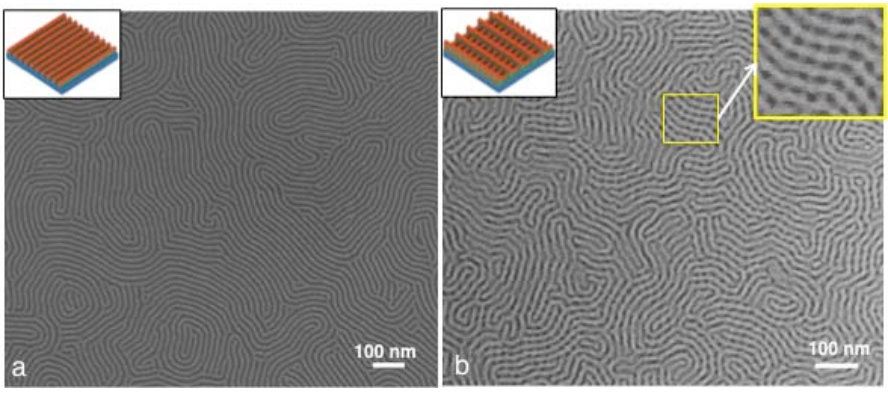


**Figure 3:** SEM images of (a) a single layer of 16 kg $mol^{-1}$ PS-PDMS BCP on top of a silicon substrate, (b) a bilayer of 16 kg $mol^{-1}$ PS-PDMS on top of 16 kg $mol^{-1}$ PS-PDMS cylinders. (Right inset in Figure 3(b) shows the zoomed-in area)