Spatial-Frequency Doubling Below the Block Copolymer Period by Templated Self-Assembly

A. Tavakkoli K. G.[1,2], K. Gotrik[3], Adam F. Hannon[3], J.B.Chang[3] , S. Nicaise[2], C.A.Ross[3], K.K. Berggren[1, 4]

[1]*Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA02139, USA*
[2]*NUS Graduate School for Integrative Sciences & Engineering (NGS), Singapore*
[3]*Department of Materials Science and Engineering, MIT*
[4]*Kavli Institute of Nanoscience, Technical University of Delft, Delft, NL*
amirtkg@mit.edu

In this study, we demonstrated a high-resolution method for doubling the spatial frequency of lines and dots of structures defined by electron-beam lithography, as well as a method for achieving a rectangular lattice in the case of dots. The method used an array of structures defined by electron-beam-lithography (EBL) to template block copolymers. The spatial frequency of the obtained results was half of the original BCP pitch. This method resulted in higher resolution and higher areal density in comparison to previously reported methods for spatial frequency multiplication using templated self-assembly of BCPs, which were limited by the BCP pitch.

Figure 1 shows a schematic diagram of the major steps of the method. In the first step, the templates were fabricated such that the periods of the lines or dots were the same as the period of the BCP. After fabrication of the templates by means of EBL exposure of hydrogen silsequioxane (HSQ) resist, the templates were chemically functionalized with a hydroxyl terminated polystyrene (PS) brush (3.2 kg/mol). Then, BCPs of polystyrene-b-polydimethylsiloxane (PS-PDMS) were spin cast onto the substrates with HSQ templates. Annealing of the BCP thin film was done using a cosolvent vapor anneal consisting of 5 parts toluene to 1 part heptane. An oxygen reactive ion etch (RIE) was used to remove the PS block and leave the oxidized-PDMS patterns on the substrate.

Figure 2 shows a scanning electron micrograph (SEM) image of line frequency doubling. The BCP used in this experiments was cylindrical morphology PS-b-PDMS with a molecular weight of 45.5 kg/mol (f_PDMS =0.32). This result indicates that the PS functionalized posts, which have the same period as the BCP, can template linear spatial-frequency doubling. In this example, the period of the resultant lines (both HSQ and ox-PDMS) was half of the period of the HSQ template and the BCP. The period of the BCP and the template were 40 nm and the period of the resultant lines (HSQ + ox-PDMS) was 20 nm.

Figure 3 shows an SEM image of a rectangular lattice obtained by using the above-mentioned method. The HSQ posts formed a centered rectangular lattice with unit cell dimensions of 60 nm × 40 nm as seen in figure 3. BCPs used in this experiment were spherical morphology PS-PDMS with molecular weight of 51.5 kg/mol (f_PDMS = 0.17). The spatial frequencies of the resultant dots in the two perpendicular directions were 20 nm and 30 nm.

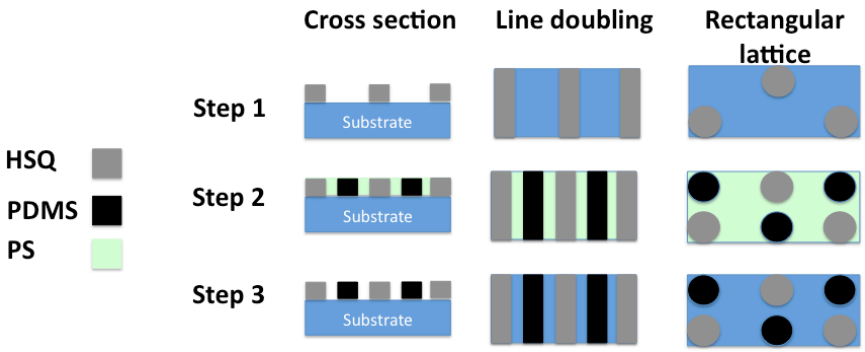

Figure 1: The major steps of the process, (step1) fabrication of the HSQ template by EBL, (step 2) spin coating and annealing of the BCP, (step 3) removing the PS matrix by oxygen RIE.

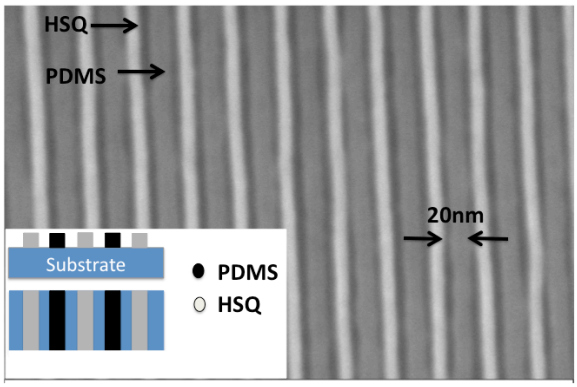

Figure 2: SEM image of the ox-PDMS micro-domains (L_0=40 nm) guided by using HSQ template with 40 nm pitch size. Line frequency doubling happened when using a PS brush and an HSQ template with the same period as the BCP. (Inset: schematic illustration of the image, in which HSQ and ox-PDMS lines are on the substrate with half the pitch of the period of the template and BCP).

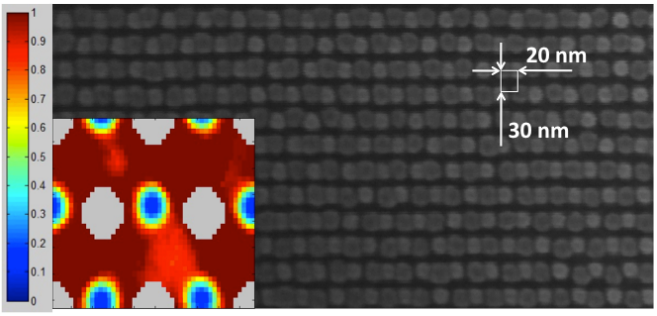

Figure 3: SEM image of the ox-PDMS micro-domains guided by using a rectangular centered HSQ template. White dots are HSQ and grey dots are ox-PDMS. The frequencies of the resultant dots in two perpendicular directions were 20 nm and 30 nm. Rectangular lattice shape and dot doubling frequency were achieved by using the PS brush (inset: Self Consistent Field Theory simulations of PS-PDMS on rectangular centered arrays, grey is HSQ posts simulated by a high impenetrable chemical potential field, legend shows PS concentration, dark red regions are 100% PS, dark blue regions are 100% PDMS (0% PS), and yellow to orange regions are diffusive boundaries between blocks; PS brush is simulated by an attractive chemical potential field to PS around post regions).