Design Space for One-hole Pattern using Block Copolymer Directed Self-Assembly

He Yi[1], Xin-Yu Bao[1,#], Christopher Bencher[2], Huixiong Dai[2], Yongmei Chen[2], H.-S. Philip Wong[1]

1 Dept. of Electrical Engineering, Stanford University, Stanford, CA 94305, USA
2 Applied Materials, Inc., 974 E Arques Avenue, Sunnyvale, CA 94085, USA
 # Present affiliation: Applied Materials, Inc., 974 E Arques Avenue, Sunnyvale, CA 94085, USA
heyi@stanford.edu

Due to the continuous scaling of electron devices and the foreseeable resolution limit in conventional optical lithography, the development of alternative lithographic approach is essential for semiconductor industry [1]. Block copolymer directed self-assembly (DSA) is a potential sublithographic patterning solution, extending the existing optical lithography with low cost and high throughput [2]. Among all the nanopatterns formed by block copolymer directed self-assembly, cylindrical microdomains have attracted specific interest due to their great potential for patterning contact holes for integrated circuits. Here we demonstrate flexible control of DSA cylindrical nanostructure formation using small topographical templates. By varying the template size, density and the polymer film thickness, nanopatterns with different number of cylindrical domains can be formed. These self-assembled holes are able to shrink the size of templates to ~20nm and beyond, and heal the imperfections (e.g. line edge roughness) of lithography [3,4].

In this paper, we mainly focus on the one-hole pattern inside round templates and explore its design space. A series of small round templates were fabricated using conventional optical lithography and dry etching on 300 mm Si wafer with sizes ranging from 45 nm to 120 nm and depth around 50 nm. The DSA process is similar to the previous report [5]. Besides the spin-speed of the block copolymer coating, the size and density of templates is one of the factors that determine the final polymer thickness in the template well after reflowing during annealing at elevated temperatures. Figure 1 shows that as the template size increases, the DSA quality decreases and more defects appears. When template size is less than 65nm, blurred cylindrical structures are formed, indicating low-quality phase separation. When the template size is larger than 90nm, more holes appear in one single template, which demarcates the border of design space. Figure 2 shows the relationship between template density and DSA pattern formation. As the template density decreases, DSA tends to behave more like DSA in larger templates with higher template density. The design space of one-hole pattern shown in Figure 3 indicates a broad process window for DSA.

[1] Hawker, C. J. et al.MRS Bull 30, 952–966, 2005.
[2] Black, C. T. et al. IBM J. R&D, p. 605, 2007.
[3] H. Yi et al. SPIE, 2012.
[4] J. Cheng et al. Adv. Mater, 20, 3155, 2008.
[5] X.-Y. Bao et al. IEDM pp.7.7, 2011.

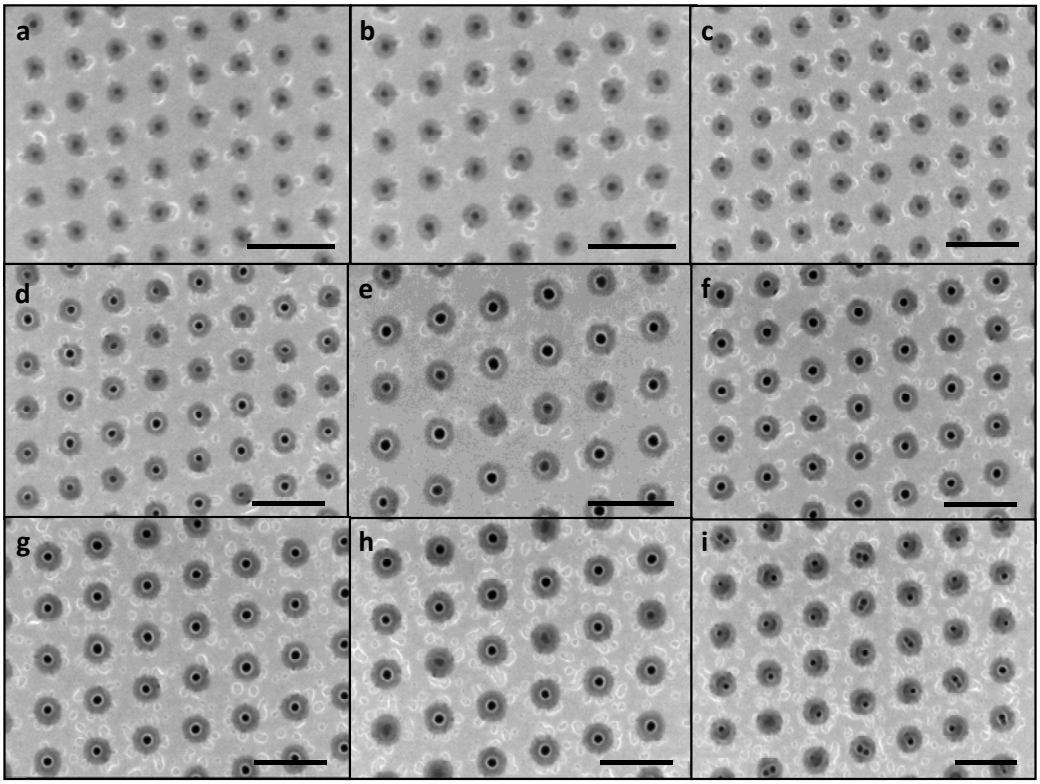

Figure 1: SEM images of DSA patterns confined by templates with different sizes from50nm to 90nm. The size of templates: (a) 50nm, (b) 55nm, (c) 60nm, (d) 65nm, (e) 70nm, (f) 75nm, (g) 80nm, (h) 85nm, (i) 90nm. It is clearly shown that when template size is smaller than 65nm, the quality of phase separation is impacted, indicated by the blurred shape of self-assembled holes. When the template size is larger than 85nm, two holes begin to appear inside one template instead of single hole. Scale bar: 200nm.

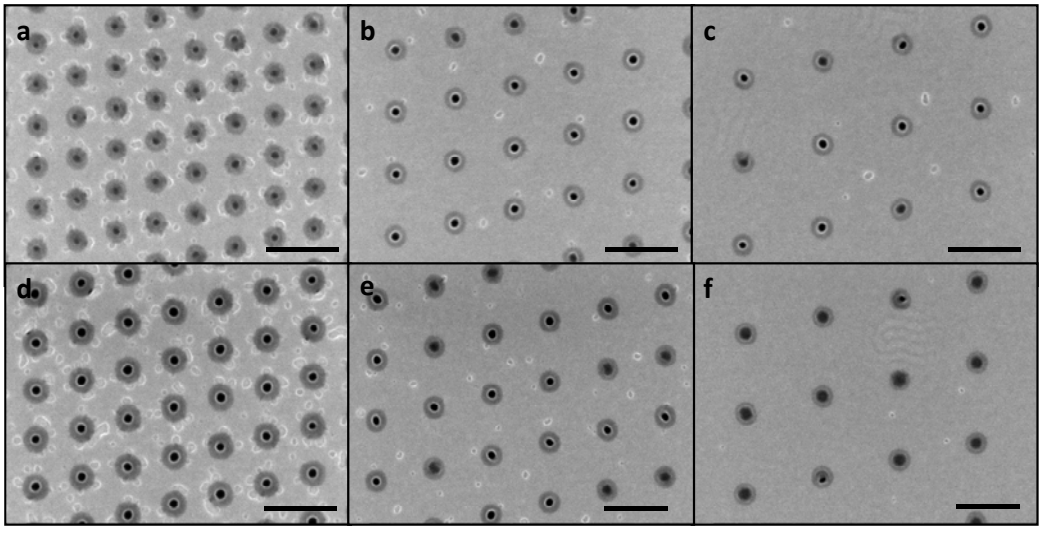

Figure 2: SEM images of DSA patterns confined by 65nm and 80nm templates

with different densities. Size of templates and the ratio between template size and pitch: (a) 65nm, 1:2, (b) 65nm, 1:3, (c) 65nm, 1:4, (d) 80nm, 1:2, (e) 80nm, 1:3, (f) 80nm, 1:4. It is important to note that as the template size decreases, DSA in (b) tends be similar with (d), indicating that DSA in smaller template size and template density tends to behave like DSA in larger template size and template density. Scale bar: 200nm.

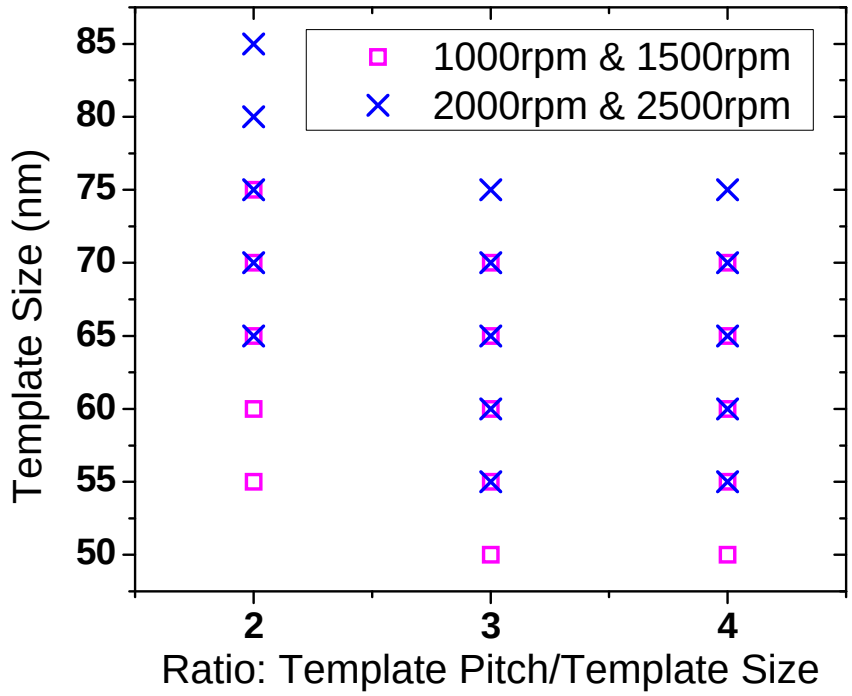

Figure 3: Design space of one-hole DSA pattern. Each data point represents a set of spin coating speed, template size and spacing to generate one-hole pattern in a round template. Note that the spin speed of 1000rpm and 1500rpm lead to the same result, as well as the spin speed of 2000rpm and 2500rpm.