Three-Dimensional Nanofabrication Using HSQ/PMMA Bilayer Resists

Hyung Wan Do[1], Jae-Byum Chang[2], and Karl K. Berggren[1]
[1]*Department of Electrical Engineering and Computer Science,*
[2]*Department of Materials Science and Engineering,*
Massachusetts Institute of Technology, Cambridge, MA, 02139
hwdo@mit.edu

Three-dimensional (3D) devices offer unique advantages over planar devices, but are difficult to fabricate. Therefore, a simple and rapid fabrication process for complex 3D nanostructures is necessary. Methods for fabricating such 3D nanostructures using electron beam lithography (EBL) include consecutive overlay exposures[1] or low and high electron energy exposures[2]. However, these approaches require alignment markers and accurate alignment routines. Here, we describe a self-aligned method of fabricating 3D nanostructures using EBL of hydrogen silsesquioxane (HSQ) and poly(methylmethacrylate) (PMMA).

We used a HSQ/PMMA bilayer resist stack with HSQ as the top layer and PMMA as the negative-tone bottom layer. A dot array was exposed on the bilayer resist stack with the dose necessary to achieve negative-tone PMMA. After exposure, the samples were sequentially developed in salty developer to remove unexposed HSQ, methyl isobutyl ketone (MIBK) and isopropanol (IPA) to remove lightly exposed PMMA, and acetone to remove unexposed PMMA. As shown in Figure 1(a) and 1(b), a nanostructure with larger diameter HSQ posts on top of smaller diameter PMMA posts was created due to the sensitivity difference between the two resists. The diameter of both posts was determined by the single dot exposure dose and the posts achieved vertical self-alignment. As shown in Figure 1(c), neighboring HSQ posts merged and formed wavy lines on top of PMMA posts when the dots were positioned sufficiently close to each other.

To better control the size and shape of the nanostructures on each resist layer, we developed a double exposure process in which smaller features on the bottom PMMA layer were defined using high dose exposures and larger features on the top HSQ layer were defined using low dose exposures. Both layers were exposed in a single writing step without removing the wafer. Nanostructures similar to those shown in Figure 1(a-c) could be created using this method with more control. Figure 2(a) and 2(b) show HSQ posts on top of PMMA posts and HSQ lines on top of PMMA posts, respectively. Because features on each resist layer can be more accurately controlled using this approach, complex 3D nanostructures can be fabricated as shown in Figure 2(c).

---

[1] J. Vila-Comamala, S. Gorelick, V. A. Guzenko, and C. David, J. Vac. Sci. Technol. B **29**, 06F301 (2011).

[2] E. J. Boyd and R. J. Blaikie, Microelectron. Eng. **83**, 767 (2006).

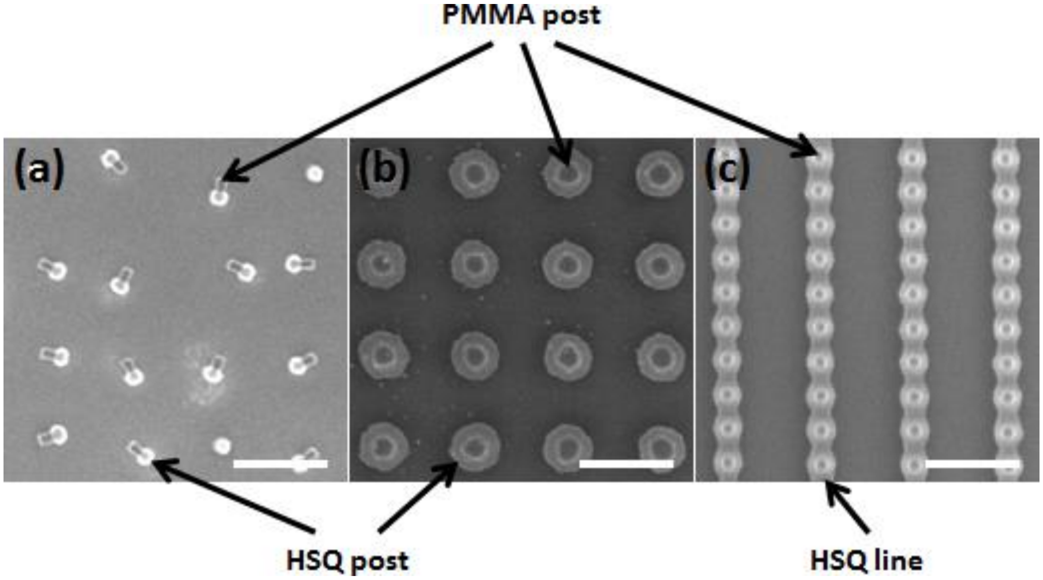

Figure 1: Scanning electron microscope (SEM) images of 3D nanostructures fabricated from single dot exposure. All scale bars are 200 nm in length. (a) HSQ posts on top of PMMA posts. Collapsed nanostructures clearly show the two resist materials. (b) HSQ posts on top of PMMA posts. Exposure dose used in (b) is 5.65 times the exposure dose used in (a). (c) HSQ lines on top of PMMA posts.

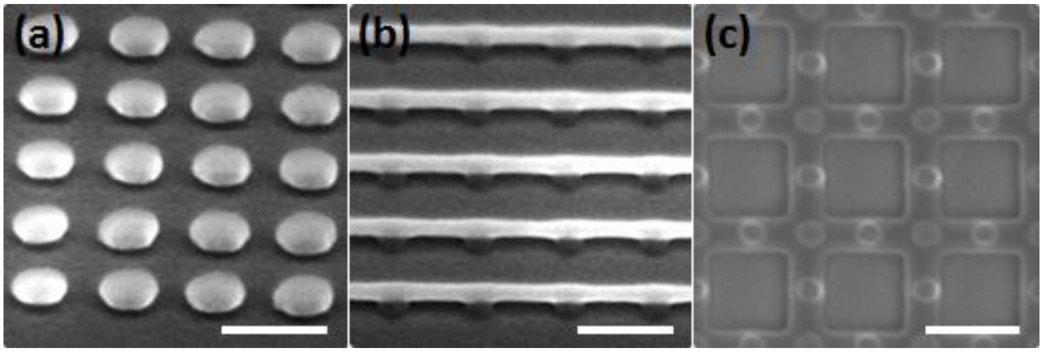

Figure 2: SEM images of 3D nanostructures fabricated from double exposure. SEM images were taken at 45° tilt angle in (a) and (b). Exposure dose of negative-tone PMMA was 7 times the exposure dose of HSQ. Scale bars are 100 nm (a-b) and 200 nm (c) in length. (a) HSQ posts on top of 30 nm diameter PMMA posts. (b) 60 nm wide free-standing HSQ lines on top of 30 nm diameter PMMA posts. (c) 75 nm wide HSQ grid on top of 50 nm diameter PMMA posts.