Patterning of High-Aspect-Ratio Nanostructures on Microtrenches using Stencil Lithography of Free-Standing Tri-Layer Membrane

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It is challenging to pattern high-aspect-ratio nanostructures on microtrenches using conventional lithographic techniques, where photoresist film is not able to uniformly cover the bottom surface of microtrenches as the aspect-ratio (depth to width) of a trench increases. Such non-uniformity causes poor definition of nanopatterns over the microtrench surfaces. Stencil lithography can provide an alternative means to construct nanostructures on microtrenches via direct deposition or etching through free-standing porous membrane[1, 2]. However, the dimension and uniformity of the nanopatterns are significantly affected by the gap between the top stencil membrane and the bottom trench wall, called "blurring" effect[2]. In this work, we demonstrate a new fabrication scheme to pattern high-aspect-ratio nanostructures on microtrenches using stencil lithography of free-standing tri-layer membrane and examine the blurring effect systematically by testing microtrenches of varying depths.

Figure 1 shows the schematic of fabrication process. First, microtrenches are formed by conventional photolithography (Fig. 1a), followed by deep reactive ion etching (DRIE) of silicon (Fig. 1b). Free-standing tri-layer nanoporous membrane comprised of Cr, photoresist (PR), and anti-reflective coating[1-2] is then placed on the microtrenched silicon substrate (Fig. 1c). The top PR film used as an etch mask in DRIE is retained on the silicon substrate, in order to have metal dots (Cr in this study) deposited on the silicon substrate only on the bottom trenches (Fig. 1d). After defining metal dots on the bottom trenches, the free-standing membrane is released off from the substrate in $H_2O_2/NH_3/H_2O$ solution[1] (Fig. 1e). The PR layer on top of the silicon substrate can still be retained (which will protect the top ridge surface of silicon in the following DRIE process) or be removed (which will have the top ridge surface of silicon etched along with the bottom trench in the following DRIE step). Using the metal dots as etch masks in DRIE, high-aspect-ratio nanopillar structures are created on the bottom trenches (Fig. 1f). Figure 2 shows the fabrication results, demonstrating that microtrenches of different depths can successfully be patterned with high-aspect-ratio nanostructures. Depending on the depths of microtrenches, the diameters of nanopillar structures vary (i.e., the deeper, the larger), which is due to the blurring effect. Capping the microtrenches, microchannels patterned with well-defined high-aspect-ratio nanostructures can be formed, which will be of great significance in various applications including microfluidics, optofluidics, and superhydrophobic surfaces.

References

[1] K. Du et al., J. Vac. Sci. Technol. B, 30, 06FF04, 2012.
[2] K. Du et al., J. Vac. Sci. Technol. B, 31, 06FF04, 2013.

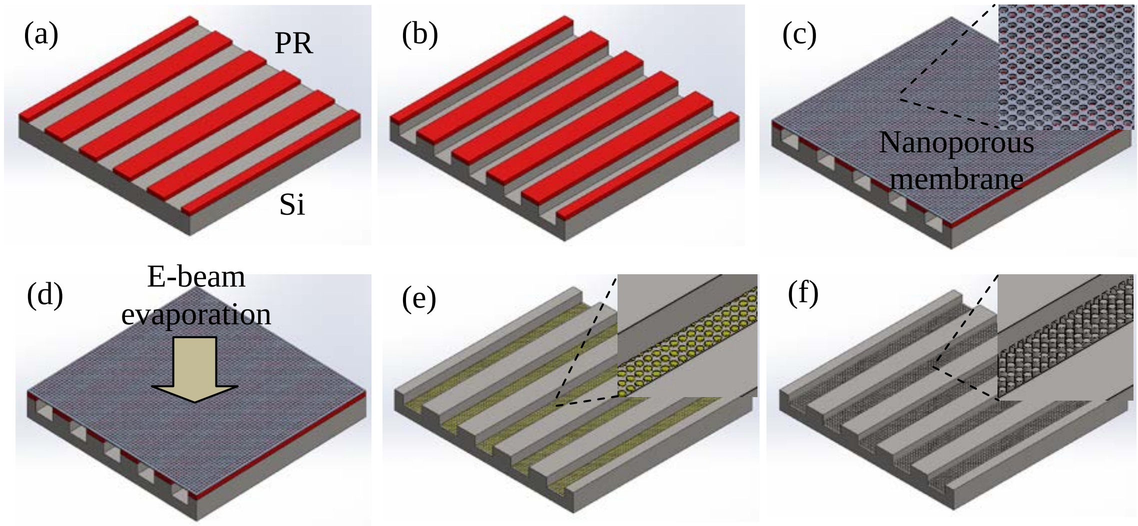

Figure 1: Schematic of fabrication process of high-aspect-ratio nanostructures on microtrenches. (a) Patterning of photoresist (PR) film on a silicon substrate by using photolithography. (b) Deep reactive ion etching (DRIE) of silicon, using the PR layer as an etch mask. (c) Placement of free-standing nanoporous tri-layer membrane on the microtrenched silicon substrate. (d) Deposition of Cr dots on the bottoms of microtrenches by e-beam evaporation through the nanoporous membrane. (e) Removal of a free-standing membrane, using $H_2O_2/NH_3/H_2O$ solution. The PR layer on top of the silicon substrate can further be removed by using acetone. (f) DRIE of the silicon substrate to form high-aspect-ratio nanostructures on the bottom of microtrenches.

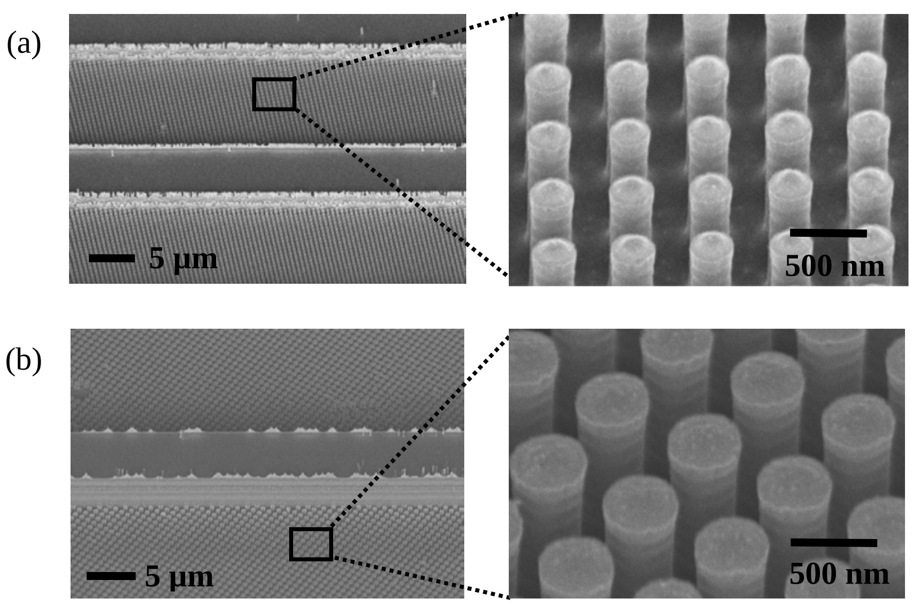

Figure 2: Scanning electron microscope (SEM) images of fabrication results. (a) Nanopillared (diameter: ~280 nm) microtrenches of 2 µm deep. (b) Nanopillared (diameter: ~400 nm) microtrenches of 4 µm deep.