Imprinted large-scale high density polymer nanopillars for various applications

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Fabrication of functional polymer nanostructures over large areas has strong potential in many emerging nanotechnology applications such as organic solar cells, tissue engineering, nanomedicine, organic light emitting diodes, and optical nanodevices. Nanoimprint lithography (NIL) is a feasible method to fabricate polymer nanostructures without affecting material functionality. The ability to use NIL for the mass-production of nanostructures would be significantly improved by availability of molds with large-scale high density nanostructures and low cost of ownership. Photolithography and e-beam lithography, which are the most commonly used methods for fabricating nanostructure molds, are significantly limited by their high cost and low throughput respectively. Here, we present a new method for fabricating molds of high-density nanopores over a 2 cm square area or larger. The method uses a free standing anodized aluminum oxide (AAO) membrane as an etch mask for inductively coupled plasma (ICP) etching of Si. The resulting Si mold offers atomic level smoothness, high hardness, and independent tunability of pore diameter, depth, and cross-sectional profile. Using these Si molds for thermal and UV NIL, we have produced large areas of high aspect ratio nanopillars of various materials. These polymer nanopillars can be used to make organic solar cells, nanoscaffolds for tissue engineering, or as a nanomedicine platform for cancer imaging and therapy.

First, a free standing AAO membrane is obtained using a voltage reduction electrochemical anodization process that produces a nanopore membrane with a barrier layer. Figure 1 illustrates the use of the AAO membrane, which is shown in Figure 2a, as a mask for the etching of a Si wafer. ICP etching of Si involves removing the barrier layer of the AAO membrane and then extending the nanopores into the Si wafer. The AAO membrane is then removed, and the Si mold is treated with FDTS to facilitate demolding during future use of the mold for nanoimprinting. Figure 2b shows a top and cross sectional view of a Si mold created using the process described above. Figure 3 shows 60 nm in diameter and ~200 nm tall SU-8 nanopillars formed by NIL using the Si mold, indicating uniform pillar diameter, height, and tubular morphology.

Nanoimprint with the large-scale nanostructured mold made by this method provides a low-cost scale-up strategy for the mass-production of polymer nanostructures. The current throughput is about 10^{12} pillars per cycle of nanoimprint. In the article, we will also demonstrate the use of these polymer nanopillars in nanomedicine applications, solar cells, and tissue engineering.

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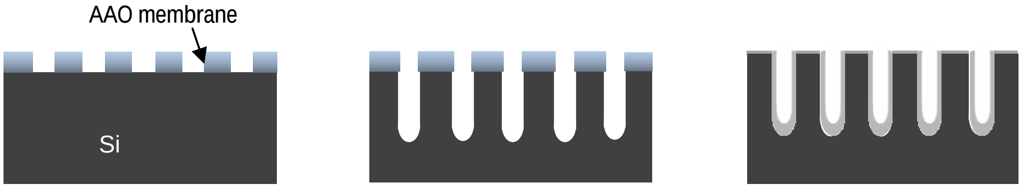

a) deposit Al_2O_3 membrane on Si

b) two-step plasma etching of Si

c) Mold treatmetn with FDTS, after membrane removal

Fig 1: Schematics of Si mold fabrication process using freestanding AAO membrane as etching mask.

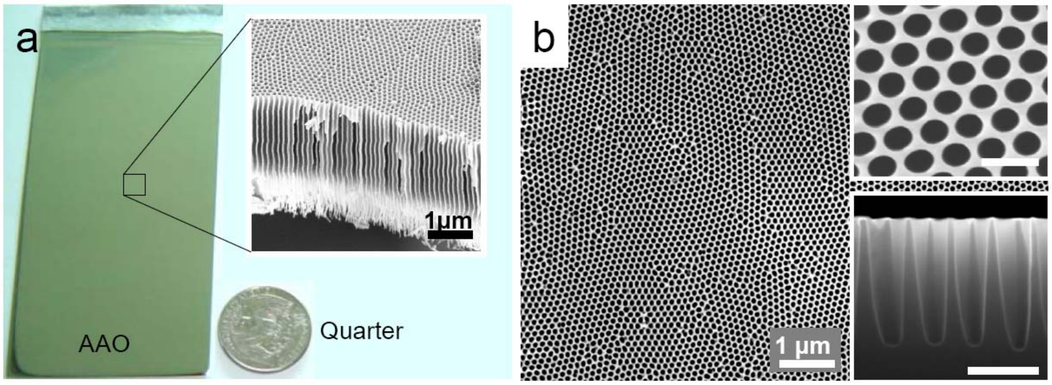

Fig. 2: a) Large-area nanoporous AAO membrane, with details shown in the inset SEM image; b) SEM topview of a nanoporous Si mold with uniform nanopores over 2 cm square. Inset SEM images show the top and cross-sectional views of mold, indicating uniform pore diameter, pore depth, and smooth surface. Scale bar in the inset images is 200 nm.

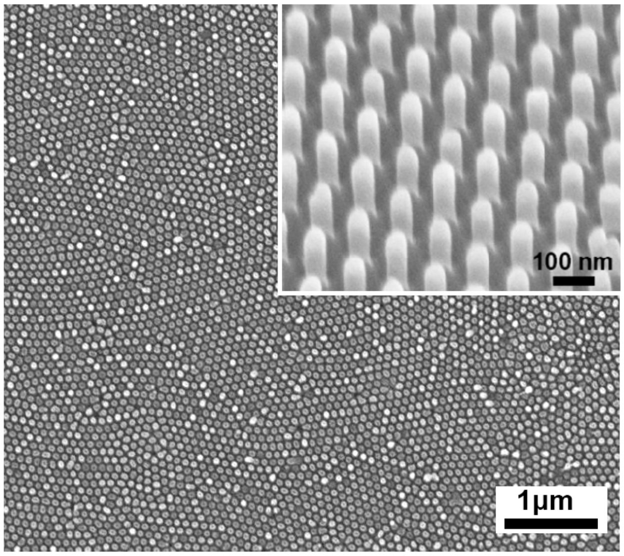

Fig. 3: SEM image of SU-8 polymer nanopillars formed by nanoimprint lithography using the Si mold shown in Fig. 2. Inset image shows the 45 degree side view of the SU-8 nanopillars. The nanoimprint process was done at a temperature of 75 °C, pressure of 2.5 MPa, and 5s UV exposure.