Nanostructured silicon membranes for control of molecular transport

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To achieve selective molecular transport through a nanofabricated membrane, precise engineering of pore geometry, density, and surface functionality are essential. Such membrane properties can be tailored to control the flux of different molecular species based on their size, charge, and chemical affinities. Here we present an approach for fabricating nanostructured silicon membranes, and describe methods for controlling and characterizing both their physical and functional properties. The techniques described here are broadly applicable for the integration of these structures into lab-on-a-chip platforms, for example microfabricated chemostats. Here they are demonstrated in a model test platform that allows the quantitative examination of molecular flux across the membrane.

Device fabrication is carried out using a combination of electron beam and conventional photolithography along with deep reactive ion etching (DRIE) to create a microfluidic network with a nanostructured membrane separating two regions of the device (Figure 1). A chrome etch mask that dictates the width and density of pores within the membrane is defined using e-beam lithography (EBL) and metal lift-off. A second masking layer is then aligned and patterned in photoresist to define the remainder of the microfluidic network. A single cryogenic DRIE step is used to transfer the complete pattern into a silicon substrate. Subsequent coating processes including Plasma Enhanced Chemical Vapor Deposition (PECVD) or Atomic Layer Deposition (ALD) are then used to reduce pore size and tune molecular transport.

The size and uniformity of membrane pores are controlled by a variety of fabrication parameters including the initial pattern dimensions, electron beam exposure, DRIE etch parameters, and coating procedures. Electron beam patterns and exposures have been optimized to create pores with a nominal width of 200 nanometers. Subsequent control over DRIE conditions, specifically control of oxygen partial pressure, allow control of pore depth relative to overall membrane height. Optimization of the etch process was carried out to improve pore uniformity and reproducibility (Figure 2). Following etching, pore size is reduced by conformally coating the membrane surface with silicon dioxide. The SiO_2 deposition is performed either by plasma enhanced chemical vapor deposition (PECVD) or atomic layer deposition (ALD). Results of these two coating methods are examined using scanning electron microscopy and focused ion beam processing. Using these techniques, a three-dimensional geometry of the membrane pore structure can be reconstructed and deposition conformality can be assessed. Functional testing of membrane properties is then accomplished by imaging the transport of fluorescent species of varying molecular weights and overall size across the membrane under different flow conditions.

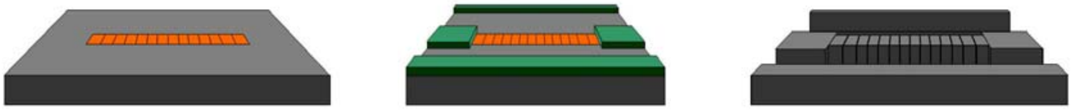
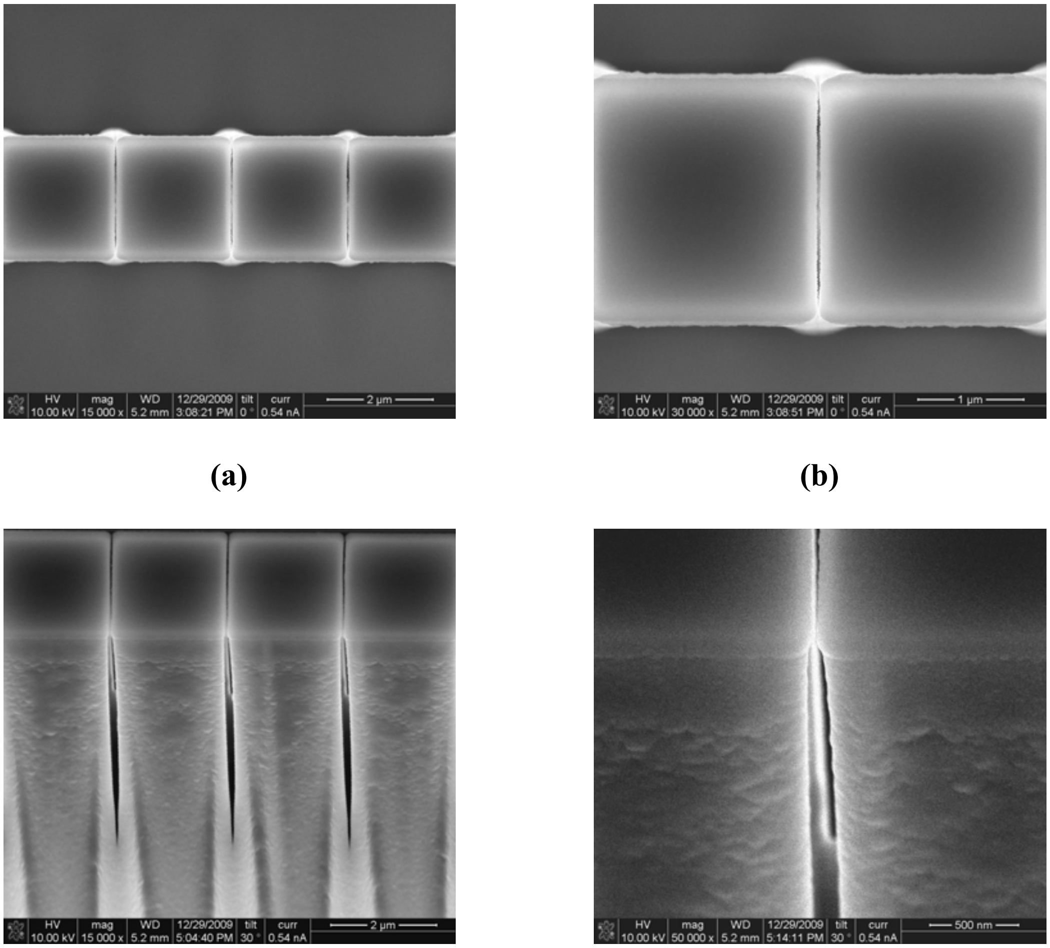

(a) (b) (c)

Figure 1. Fabrication of a nanostructured silicon membrane: **(a)** e-beam lithography for membrane patterning, followed by Cr deposition and lift-off, **(b)** optical lithography patterning defines the microfluidic network, and **(c)** a single cryogenic deep reactive ion-etch is used to transfer the pattern into a silicon substrate.



(a) (b)

(c) (d)

Figure 2. SEM images of a nanostructured membrane in silicon: **(a)** and **(b)** top view, **(c)** and **(d)** side view (sample tilted by 30^{o}).