Buried Silicon Dioxide Nanochannels Fabricated by Nanoimprint, Etching and Self-Sealing, Self-Limited Thermal Oxidation

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Nanofluidic channels are critical to uncoiling and stretching genomic length DNA for bio-analysis [1], but are challenging to fabricate with sub-50 nm diameters. Typically channels are etched into quartz (transparent materials are required for analysis by fluorescence microscopy) and capped using low-yield, quartz-quartz bonding [2] which is sensitive to trapped dust and difficult to automate. Here we report a novel method for fabricating nanochannels buried in transparent silicon dioxide with well controlled sizes (as small as 10 nm in diameter) using simplified, high-yield fabrication steps including self-sealing and self-limiting thermal oxide growth. This method creates robust nanochannels using lower-cost silicon wafers and removes the requirement to seal devices manually, while maintaining a uniform material surface for eletrophoretic passivation treatments.

In our channel fabrication, we first pattern a Si wafer using nanoimprint lithography (NIL) and a two-step deep reactive ion etch (DRIE) to create nanostructured features in silicon, and then oxidize the Si so that the channel top is self-sealing and the channel diameter is self-limiting. Particularly, 50 nm thick SiO2 layer was grown on Si and grating trenches of 30-50nm width and 200 nm period were patterned by nanoimprint lithography (NX 2000 with NX 1020 imprint resist, Nanonex) and standard RIE. The resulting SiO2 grating then acted as an etching mask for DRIE of Si, which was etched ~ 400nm deep. Characteristic *scalloping* of the sidewalls from the cyclic DRIE process can be smoothed by tailoring the etch process using reduced cycle times and lower gas flow rates [3]; here, we use two independent etching steps, starting with short cycle times and followed by a single longer etch, to create a oxide growth template for buried nanochannels.

A nanostructured grating trench, etched into a silicon substrate is shown in Fig.1a. The initial 8-cycle etch is followed by a longer, single etch to create the thermometer-like structure with a thin neck that opens to a bulb well below the surface. The silicon wafer is then oxidized in a bench-top oven (Vulcan 3-550, NDI) at 1000°C in atmosphere. Fig. 1b shows the nanochannel after 5hrs oxidation. The structure is self-sealing because the lateral oxide growth in the upper neck portion closes off the lower bulb region to further oxidation forming a sub-10nm diameter nanochannel. A similar sample, cleaved on two, orthogonal Si crystal planes is shown in Fig. 2 and clearly demonstrates that the nanochannel is fully sealed and continuous. Self-limiting channel diameters are achieved by choosing the duration of the last etch step so that all surrounding silicon is consumed before the bottom bulb portion closes. This allows wide process latitude during oxidation. Figure 3 shows self-sealed and self-limited nanochannels completely buried in grown thermal oxide. We have demonstrated a generalized method to use DRIE to sculpt silicon on the nanoscale and have shown a method to fabricate inexpensive and robust nanochannels buried in silicon dioxide.

[1] Tegnefeldt *et. al.* "The dynamics of genomic-length DNA molecules in 100-nm channels", PNAS 101(**30**), 2004.
[2] Reisner, Morton *et. al.* "Statics and Dynamics of Single DNA Molecules Confined in Nanochannels, PRL **94** 2005.
[3] Morton *et.al* "Wafer-Scale Patterning of High-Aspect-Ratio Silicon Nanostructures…", EIPBN 07, Denver 2007.

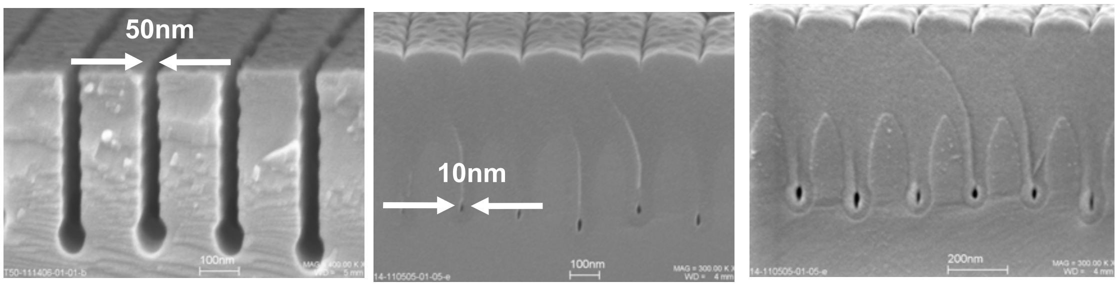

Figure 1. a) Deep Reactive Ion Etching of Nanoimprinted Silicon. Two-step etch process creates bulbous nanochannel well below substrate surface. **b)** Thermal oxidation of silicon nanostructures seal in an open nanochannel. **c)** Dilute HF dip is used to clearly delineated the oxide and silicon under SEM.

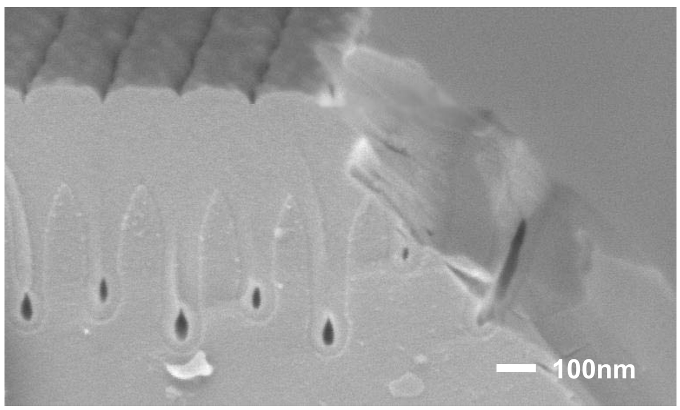

Figure 2. a) Continuity of the sealed nanochannels is shown by cleaving the substrate along two perpendicular crystal planes.

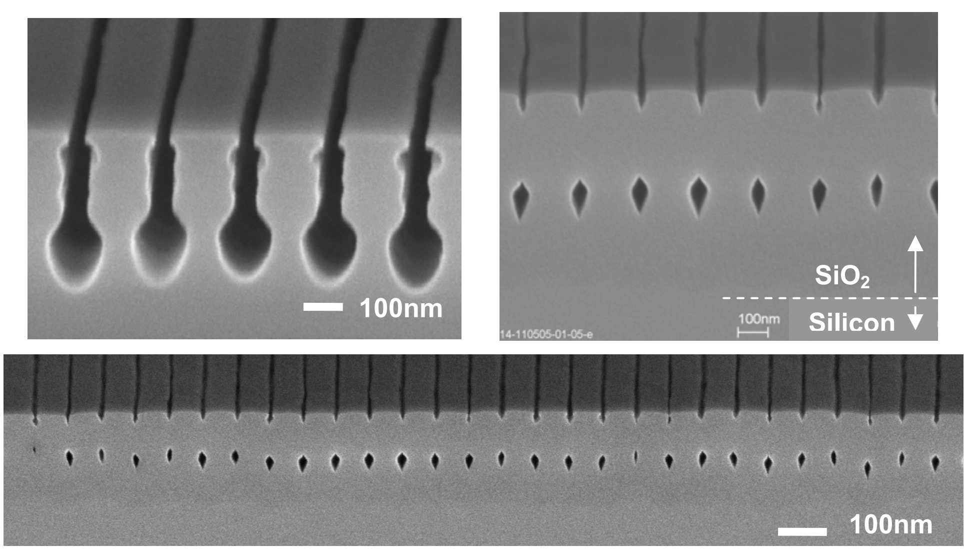

Figure 3. a) DRIE can be tailored to fabricate structures with different critical parameters. **b)** The same structure after thermal oxidation showing fully buried, self-sealed nanochannels; all the remaining silicon has been oxidized so the channel size will not change with longer oxidation times. The boundary between the silicon and oxide is shown. **c**) Wide angle view showing an array of nanochannels.