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Fabrication of In-Plane Nanochannels by Focused Ion Beam Milling

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Focused ion beam (FIB) milling is well suited for fabrication of in-plane nano-fluidic devices. With FIB milling, we are able to confine the lateral dimensions (width and depth) to the nanoscale, arrange the features in any two dimensional layout, and to integrate the nanofeatures directly into microfluidic devices. We have investigated two methods for FIB fabrication of nanofluidic channels in glass. The first technique uses a chromium film to minimize surface charging, whereas the second technique employs a flood gun to minimize surface charging. Nanochannels are milled with a single pore or multiple pores in series for resistive-pulse sensing of hepatitis B virus (HBV) capsids. Multiple nanopores in series allow sensing of each capsid multiple times for more accurate determination of relative particle size and charge.

Both fabrication techniques begin with the machining of V-shaped microchannels into a substrate by conventional microfabrication. Nanochannels are then milled into the substrate with the FIB-SEM instrument to connect the microchannels (Figure 1a). A 50-pA Ga^+ beam at 30 kV is used to mill the nanochannels, and a 20-pA Ga^+ beam at 30 kV is used to create the bridging nanopores. Figure 1b shows the nanopore dimensions are precisely controlled due to the linear milling rate of the glass. The pores can be easily milled to match the geometry of the analyte of interest for resistive-pulse sensing or other applications. The completed device composed of nano- and microchannels is sealed with a glass cover plate.

Deposition of a conductive film of chromium on the substrate minimizes surface charging and, therefore, allows for precise milling and imaging with the FIB and scanning electron microscope (SEM). Milling through a Cr film also has the advantage of screening ion beam interactions from the glass, which can be used to mill sub 5-nm channels [1]. Additionally, the chromium layer protects the surface of the substrate from redeposition of milled material on the surface around the features. However, if the film is not uniformly thick, milling through the chromium layer can lead to unwanted depth gradients, which are particularly noticeable at nanometer length scales

Alternatively, an electron flood gun can be used to minimize surface charging by bathing the surface of the device with a low energy electron beam during the milling process. Use of a flood gun circumvents the need to coat the substrate with a conductive metal film. An example of a nanochannel milled by this method is shown in Figure 2. The nanochannel has two nanopores in series for resistive pulse sensing of virus capsids. The nanopores have a cross-section of 40 nm x 40 nm, which is tailored to sense the HBV capsids (36 nm diameter). This device permits the sensing of capsids as they pass through the nanopores which allow the determination of relative size from the pulse amplitude as well as electrophoretic mobility from the transit time between the pores. Figure 3 shows the current trace from sensing of HBV capsids [2].

References:

[1] L. Menard and J. M. Ramsey, Nano Letters **11** (2011), p. 512-517.
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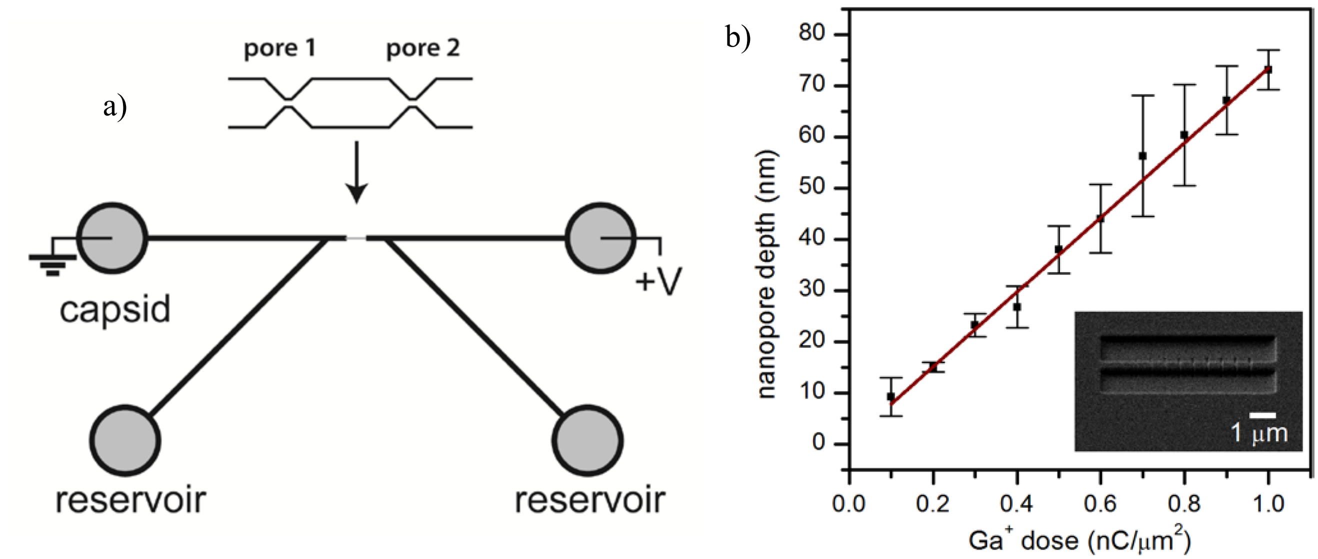

Figure 1. a) Schematic of two V-shaped microchannels with a bridging nanochannel b) Variation of nanopore depth with Ga^+ dose, as measured by AFM. The inset shows an SEM image of pores milled with increasing Ga^+ dose.

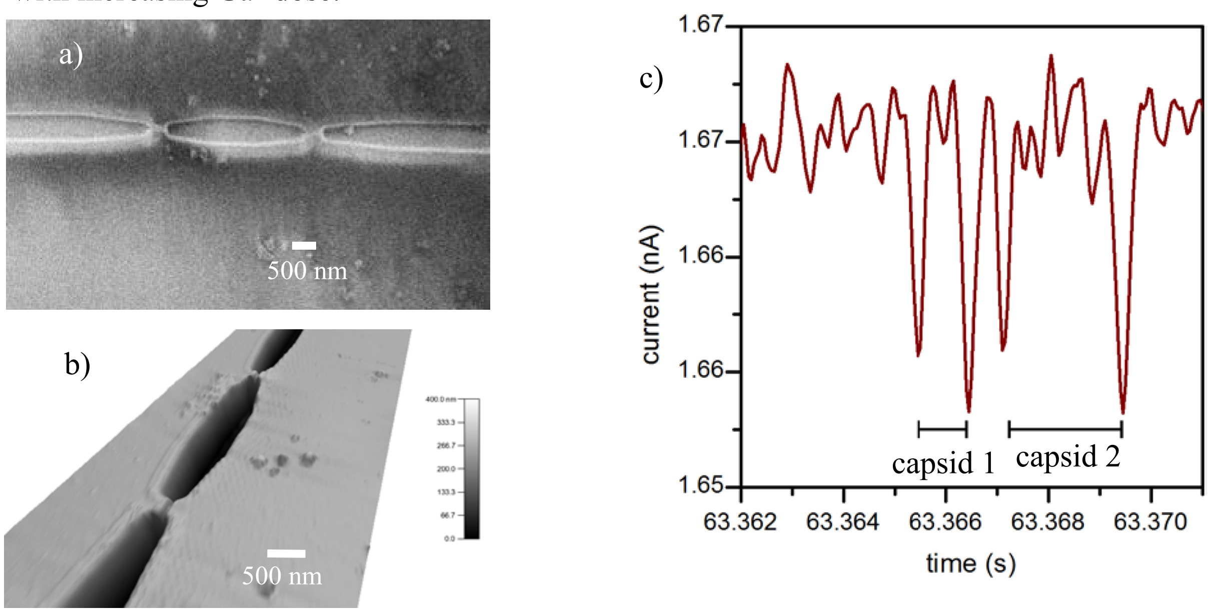

Figure 2. a) SEM image of two nanopores in a nanochannel milled by the flood gun method. b) AFM image of the device in (a). c) Variation of current with time through the two-pore nanochannel device in (a) for resistive pulse sensing of HBV capsids. Each current pulse corresponds to the transit of one capsid through one nanopore.

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