Reflected beam illumination microscopy using a microfluidics device – progress report 6/15/14;

Conrad D. James, Patrick S. Finnegan, Ronald F. Renzi – Sandia National Laboratories

For FY14, the Sandia National Laboratories team has designed and fabricated a first generation rapid testing microfluidic device with integrated sidewall mirrors. Several methods currently exist to fabricate and optimize 45degree angled sidewalls in silicon [Seale 2008, Xu 2011], and for this effort we have utilized the potassium hydroxide (KOH) with organic surfactant approach [Rola 2014]. The schematic of the current device fabrication approach is shown in Figures 1 and 2. Silicon wafers with (100) orientation were cleaned and then a 1 μm thermal oxide was grown on the substrates. Photoresist was spun on wafers, and then channel features of varying width (50 -200 μm) were created on the substrates using photolithography. The features were then transferred into the oxide with a reactive ion etch (Figure 1c). Channels with 45 degree angled sidewalls were then etched into the silicon substrate using a KOH solution with TritonX-100 detergent added to improve the smoothness of the etched sidewalls [Rola 2014]. Since the KOH etch chemistry is selective for silicon and doesn't etch the silicon dioxide, the oxide mask is undercut during the etch process leaving oxide overhangs (Figure 1e-f).

After the wet etch process, the substrates were rinsed thoroughly, and subjected to a buffered hydrofluoric acid etch to remove the oxide mask (Figure 2a). Atomic force microscopy (AFM) was used to examine the surface roughness of the sidewalls (R_{rms}=4.14nm) in comparison to the roughness of the top of the silicon wafer that was previously under the oxide mask (R_{rms}=1.75nm). The bottom surface of the channel has increased surface roughness due to the difference in the etching plane of the bottom surface (100) to the sidewalls (110). After another batch of thorough rinsing, substrates were placed into an evaporator and coated with a thin layer of aluminum metal (Figure 2b). Aluminum was chosen due to its high reflectivity in the optical wavelength range compared to other metals. Figure 2d shows a channel with 45° angled sidewalls as measured with scanning electron microscopy (SEM) and contact profilometry. After wafers were coated with aluminum, they were sawed into chips in order to leave open ended channels at two opposing edges of each chip (Figure 2e). Then, chips were anodically-bonded to pyrex coverslips to enclose the microchannels for testing. The open-ended channels allowed for suspensions of cells to be placed at the end of a set of channels, and capillary forces drew the suspension into the channels.

After preliminary testing was completed, we initiated the design process to generate a full multi-layered microfluidic system for the reflected beam micromirror chips. Figure 3 shows an example schematic of a second prototype microfluidic device. The channel inlets and outlets (black circles, 200 micrometer diameter) are located at the distal ends of the channels (red). The channel width is varied from 50-300 micrometers wide in order to examine the impact of the channel width (and thus distance between mirrored side-walls) on the reflected beam imaging. The inlets/outlets will be etched into the silicon substrate using the deep reactive ion etching technique [Laermer 1996]. This method will produce axially-straight etches from the back side of the substrate to the front side where they will interface with the wet-etched channels.

The inlets/outlets will be placed at the ends of the channels such that 45° mirrored sidewall portions of the channels are not sacrificed. After the inlets/outlets are etched, the chips will be interfaced with a microfluidic manifold that allows the robust coupling of commercially-available fluidic tubing to the chip and to a syringe pump.

References:
Seale et al., J Microscopy (2008), 232:1.
Xu et al., Sensor Actuat A-Phys (2011), 166:164.
Rola et al., Microsyst Technol (2014), 20:221.
Laermer, F., and Schilp, A., 1996, U.S. Patent No. 5,501,893.

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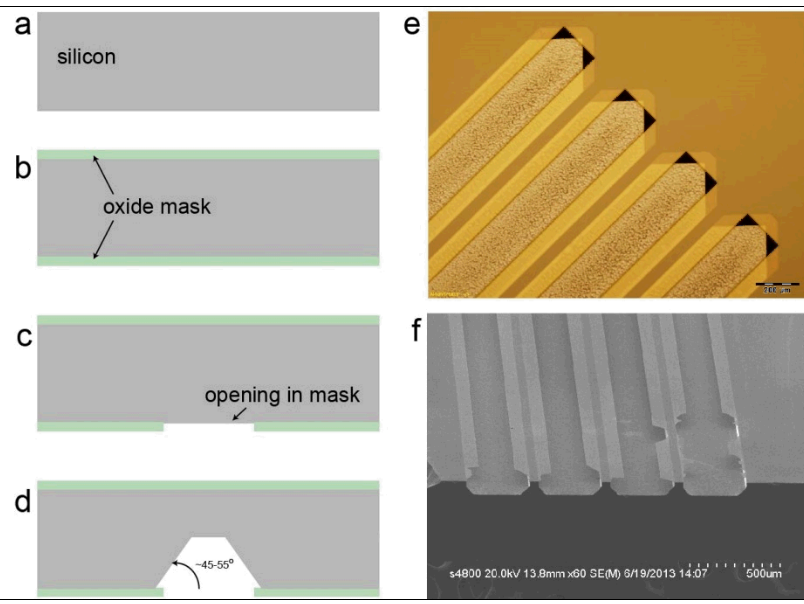

Figure 1: (a-d) Fabrication process for producing microchannels with 45° angled sidewalls. (e) Optical micrograph and (f) scanning electron micrograph of a set of microchannels with the oxide mask left on top.

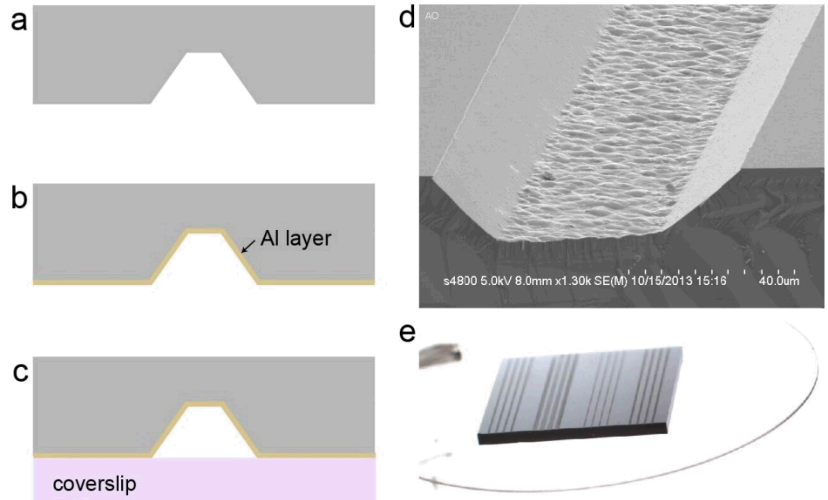

Figure 2: (a-c) Final fabrication steps for producing microchannels with highly reflective mirror sidewalls for reflected beam imaging of cells. (d) Scanning electron micrograph of a microchannel with 45° angled sidewalls (e) Optical micrograph of a microchannel chip anodically-bonded to a pyrex glass coverslip.

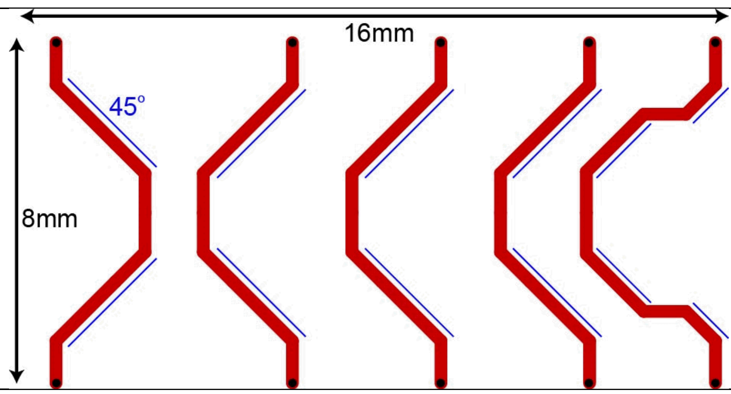

Figure 3: Schematic of the second generation microfluidic channel device with integrated sidewall mirrors. The inlets/outlets (black) are located at the distal ends of the channels (red). The regions where the sidewalls will be angled at 45° (from the substrate surface) are highlighted (blue).