Fabrication and Sharpening of Silicon In-plane Microneedles with Open Capillary Networks

Y. Li[1,2], H. Zhang[1], R. Yang[1], C. Zhu[1], W. Hu[1], F. Tazrin[1], M. Kaddoura[2], E. J. M. Blondeel[2], B. Cui[1]
[1]Department of Electrical and Computer Engineering, University of Waterloo, 200 University Ave. West, Waterloo, ON, N2L 3G1, Canada
[2]ExVivo Labs Inc., 3 Regina St. N, Waterloo, ON, N2J 2Z7, Canada
y2554li@uwaterloo.ca

Microneedle technologies have drawn increasing attention for realizing the minimally-invasive platform, capable of monitoring the biochemical and neurochemical information in a real-time and continuous fashion.[1] The consistent monitoring of biomarkers necessitates adequate long needles to reach sufficient penetration depths for accessing abundant dermal bodily fluids.[2,3] As such, the in-plane needles (i.e., needle axis parallel to wafer surface with length defined by the lithography step, unlike out-of-plane needle with needle length defined by the etching step) are preferred for easy fabrication of long needles.[4,5] This work presents a deep reactive ion etching (DRIE) of silicon in-plane microneedles integrated with open capillary microfluidic networks.

The schematic processing is shown in Fig. 1a-c. First, A single layer of AZ 4620 photoresist with a thickness about 10 μm is spun onto a 4-inch wafer (380 μm thickness), following by a standard photolithography (Fig. 1a). Then the Bosch DRIE process is used for simultaneous etching of 200 μm wide needle shafts and 10 μm wide trenches from the same side (Fig. 1b). The etching of the narrow trenches is switched off automatically at a certain depth associated with the aspect-ratio depended etching, without needing a separated masking. Finally, the needle shaft is sharpened by using a mixed solution of hydrofluoric acid and nitric acid in the presence of a remaining silicon at bottom (Fig. 1c).

Alternatively, a double-sided processing is developed on a 4-inch wafer (double-side polished, 500 μm thickness), as shown in Fig. 1d-f. First, the wafer backside is patterned by photolithography and DRIE to etch 10 μm wide open trenches (Fig. 1d). The process is repeated for the frontside, but rather than trenches, the photoresist is patterned to allow through-wafer etching of needle shaft aligned to overlap with the trenches (Fig. 1e). The last step is the isotropic wet etching for sharpening the needle shaft (Fig. 1f). Here the trench side of the wafer is attached to another fresh Si wafer to incorporate the sacrificial layer and protect the trenches against the attack of the aggressive chemicals. This final step is a critical and novel process for creating sharpened in-plane microneedle structures. The tip sharpening is realized by incorporating Si sacrificial structures that resulted in decreased etching rates from the tip top to bottom, associated with the buildup of concentration gradient of the etching species.

In the experiments, in-plane microneedles with tip radii less than 5 μm, tapering smoothly from the apex to the base, are fabricated by performing the Bosch DRIE and subsequently wet etching on the frontside only (Fig. 2, using steps shown in Figure 1a-c). Etching from both sides (using steps shown in Fig. 1d-f) results in millimeter-long sharpened Si microneedles with well-protected open microfluidic channels (Fig. 3). Such sharp microneedles have been demonstrated to be sufficiently robust to penetrate porcine skins, with needles being intact after repetitive penetrations. The capillary filling of the open microfluidic network with water is also demonstrated.

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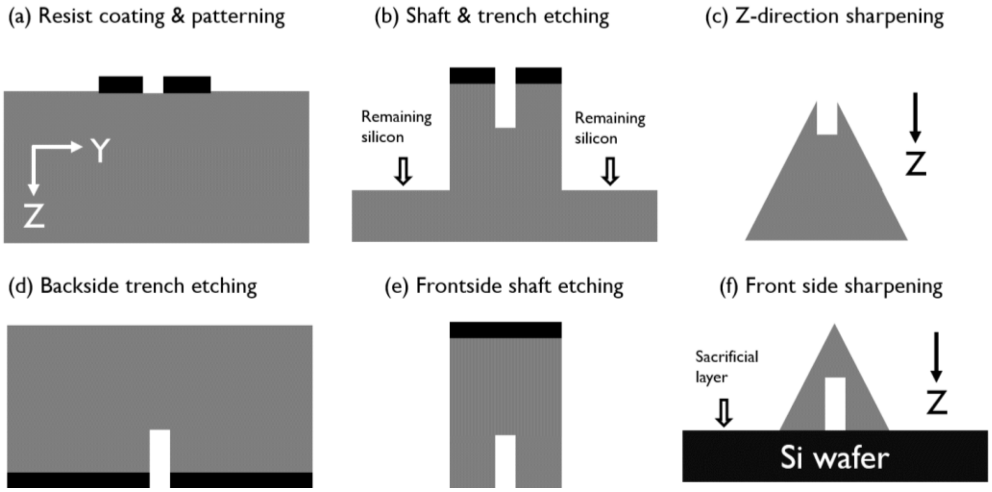

Figure 1: Schematic fabrication and sharpening of in-plane silicon microneedles.

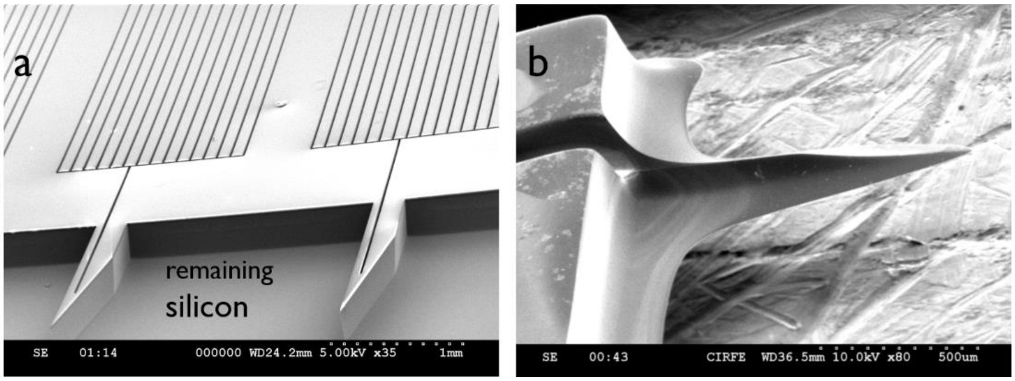

Figure 2: SEM micrograph of the single-side processed in-plane microneedles: (a) before and (b) after sharpening.

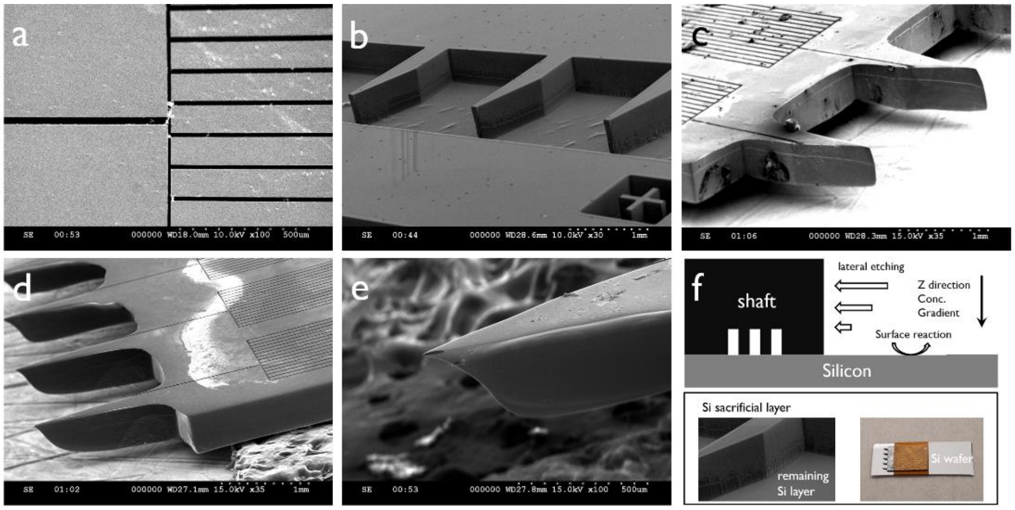

Figure 3: SEM micrograph of the double-side processed microneedles: (a) 100 cycles backside trench etching; (b) 900 cycles and (c) 1200 cycles frontside needle shaft etching; (d) sharpened needle and (e) zoom-in view of needle tip, (f) schematics of the sharpening mechanism.