Ultra high aspect ratio sub-50 nm deep silicon trenches by photo-assisted electrochemical etching

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Deep silicon etching using cryo-etching or non-switching Bosch process has been well developed that can achieve nanoscale ultra-high aspect ratio (protruded) pillar or line structures [1-2]. However, it is far more challenging to etch (recessed) deep nanoscale holes or high aspect ratio narrow trenches because the etching gas/etching product would have difficulty to get into/out of the holes or trenches. Here we show that with optimized process sub-50 nm wide and ~33 μm deep trenches (aspect ratio 660:1) was obtained using photo-assisted electrochemical etching, which has been studied since 1990s as a deep etching technique [3-4].

Figure 1 showed the etching setup, as well as the process steps for the fabrication of 2D inverted pyramid or 1D V-shaped trench array. The electrochemical etching occurs preferably at positions with high electrical field, i.e. the sharp tips of the inverse pyramid or V-shaped trenches etched into silicon using anisotropic KOH etching. The substrate was chosen as <100> n-type silicon with 1-5 Ω.cm resistivity. For electrochemical etching, a solution of hydrofluoric acid : ethanol : deionized water (1:2:7) was prepared as electrolyte. An infrared LED (λ = 850 nm) was used for illuminating backside of the Si in order to produce electron-hole pairs. The etching current was 3 mA and time was 20-30 min.

Figure 2 showed the electrochemical etching results. As it is nearly impossible to break the wafer along the entire length of the nanoscale pore, only sections of the pores were revealed (Fig. 2a). The pore has a diameter of ~100 nm and height of 45 μm. For etching started with 1D V-shaped trench array, sub-50 nm wide and ~33 μm deep trenches were formed (Fig. 2b-c). Interestingly, when the trenches were not adequately etched for the two slopped sides to meet, etching occurred on both sides, leading to two high aspect ratio narrow trenches for each starting wide trench (Fig. 2d).

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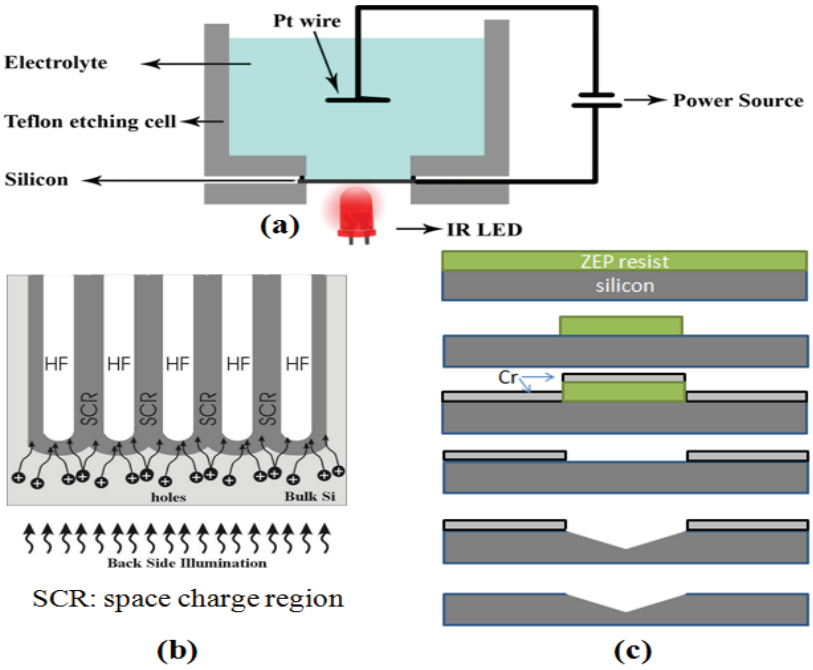

Figure 1. Photo-assisted electrochemical etching of silicon. (a) Schematic experimental setup; (b) Etching mechanism; (c) Process steps for the fabrication of inverse pyramid or V-shaped trench structures by electron beam lithography and KOH etching.

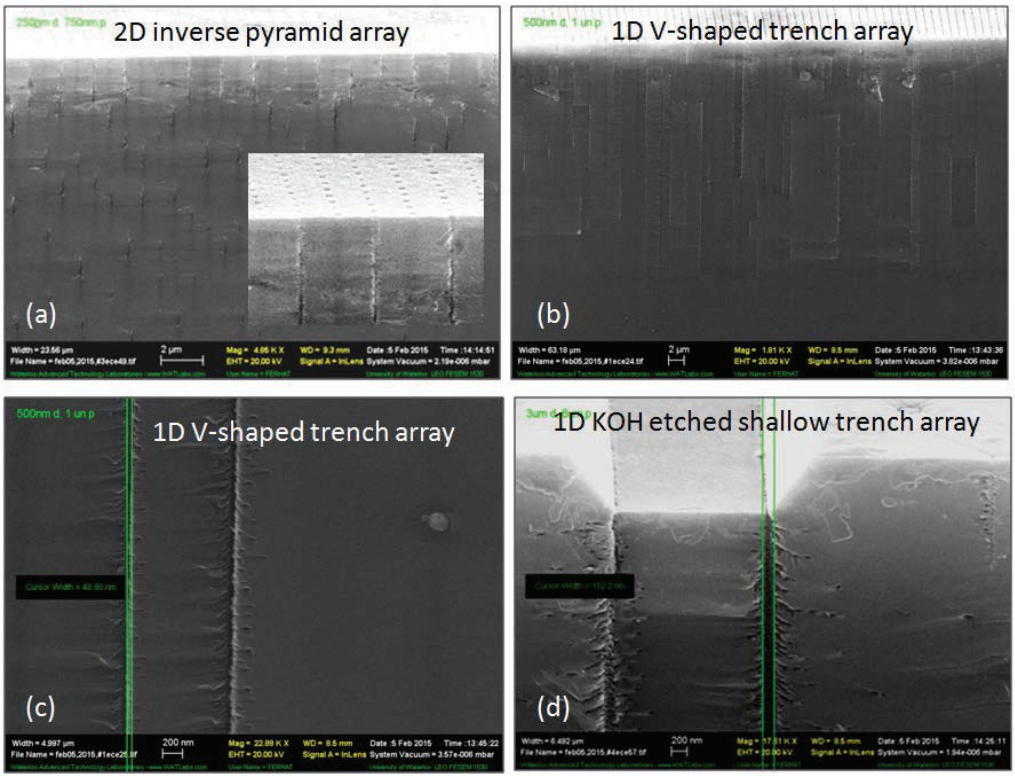

Figure 2. SEM images of deep pores or trenches etched into silicon by photo-assisted electrochemical etching. (a) 2D pore array with pore diameter of about 100 nm and depth of 45 μm; (b-c) 1D trench array with aspect ratio of 660:1 (50 nm wide, 33 μm deep); (d) Etching of a " _/ " shaped trench, with two narrow trenches resulted from the two sides of each original wide trench.