Buried nanochannels and texturized surfaces fabricated by focused helium ion implantation

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The focused helium ion beam microscope is a versatile nanofabrication instrument achieving direct-write and resist-based lithography with sub-10 nm resolution [1]. In initial investigations of helium ion beam processing for applications in the semiconductor industry, subsurface damage and swelling of bulk silicon substrates due to helium ion implantation was noted [2]. However, subsequent research showed that the generally deleterious swelling effect can be leveraged for specific nanofabrication tasks [3]. The swelling effect results from the formation of helium nanobubbles, which for increasing ion dose, coalesce and form larger voids [4]. We explore these swelling effects for silicon substrates and demonstrate tailored nanofabrication techniques for forming subsurface nanochannels and textured surfaces. Following are two application examples.

Firstly, site-specific and predictable swelling height at a given ion dose (Fig. 1a) enables the deterministic formation of an array of hemispherical protrusions in pure silicon. Here, helium ions were shallowly implanted (Fig. 1b) under normal incidence, with 15keV energy, and a dose of 5×10^{17} ions/cm^2. 1μm circles in a 4 by 4 array were scanned concentrically from outside in using a 1pA beam (nominal probe size 0.5nm) with a scan spacing of 0.5nm.

Secondly, one can induce extended lateral voids to form more complex planar geometries. In Fig. 1c, we present a set of annular structures patterned in silicon under normal incidence, with 15keV energy, and varying doses. Each annulus has a nominal inner radius of 0.7μm and nominal outer radius of 1.2 μm scanned concentrically from inside out using the same beam specifications as above. A portion of one annulus was cross-sectioned using focused gallium ion beam milling at 30keV (Fig. 1d), revealing an open nanochannel within the annular structure. Thus, one can pattern with predictable swelling heights and also fabricate subsurface nanochannels.

In summary, we propose that the controlled formation of voids and subsurface channels combined with the nanoprecise positioning accuracy of the helium ion microscope can enable applications in as yet underexplored areas. This ion implantation technique may be used to prototype different surface textures for strain engineering as well as to form custom near-surface channels for nanofluidic devices.

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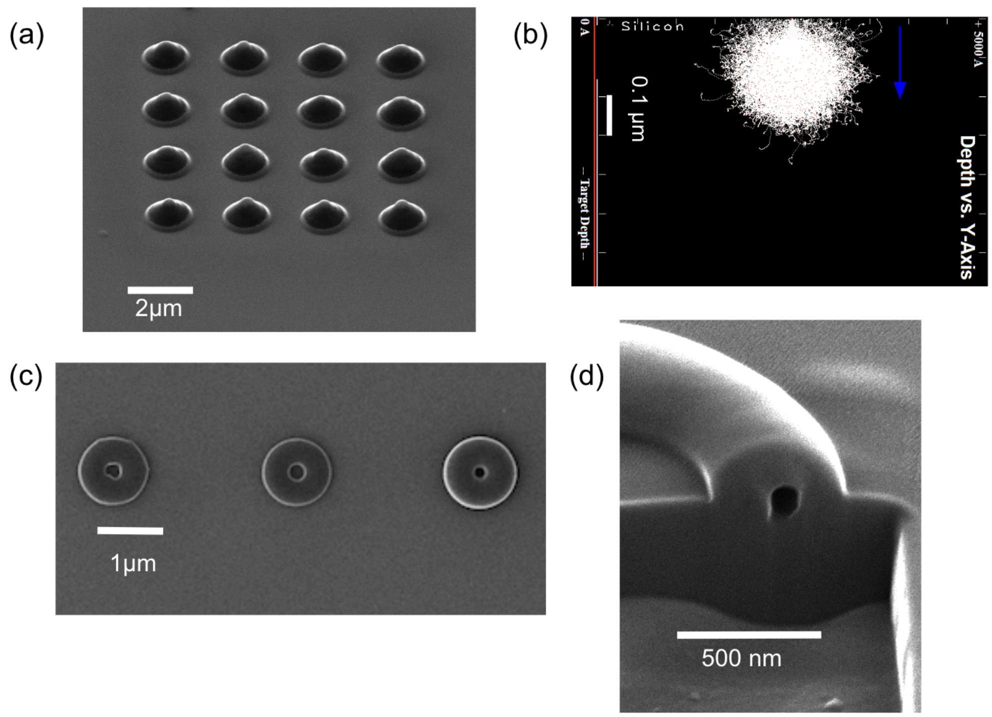

Figure 1: (a) Helium ion micrograph of a 4x4 array of raised 1μm circles fabricated using 15keV helium ion implantation into bulk silicon using a dose of 5×10^{17} ions/cm^2. (b) SRIM simulation of 15keV helium ions incident on silicon shows the shallow penetration depth. (c) Dose series of helium ion irradiated annulus patterns at 6×10^{17}, 7×10^{17}, and 8×10^{17} ions/cm^2. An annulus fabricated using 6×10^{17} ions/cm^2 dose was cross-sectioned by gallium FIB as shown in (d), revealing the subsurface channel.