3D Patterning of Si Micro and Nano Structures by Focused Ion Beam Implantation, Si Deposition and Selective Si Etching

Andreas C. Fischer, Kristinn B. Gylfason, Lyubov M. Belova, B. Gunnar Malm, Mohammadreza Kolahdouz, Göran Stemme and Frank Niklaus
KTH Royal Institute of Technology, Stockholm, Sweden
andreas.fischer@ee.kth.se

Yuri G.M. Rikers
FEI Electron Optics, Eindhoven, The Netherlands

The ability to micro- and nanostructure silicon (Si) in three dimensions (3D) brings a wealth of opportunities in MEMS, NEMS, nanoelectronics, and nanophotonics, due to the beneficial mechanical, electronic, and optical properties of Si. However, complex 3D Si structures can only be implemented by using complicated process schemes involving advanced semiconductor processes. The implementation of simple Si micro and nanostructures has been demonstrated by using localized ion implantation with a focused ion beam (FIB) in combination with subsequent selective Si etching [1-3].

We report a method for additive layer-by-layer fabrication of arbitrarily shaped 3D Si micro- and nanostructures. This method is schematically illustrated in Figure 1, and involves an iterative process of defining a pattern with implanted gallium ions (Ga^+) in Si layers using FIB writing (Figure 1, Steps 1 and 3), followed by chemical vapor deposition of 40-70 nm thick Si layers (Figure 1, Step 2). The local implantation of Ga+ ions into Si causes an etch selectivity towards various wet or dry etching techniques [1-3]. By repeating Steps 2 and 3, 3D structures are defined within the deposited Si layers. The defined 3D Si structures can be formed by selective free-etching (Figure 1, Step 4) as a final patterning step.

To demonstrate the method, the 3D Si structures shown in the SEM image in Figure 2a have been fabricated by two implantations and one Si deposition. The structures consist of four raised Si platforms, with cantilevers extending out from the platforms. The resulting suspended beams have a width of 500 nm, a thickness of 40 nm and a length of up to 4 µm. Indicated in Figure 2a are the enlarged areas shown in Figures 2b and 2d, the line height profiles of Figures 2e and 2f, and the cross section of Figure 3. Figure 2b is an enlarged view of two cantilever beams. The KOH etch has freed the narrow beam, while the wide beam is still supported. The beams show no signs of stress, and are flat after the free-etch. Figure 2c shows the height profile of the complete structure, as measured by white light interferometry.

---

[1] J. Brugger, et al., "Si Micro/Nanomechanical Device Fabrication Based on Focused Ion Beam Surface Modification and KOH Etching", *Microelectronic Eng.,* Vol.35, pp.401-404, 1997.
[2] B. Schmidt, et al., "Writing FIB implantation and subsequent anisotropic wet etching for fabrication of 3D structures in Si", *Sens. Act. A*, Vol.61, pp.369-373, 1997.
[3] N. Chekurov, et al., "The fabrication of Si nanostructures by local gallium implantation and cryogenic deep reactive ion etching", *Nanotechnology*, Vol.20, pp.065307, 2009.

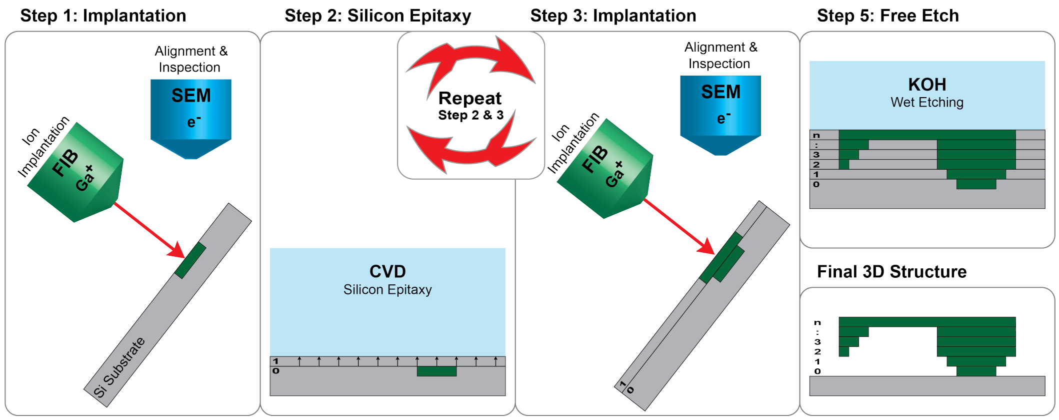

Figure 1: *The process scheme for 3D-patterning of arbitrarily shaped Si micro- and nanostructures, using focused ion beam writing, Si epitaxy, and selective Si etching in KOH.*

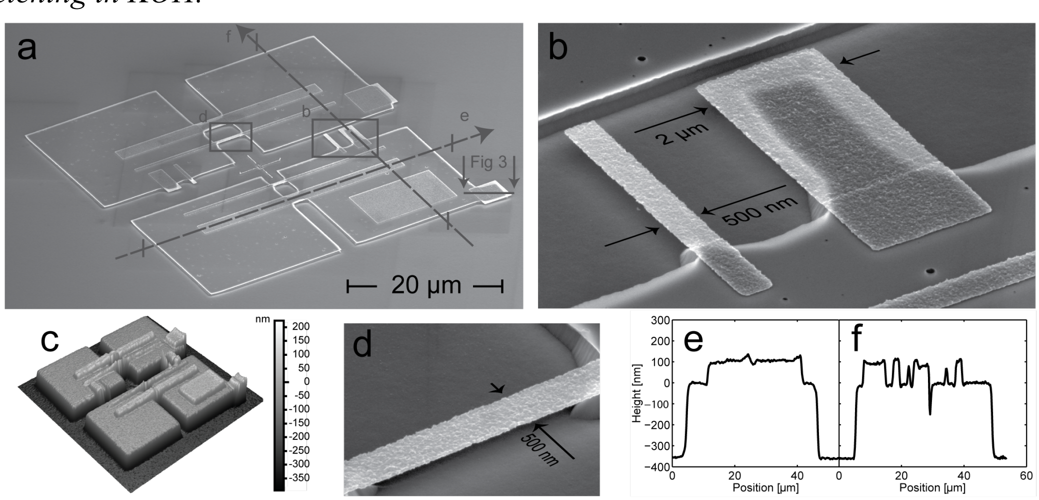

Figure 2. *a) An SEM image of the fabricated 3D structure. Indicated in the image are the enlarged areas shown in b and d, the line height profiles of e and f, and the cross section of Figure 3. b) An enlarged view of two cantilever beams. It is visible that the narrow beam is free-etched while the wide beam is still supported. c) The height profile of the complete structure, as measured with white light interferometry. d) An enlarged view of a doubly clamped beam. e) Height profile along a doubly clamped beam. f) Height profile along a cantilever beam.*

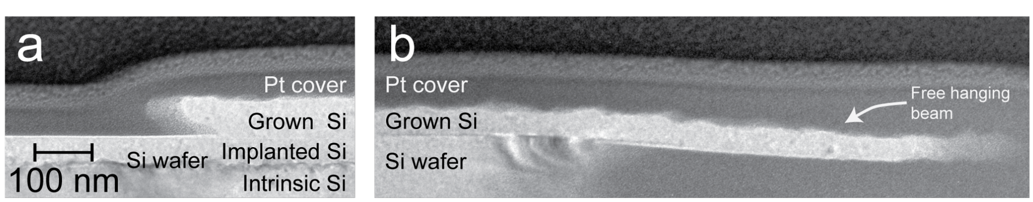

Figure 3. *TEM cross sections at: a) The edge of the deposited and implanted beam layer. b) The suspended deposited and implanted beam layer.*