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Fabrication of 3-Dimensional Silicon Structures with Greyscale DRIE

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***Abstract*— A method is presented to fabricate complex 3-dimensional (3D) silicon objects using a simple three step process composed of commonly available fabrication procedures. The combination of greyscale photolithography, silicon etch, and Silicon-on-Insulator wafer lift-off allows for near-arbitrary 3D structure fabrication without overhangs with a vertical resolution as fine as 60 nm and horizontal resolution of 600 nm using the equipment described.**

***Clinical Relevance*— The fabrication of stiffening devices for neural implants is time consuming due to the complexity of 3D shanks designed to reduce insertion force. This method allows a faster fabrication process for such stiffeners as well as similar objects.**

I. INTRODUCTION

Neural implants face an optimization challenge between making devices stiff enough to enter brain tissue without buckling, while being flexible to minimize mechanical mismatch with the tissue [1]. The use of stiffening devices which can later be removed from brain tissue allows for an approximation of both needs [2]. However, wafer-scale fabrication of sufficiently sharp 3-dimensional microstructures can be a costly and time-consuming task, often requiring many steps [3].

We describe a sub-micron resolution fabrication method to produce complex 3-dimensional silicon objects such as neural implant insertion shuttles in a single expose-develop-etch process. This is achieved by performing greyscale lithography, deep reactive-ion etching (DRIE), and hydrofluoric acid (HF) etch release on a silicon on insulator (SOI) wafer.

II. METHODS

Greyscale lithography was performed with AZ4620 photoresist spun to 5 µm, though other resists produced comparable results. Patterns were designed with KLayout (klayout.de), exported as .DXF files to a Heidelberg MLA150 Maskless Aligner, and exposed with a 375 nm laser, with the exposure dose modulated between 0 and 510 mJ/cm^2.

An SPTS Pegasus DRIE was used with 2s deposition step (125 sccm C_4F_8, 20 sccm SF_6, 20 sccm O_2, coil 2000 W, platen 0 W) and 3.5s etch step (125 sccm SF_6, 200 sccm O_2, coil 2800 W, platen 120 W).

Wafers were soaked in 49% HF for 24-36 hours to etch the buried oxide layer, releasing the devices.

III. RESULTS

Photoresist sensitivity was observed at exposure doses above 40 mJ/cm^2, with full resist removal observed at doses of approximately 200 mJ/cm^2 and above. The MLA150 has a minimum step of 2 mJ/cm^2, which produced a 60 nm step height in resist. Final structures achieve a horizontal (x-, y-) resolution limited by the tool resolution (600 nm with the MLA150) and a vertical (z-) resolution determined by etch selectivity, with a 1:1 selectivity producing 60 nm steps. Fig. 1 shows a pattern on a test wafer etched at a 7:1 selectivity to demonstrate a structure suitable for use in future neural implant stiffener fabrication.

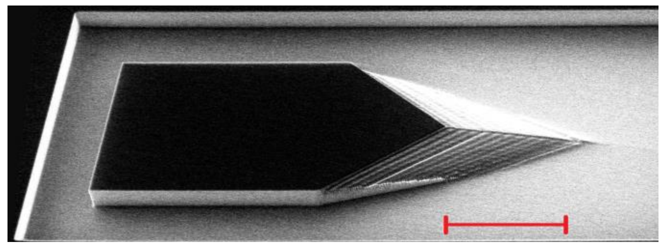

Figure 1. SEM image of a prototype for a neural implant shuttle etched into a non-SOI wafer. The 7:1 (Si:Photoresist) etch selectivity used here allowed for a maximum structure height of 32 µm, with up to 75 steps of 0.4 µm height each. Scale bar 100 µm.

IV. DISCUSSION & CONCLUSION

Demonstrated here in the context of neural implant shuttle fabrication, greyscale photolithography with anisotropic etching offers a wide range of potential applications for microfabricated device and complex shape development as well as offering significant time and cost savings for existing designs. Due to its modularity, this procedure can be extended to any toolset capable of a greyscale photoresist exposure and an anisotropic etch process with tunable selectivity between the target material and photoresist, with (optionally) a release etch process.

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