Techniques of cryogenic reactive ion etching in silicon for fabrication of sensors

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Cryogenic etching of silicon, using an inductively coupled plasma reactive ion etcher (ICPRIE), has extraordinary properties which when utilized can lead to unique structures difficult to achieve in other etching regimes. In this work, we demonstrate three techniques which capitalize on the cryogenic properties to create several sensors for the optical, electrical, magnetic, and mechanical regimes. The techniques demonstrated here are: single step deep etches with controllable sidewall profiles, using the cryogenic etch for thick metallization and liftoff with a thin photoresist masks, and finally use of a two step cryogenic etches for deep etching with reduced sidewall undercutting.

High selectivity of silicon over photoresist and silicon dioxide permit high aspect ratio structures, of up to 10 to 1 to be etched in a single etch step. This feature is used to create 70-90 micron tall silicon pillars with diameters of 5, 10, 20, and 50 microns arranged in a hexagonal array, from 1.5 microns of photoresist for use as solar cells. Since the passivation and etching are performed simultaneously in cryogenic etches, chopping roughness is not seen and smooth sidewalls are formed. Sidewall profile is controlled using a single gas, O_2, allowing for the angle to be varied from positive to negative sloping.

The high selectivity of photoresist means that the mask can also be utilized for both as the etch mask and a metallization mask. A 1.5 micron photoresist mask allows for a 20-30 micron trench to be etched in silicon. The sample then can be metalized, using thermal evaporation, with over 15 microns of copper or over 7 microns of iron. Liftoff is subsequently performed using the etch mask. This technique transfers the demanding profile requirements of thick photoresist to the more controllable and repeatable etching process for creation of planar microcoils in silicon with copper and magnetic shims in silicon with iron.

As a final example, taking advantage of the anisotropic nature of cryogenic etching, the cryogenic etch was applied in making a MEMs mechanical resonator. Utilizing the high selectivity of silicon dioxide, as an etch mask, deep silicon etches are demonstrated in a two step process. The first step is etched with minimal forward power to protect the mask as long as possible, then a second etch step is employed with higher forward power to get the etch reactants deeper into etch trench. Employing the second step allows for extension of etch depth with significantly reduced lateral etching and mask undercutting.

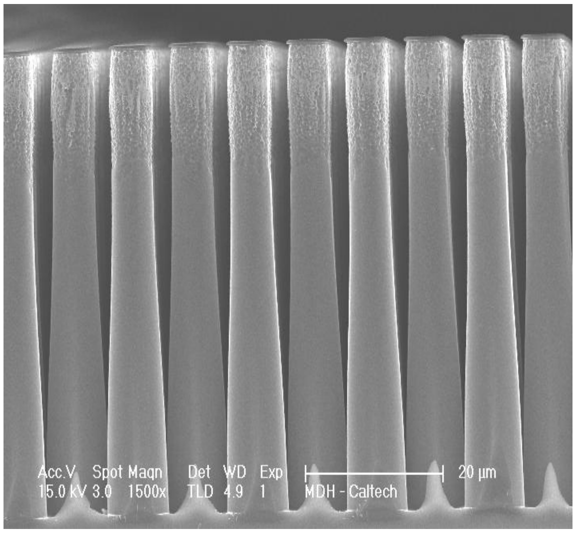

Fig 1. High aspect ratio silicon photo detectors etched using a 1.5 micron photoresist mask demonstrating profile control of cryogenic etching.

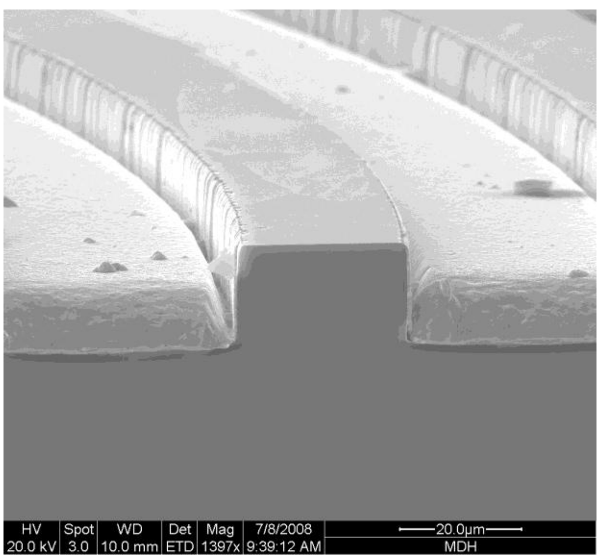

Fig 2. Cross section of 9 microns of copper embedded 20 microns deep into silicon. This demonstrates the second cryogenic etching technique of using the thin 1.5 micron thick photoresist etch mask to liftoff thick metallization for creation of planar microcoils.

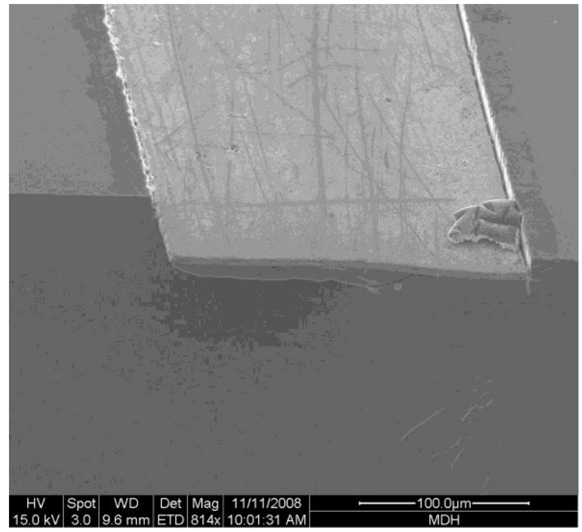

Fig 3. Cross section of 7 microns of iron embedded 18.5 microns deep into silicon. This demonstrates the second cryogenic etching technique of using the thin 1.5 micron thick photoresist etch mask to liftoff thick metallization for creation of iron magnetic shims.

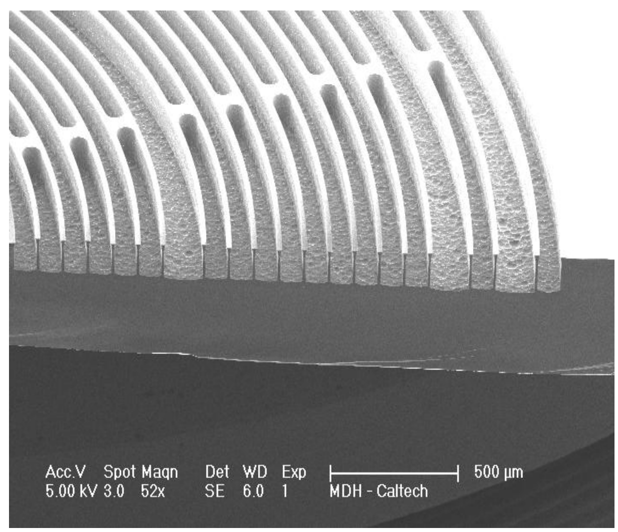

Fig 4. Cross section of a MEMs resonator etched 175 microns into silicon using a 5 micron silicon dioxide mask. This demonstrates the third technique, utilization of a two step cryogenic etch changing from low to high Forward etching power.