Mask-less Wet Etching using Laser Induced Local Heating

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Mask-based photolithography and parallel processing enable large scale batch fabrication which reduces the cost of high-volume products. However, this manufacturing paradigm makes prototyping very expensive, because masks require frequent redesigns and batch fabrication tools require process optimization, which becomes obsolete when the mask is redesigned. To facilitate prototyping we are developing a method for selective etching which does not require any mask. We report on a mask-less process for deep potassium hydroxide (KOH) wet etching of silicon. The silicon is exposed to the etchant over its entire surface, but etching location and rate are controlled by localized heating with a laser.

The system (Figure 1) consists of a 532nm green laser with maximum output power of 10W. The laser is passed through various focus and attenuation optics before arriving at normal incidence to the silicon substrate. The system allows for real time digital imaging in both bright and dark field illuminations while the laser is active and during etching. The sample is contained in a copper (chosen for KOH etch resistance) chip holder, which accepts 1cm x 1cm chips < 3mm in thickness. The liquid chamber of the chip holder is flooded with KOH and a glass cover slip is placed without adhesion to over the liquid chamber to prevent splashing. Although the chips are currently limited to 1cm^2, the sample stage can handle a 4” wafers and allows travel to the full sample. The sample stage has micron precision motion control in the XY plane and may be driven through a LabView program. This program allows controlled position, speed, and acceleration using command line interfaces or through free hand control with a joystick.

Like many chemical reactions the etching rate of Si (in any crystal orientation) by KOH is described by the Arrhenius Equation [2]:

$$R = R_0 \exp(-E_a/kT) \qquad (1)$$

where R_0 is a material-specific etch constant, E_a is the activation energy, k is Boltzmann’s constant, and T is the temperature in Kelvin. To limit the natural etching as much as possible, the chip and holder are chilled to ~273K in a standard commercial freezer. A SEM of a resultant etch hole from this setup with a 4min etch at an input laser power of 4W is shown in Figure 2. Note that the <111> crystal planes, which etch much slower than the <100> or <110> planes, are evident and show significant redeposition. A dark field video of this experiment was awarded the image Grand Prize at EIPBN 2007 and can be viewed at www.eipbn.org/video1.html. By chilling the KOH along with the holder and chip but maintaining all other experimental conditions, the redeposition is greatly reduced and the limitations in etching by the <111> planes can be widely overcome (Figure 3). By chilling the KOH etch depth can be increased (over 30μm). The etch depth achieved with various etching times is shown in Figure 4. We are currently investigating the possibility of further enhancing the etching selectivity by using electrostatic potential [3] to slow the etch rate where the substrate is not heated.

References:

[1] R.J. von Gutfeld, “Laser-enhanced patterning using photothermal effects: maskless plating and etching,” J. Optical Society of America, Vol. 4, No. 2, February 1987

[2] M.M. Noor, B. Bais, and B.Y. Majlis, “The Effects of Temperature and KOH Concentration on Silicon Etching Rate and Surface Roughness,” Proceedings of ICSE, pp 524-528, Penang, Malaysia, 2002.
[3] G.T. Kovacs, Micromachined Transducers Sourcebook, McGraw-Hill, 1998.

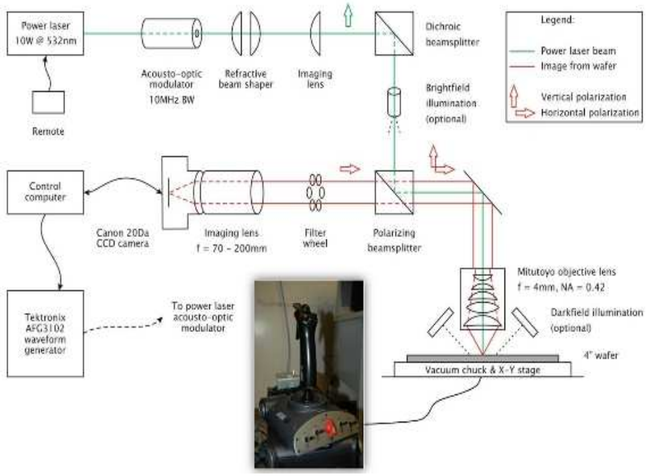

Figure 1: Laser etching system setup.

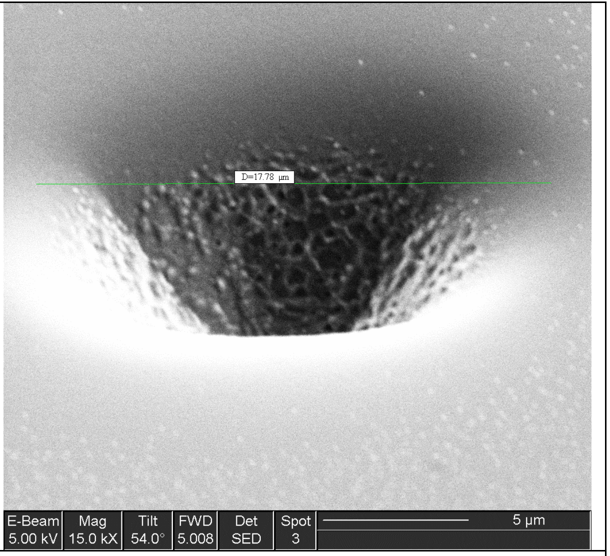

Figure 2: A scanning electron micrograph of an etched hole with a 10µm laser beam size. The resulting etch hole size is ~17.5µm, and the <111> planes of KOH are evident.

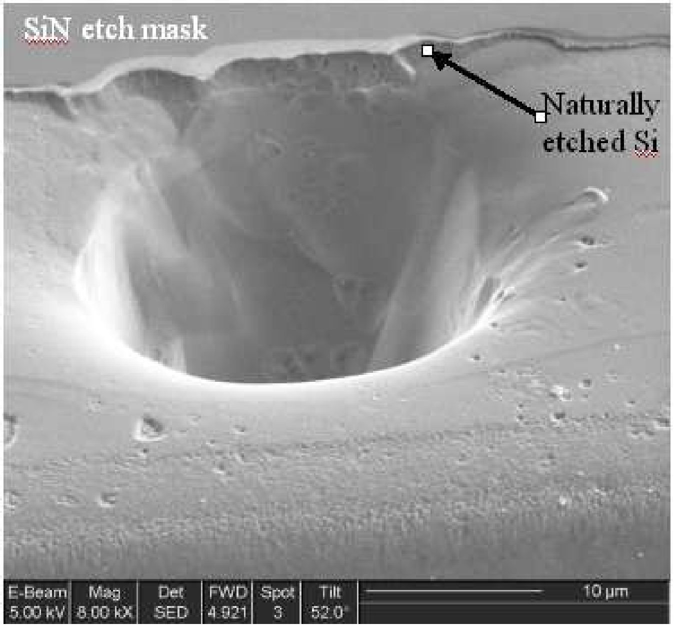

Figure 3: A scanning electron micrograph of an etched hole with a 10µm laser beam size. As a reference to the background Si etching away from the laser beam, the etch is performed near a SiN etch mask layer. The resultant etch hole is only 12µm in diameter.

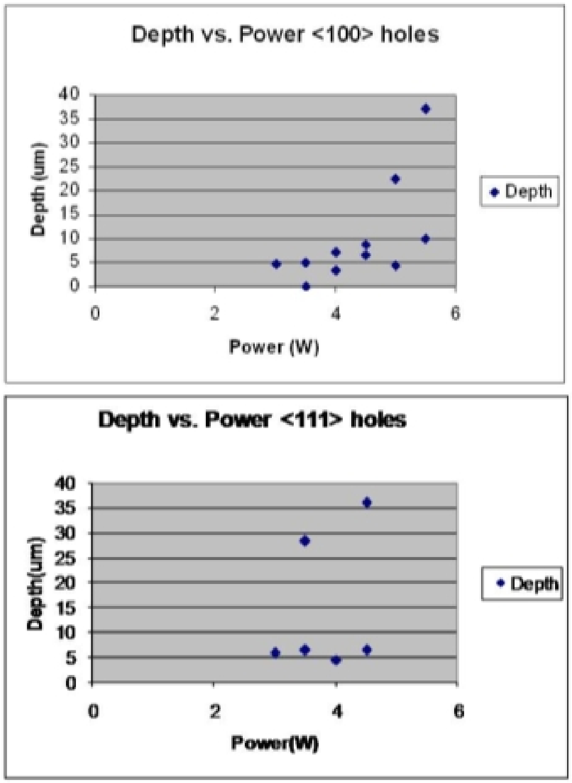

Figure 4: Etch depth vs Incident laser power for 1min etches in <100> and <111> Si wafers. The formation of hydrogen bubbles causes occasional defocusing of the laser beam reducing etch rate.