Ga-cluster free Si surface post ion beam exposure

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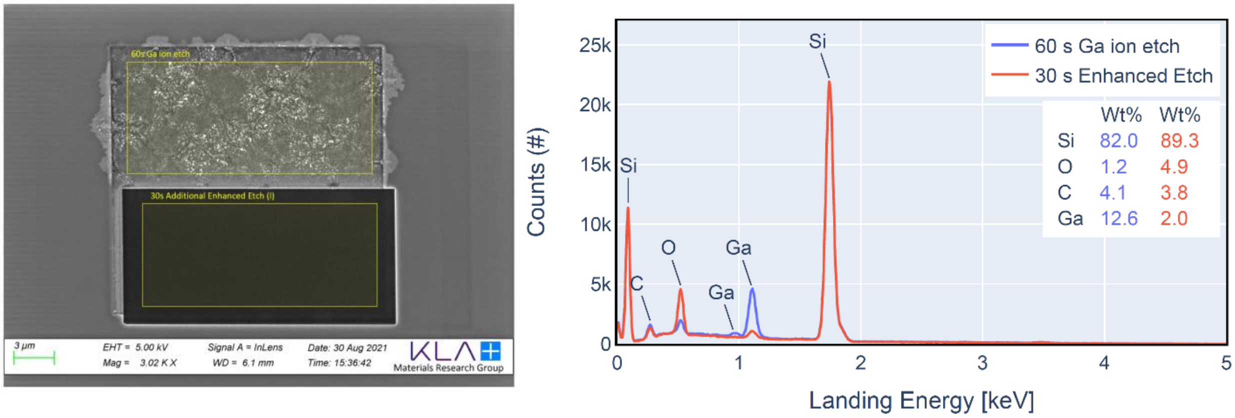
Focused ion beam technology is commonly used in the semiconductor industry due to its unique abilities for prototyping microelectronic devices and patterning as well as achieving high resolution imaging and ion lithography [1,2]. However, the impinging highly energetic Ga-ions (30keV) create lattice damage to crystalline surfaces, leading to amorphized surface layers, while also implanting Ga ions into the lattice. If the sample with implanted Ga-ions is subsequently annealed to a temperature of above 150°C, the implanted Ga ions form unwanted clusters that can be detrimental to microelectronic devices and create surface roughness.

Here, we demonstrate a solution to achieve a Ga cluster-free Si surface post ion beam exposure and subsequent annealing. For this study, a Thermo Scientific™ Helios™ G4 UC DualBeam™ focused ion beam (FIB) instrument is used, which is equipped with an iodine gas-injection system (GIS). Adding iodine gas to the Ga-etch (“Enhanced Etch”) typically leads to an increased etch rate as well as a reduced surface roughness and redeposition. Using the enhanced etch as a final etch step, it is found that the amount of Ga ions implanted on the surface is significantly reduced, resulting in a smooth and Ga cluster-free surface post annealing.

Energy Dispersive X-Ray Spectroscopy (EDX) measurements reveal that a Si surface etched with an ion beam only results in a Ga surface concentration of 12.6 at. %, while a reduced Ga concentration of only 2.0 at. % is found when adding iodine to the ion beam (see top and bottom half of the etched square in Image 1). Upon annealing the sample, no cluster formations are observed due to the reduced Ga content on the Si surface. Additionally, Atomic Force Microscopy (AFM) measurements demonstrate that the surface etched with the iodine addition leads to an average surface roughness of only 1.7nm while an average surface roughness of 8.9nm is measured for the surface exposed to the ion beam only.

Image 1



Left: SEM image of a 20µm x 20µm area of a Si surface exposed to an ion beam of 0.79nA (30 kV) for 60s. The bottom half of the square was then exposed to the enhanced etch for 30s before annealing the sample at a temperature of 150°C. Ga clusters only form in the top half of the square, the area not exposed to the enhanced etch.

Right: EDX measurements in both areas demonstrate that the surface Ga concentration in the ion beam exposed area (top half) is 12.6%, while using the Enhanced Etch results in a significantly reduced Ga concentration of only 2.0%.

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[1] Alias *et al.*, “Enhanced Etching, Surface Damage Recovery, and Submicron Patterning of Hybrid Perovskites using a Chemically Gas-Assisted Focused-Ion Beam for Subwavelength Grating Photonic Applications”, J. Phys. Chem. Lett. 2016, **7**, 137-142

[2] Callegari *et al.*, “Focused ion beam iodine-enhanced etching of high aspect ratio holes in InP photonic crystals”, J. Vac. Sci. Technol. B, 2007, **25**, 2175-2179