Backside circuit edit with gas assisted etching on a platform with multiple focused ion beams.

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The gallium focused ion beam (FIB) is widely used in semiconductor industries for circuit editing, failure analysis, and nanofabrication. One important aspect for circuit editing is to etch down to a metal layer from backside of circuit at a reasonable etching rate. Also, it should be convenient to obtain endpoint detection and etch selectivity compared to other semiconductor materials. Gas-assisted etching (GAE) is a general way to etch down relatively thick Si layer down to a metal layer with the combination of focused ion beams (Ga or neon) and reactive gases (e.g. XeF_2). It is necessary to evaluate the enhancement of GAE in the new platform and explore applications in endpoint detection for circuit failure analysis and editing. Here, we demonstrate the GAE of Si using Ga ion beam and XeF_2, imaging with focused helium ion beams, and even more accurately etching using the focused neon ion beam in the Zeiss NanoFab.

For this backside circuit editing application, a relatively thick layer (~10µm) of Si layer was left in a larger pre-etched pit. For our tested chip, we used multiple-step Ga milling to minimize the sidewall re-deposition issue. If the Ga ion beam is used alone, it would take much longer time to etch down the metal layer. We found it took dose of 46 $nC/\mu m^2$ to etch down to the metal layer as shown in Fig 1A. So, it would take a relatively long time (>10 hr for 10µm×10µm pit) to achieve this with an ion beam current of 100 pA.

With the assistance of XeF_2 gas, it is much faster to etch the thick Si layer with the Ga ion beam. For example, it only took 0.6 $nC/\mu m^2$ and a very short time (less than 10 min) to expose the metal layer with XeF_2-assisted etching (as shown in Fig 1C) using ion beam current 100 pA. As expected, the surface of surrounding of the etched pit is porous due to non-selectively etching of XeF_2 gas alone on the Si surface (Fig 1B). More importantly, we were able to use end-point detection for circuit editing for this case. Fig 1D shows the dose for the start of exposure of metal layer. At the dose of 0.4 $nC/\mu m^2$, a portion of the metal layer was first exposed. This event is apparent from the ET signal and represents a reliable method to stop etching at the target layer. Alternatively, if we continue to perform GAE processing after we detect the first metal layer, this process could selectively etch insulator without etching metal structures with moderate ion beam current.

The new platform also permits the use of a focused neon ion beam to subsequently and more accurately etch smaller window and achieve higher precision. The etching rate can again be increased with assistance of XeF_2 gas. With the finely focused neon ion beam, we could also cut the fine metal line and re-deposit insulator or metallic nanostructures to complete the circuit editing process.

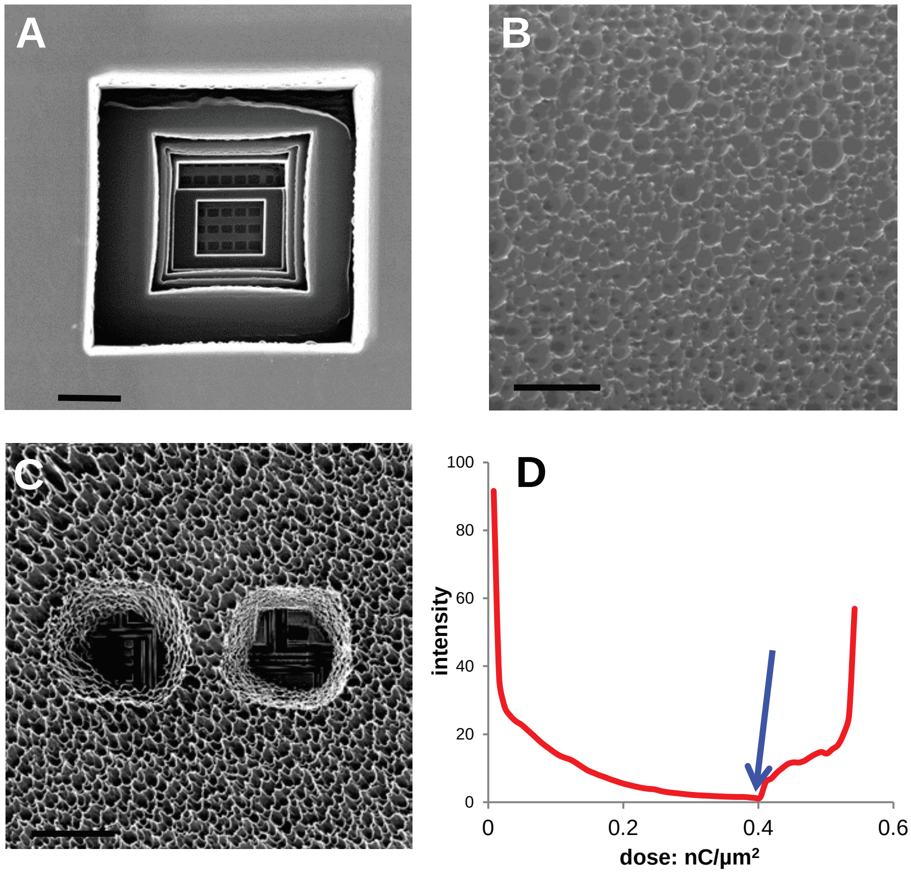

Figure 1: Enhancement of XeF_2-assisted etching of Si using Ga ion beam for backside circuit editing: (A) helium ion image of multiple-step etching with Ga ion beam only with total dose 46 nC/µm^2 (scale bar: 5µm); (B) helium ion image of XeF_2 etching on Si surface ((scale bar: 20µm);); (C) helium ion image of double windows with Ga ion beam for 0.6 nC/µm^2 (scale bar: 10µm); (D) end-point detection for XeF_2-assisted etching (blue arrow indicating the start of exposure of metal layer).