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Circuit Editing and Failure Analysis Applications using a Three-Ion-Beam (Ga, He and Ne) System and Gas Injection System (GIS)

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The focused ion beam (FIB) is widely used in semiconductor industries for circuit editing (CE), failure analysis (FA) and nanofabrication. Gallium FIB is most developed for CE and FA for feature size >10 nm. In general, after the FIB processing, the structural characterization is performed using SEM. A gas injection system (GIS) is integrated into a FIB or SEM microscope system to mill or deposit the materials in electron or ion induced processing in CE and FA. Ga FIB induced processing cannot fabricate small enough metal or insulator nanostructures to meet the shrinkage of feature size in current semiconductor processing. In the Zeiss NanoFab system, the Ga ion beam is used to perform the fast and large scale milling, and the helium ion beam is used to obtain the high resolution images. In addition, the neon ion beam is used to mill or assist deposition of smaller functional structures. Appropriate precursors for ion induced etching or deposition are introduced via an integrated GIS. In this paper we evaluate applications in CE and FA using a combination of three different focused ion beams.

The first example is the enhanced etching of silicon (Si) for the backside CE using a Ga ion beam in combination with XeF_2 gas. A relatively thick layer (~10µm) of Si layer was left in a larger pre-etched pit for backside CE. If the Ga ion beam is used alone, it would take much longer time to etch down the metal layer. We used multiple-step Ga milling to minimize typical sidewall re-deposition. It took a dose of 46 $nC/\mu m^2$ to etch down to the metal layer as shown in Figure 1A. With the assistance of XeF_2 gas, it only took 0.4 $nC/\mu m^2$ to begin exposure of the metal layer as shown in Figure 1B. The enhancement factor is as high as 100 and it takes much less time, 10 min with XeF_2 comparing to 600 min without XeF_2. More importantly, we were able to use end-point detection for CE for this case. Figure 1C shows that the dose of 0.4 $nC/\mu m^2$ initiates exposure of the metal layer. This event is apparent from the signal of the secondary electrons collected on the Everhardt Thornley (ET) detector and represents a reliable method to stop etching at the target layer. Figure 1D gives another example of enhanced etching of SiO_2 film on Si substrate with a combination of the neon ion beam and XeF_2 gas. From this curves, we can see the enhancement factor is larger than 3 for both thick and shallow SiO_2 layer. Figure 1E shows an additional example of neon ion beam milling with high accuracy for front-side CE for milling a box 150nm×150nm and 400nm deep. It is obvious that endpoint information from curve peak and bottom of Figure 1F can be obtained for metal and insulator layers. The neon ion beam can be also used to cut the fine metal line with good control in CE and FA applications.

Metal and insulator nanostructures for CE and FA can be deposited with ion beam induced processing. Helium and neon ion beams used in conjunction with precursor chemistries delivered through a GIS deposit fine metal lines such as Pt, W and Co for conductive electrical connections for CE. Figure 2A shows helium ion deposited 10 nm Co lines with 50 nm pitch on metal fingers. Insulator materials can be deposited from precursors such as TEOS and PMCPS. Figure 2B shows an array of PMCPS squares with 200 nm thickness deposited using a helium ion beam. Both metal and insulator structures prepared in helium or neon ion beam induced processing exhibit good corresponding properties: ultralow resistivity as 100 $\mu\Omega\cdot cm$ for metal line and ultrahigh resistivity as 10^{13} $\Omega\cdot cm$ for insulator pad.

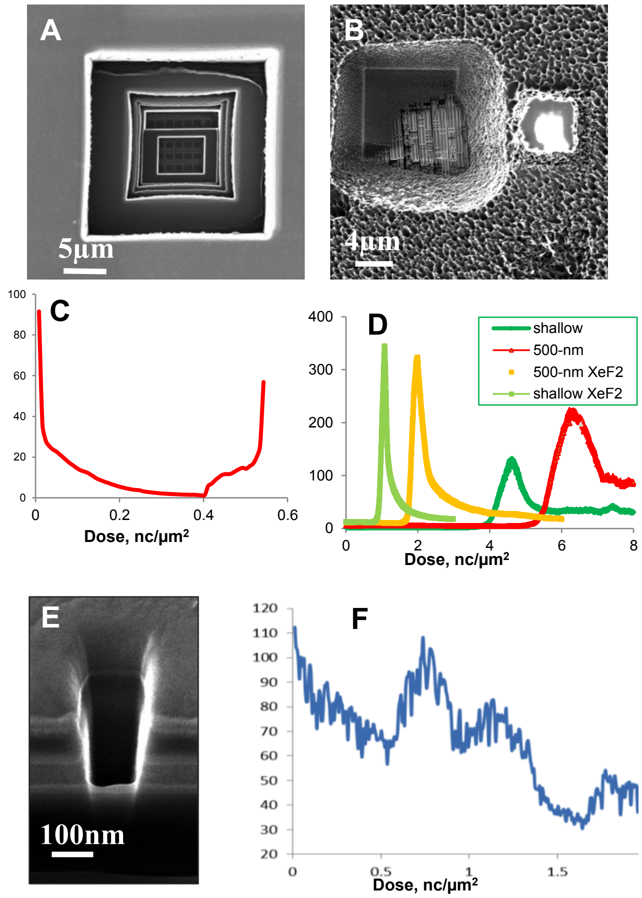

Figure 1. (A)-(B) helium ion image of Ga ion beam etching Si from backside of circuit (A) multiple-step milling with Ga ion beam only with total dose 46 nC/μm^2; (B) XeF_2 assisted etching; (C) end-point detection for XeF_2-assisted Si etching for tested chip as in (B); (D) comparison of endpoint detection for with and without XeF_2 to etch SiO_2 film on Si substrate using neon ion beam; (E) tilted helium image of etching box on front side of tested chip; (F) endpoint curves for Ne milling processing in (E).

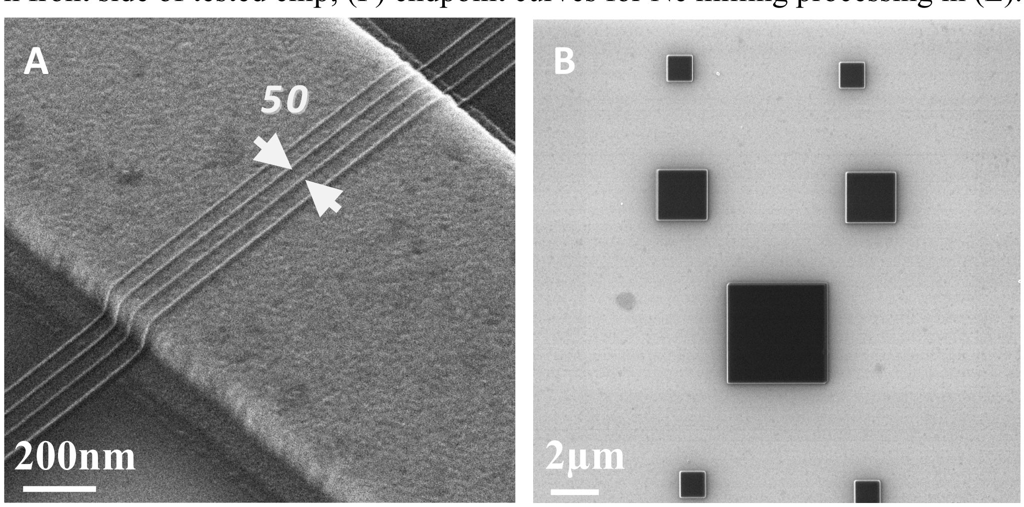

Figure 2. Helium ion image of deposited metal and insulate: (A) tilted view, four Co lines on four finger structures; (B) top view, insulator pad arrays of PMCPS.