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O^+ PFIB Milling and Measurement of FIB Damage in Silicon

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Minimizing surface damage during focused ion beam (FIB) specimen preparation is an important factor for high quality images and analytical results in modern, corrected S/TEM microscopes. Using conventional Ga^+ FIB milling, techniques using reduced accelerating voltages for final polishing to minimize sample damage are commonly employed [1]. Nowadays, new column and source technologies allow for multiple ion species to be employed for sputtering at high and low accelerating voltages. With the introduction of these alternative ion species for milling, it is of interest to characterize the ion-solid interaction with respect to FIB sidewall damage in an effort to understand whether ion species other than Ga^+ might produce better TEM samples for high resolution STEM (HR-STEM) imaging.

Previous studies on single crystal silicon have characterized gallium, xenon and argon FIB sidewall damage to be ~ 22 nm, ~ 13 nm and ~ 37 nm, respectively, using an accelerating voltage of 30 kV [1, 2, 3]. Smaller sidewall damage layers are observed with lower accelerating voltages. On the same substrate, modeling indicates that milling with heavier ions will produce less sidewall damage than with a lighter ion of the same energy [3]. Therefore, one expects slightly more sidewall damage with oxygen (atomic number 8) than with gallium (atomic number 31) and xenon (atomic number 54). In this study, the sidewall damage on single crystal silicon after O^+ plasma FIB (PFIB) milling is presented.

Cross-sections of a blanket silicon wafer were prepared using a Thermo Scientific Helios Hydra™ DualBeam™. Specimens were polished with energies of 30, 5, and 2 kV using incident angles of 88°, 86°, 84° respectively. Each sidewall was protected using electron beam induced deposition (EBID) of 2 keV platinum. Conventional in situ lift-out TEM samples of the milled cross-sections were prepared using the Hydra equipped with an EasyLift™ nanomanipulator. Sidewall silicon damage was analyzed by HR-STEM on a SCORR-corrected Thermo Scientific Themis Z™ operating at 300 keV.

Figure 1 shows a HR-STEM image of the amorphous sidewall damage from O^+ FIB milling with 30 kV. Unlike calculated values from SRIM [4], the experimental results reveal that amorphous sidewall damage is approximately 45 nm at 30 kV (shown with experimental results in Table 1). The O^+ sidewall amorphous damage decreases dramatically as a function of energy and is 2 times larger than 30 kV Ga^+ FIB and nearly 4 times larger than 30 kV Xe^+ PFIB sidewall damage.

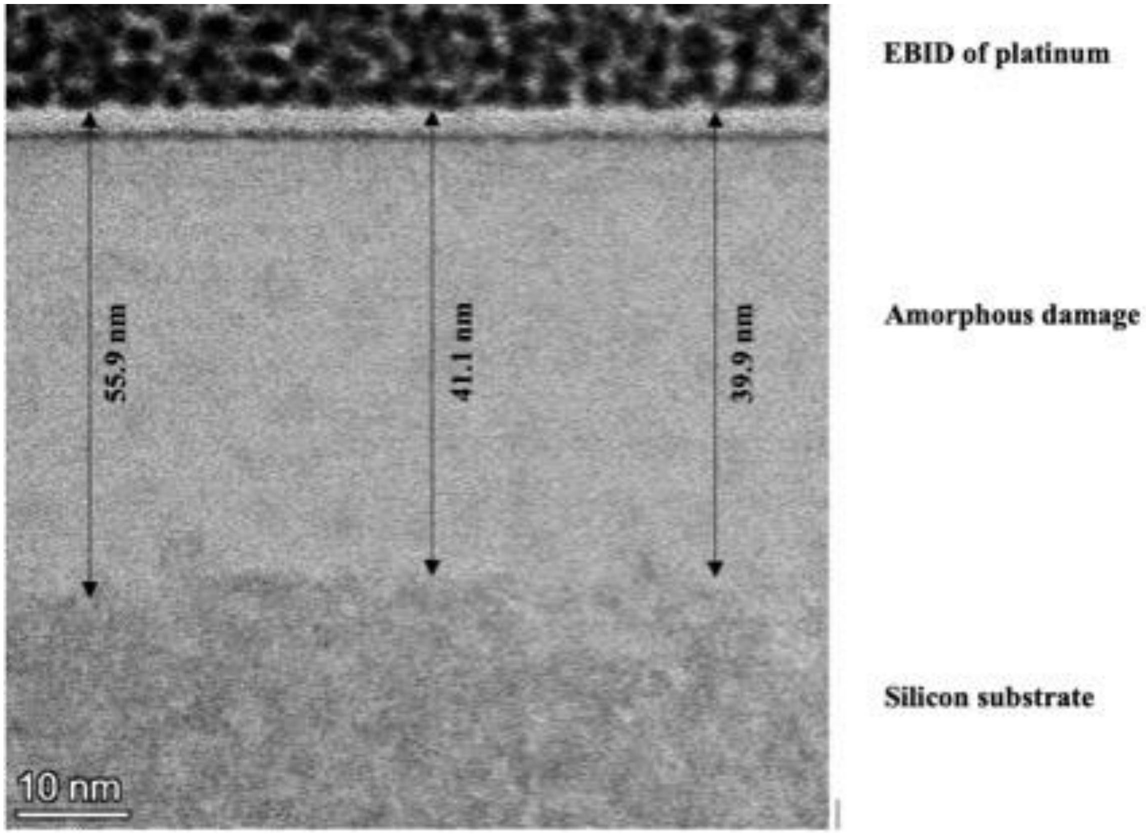
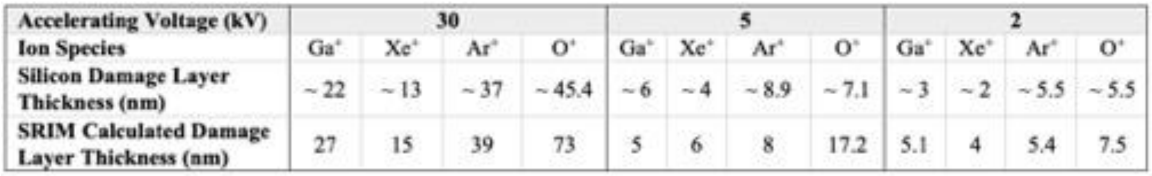


Figure 1. 300 keV bright-field HR-STEM images of amorphous sidewall damage in Si from an O+ PFIB with 30 kV.



Accelerating Voltage (kV)	30				5				2			
Ion Species	Ga^+	Xe^+	Ar^+	O^+	Ga^+	Xe^+	Ar^+	O^+	Ga^+	Xe^+	Ar^+	O^+
Silicon Damage Layer Thickness (nm)	~ 22	~ 13	~ 37	~ 45.4	~ 6	~ 4	~ 8.9	~ 7.1	~ 3	~ 2	~ 5.5	~ 5.5
SRIM Calculated Damage Layer Thickness (nm)	27	15	39	73	5	6	8	17.2	5.1	4	5.4	7.5

Figure 2. Summary table of sidewall FIB damage layer thickness (nm) in Silicon after Ga+, Xe+, Ar+ and O+ milling with 30 kV, 5 kV and 2 kV.

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