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2 keV Ga^+ FIB Milling for Reducing Amorphous Damage in Silicon

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Focused ion beam (FIB) specimen preparation techniques have been successfully used for nearly all types of (scanning) transmission electron microscopy (S)TEM methods. However, the milling process from high energy Ga^+ FIB columns (e.g. 30 keV) can impart sufficient surface damage (i.e., ~ 20 nm per specimen side for Si) to impede quantitative high resolution STEM and TEM imaging. Previous results have shown that amorphization damage in Si and GaN can be removed by chemical wet polishing after FIB milling [1,2]. However, chemical polishing methods are material dependent and are difficult or impossible to use for complex multi-phase or multi-layered specimens. Previous results have shown that better high resolution TEM images can be obtained by FIB polishing a 30 keV FIB prepared specimen with a 10 keV ion beam [1,3]. Low energy broad beam Ar^+ ion milling has also been used to reduce FIB damage for HRTEM [1,4]. In this paper, we discuss specimen surface quality improvements using a FIB column whose ion beam energy can be reduced to 2 keV, resulting in the lowest amount of FIB damage reported to date.

A blanket wafer Si substrate specimen was prepared for TEM analysis using conventional 30 keV FIB milling via the in-situ lift-out and Omniprobe total release technique [5] using an FEI Strata 400S DualBeam instrument equipped with a Sidewinder FIB column. Lines were FIB milled into the specimen using beam energies of 30 keV, 5 keV, and 2 keV, and were used to assess the sidewall damage at these energies. Then the surface of the specimen was FIB polished with the Ga^+ ion beam at +/- 85^o incident angle at 5 keV and then at 2 keV. The sidewall damage and surface quality of the specimen was observed using HRTEM imaging with an FEI Tecnai F20 equipped with a spherical aberration coefficient (Cs) image corrector operating at 200 keV. The specimen was plasma cleaned using a Fischione plasma cleaner after each FIB milling procedure prior to TEM observation.

FIGS. 1a,b,c show Cs corrected [110] HRTEM images of the amorphization sidewall damage from a 30 keV, 5 keV, and 2 keV Ga^+ FIB beam respectively. Note that the amorphization sidewall damage layer decreases dramatically with energy. FIGS. 2a,b,c are Cs corrected [110] HRTEM images of the surface of Si polished using a 30 keV, 5 keV, and 2 keV Ga^+ FIB beam respectively, showing that the image quality improves dramatically with a decrease in ion energy. FIGS. 3a,b show a [110] HRTEM image and corresponding filtered image of a 2 keV FIB polished Si specimen showing excellent signal to noise and obvious dumbbell splitting.

Ion-solid interactions predict that lighter incident ions will produce more surface damage than heavier incident ions [see chap. 2 in ref. 6]. This implies that Ga^+ ions will yield less specimen damage compared to similar energy beams from conventional Ar^+ ion mills, and thus, may negate the need for broad beam Ar^+ ion milling of FIB prepared specimens.

References

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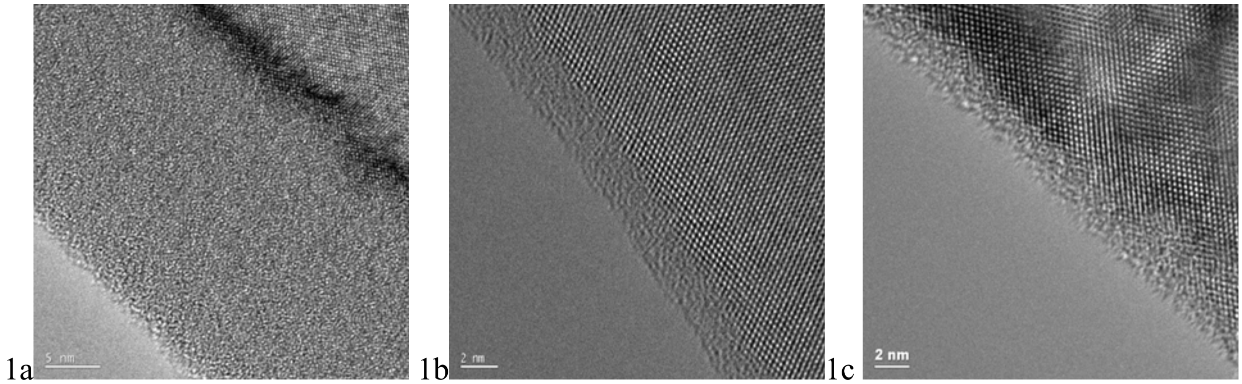

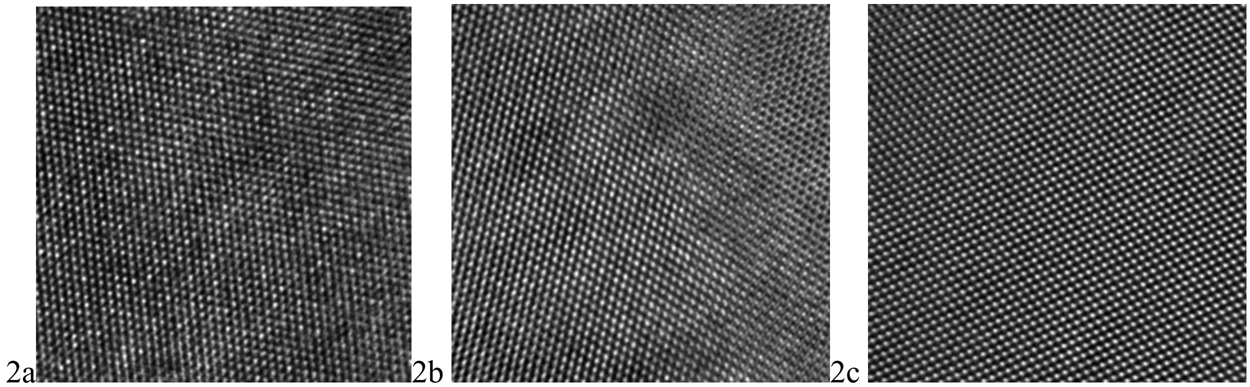

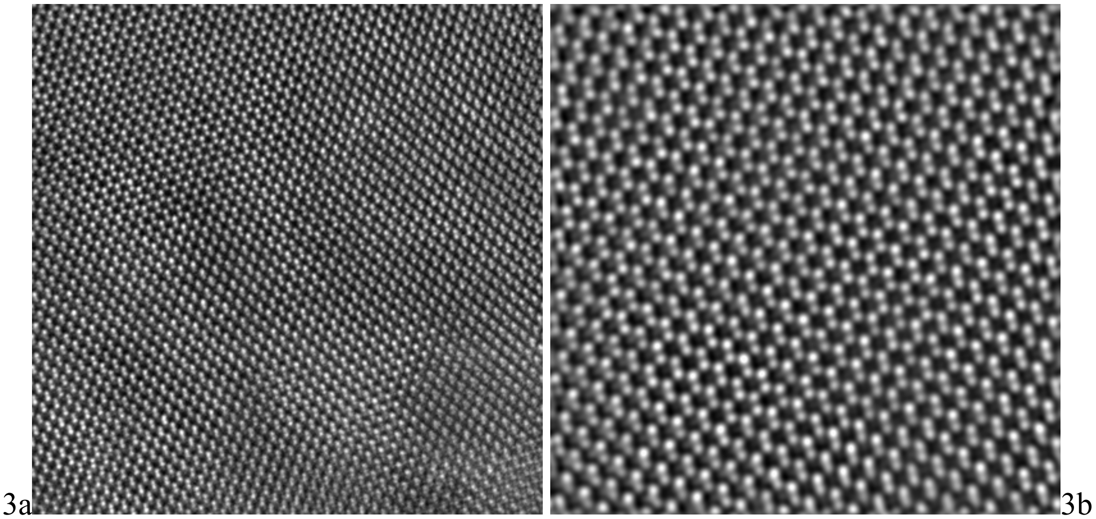

FIG 1. Cs corrected [110] HRTEM images of amorphization sidewall damage in Si due to (a) 30 keV, ~ 21 nm, (b) 5 keV, ~ 2 nm, (c) 2 keV, ~ 0.5 – 1.5 nm.

FIG 2. Cs corrected HRTEM images of [110] Si FIB polished at (a) 30 keV, (b) 5 keV, (c) 2 keV.

FIG 3. Cs corrected HRTEM images of [110] Si dumbbells FIB polished at 2 keV (a) actual image (b) filtered image.