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# SURFACE DAMAGE IN SILICON AFTER 30 KeV Ga FIB FABRICATION

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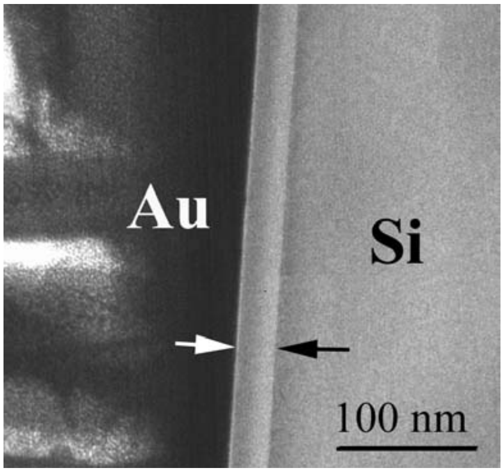
Focused ion beam (FIB) systems have been widely used over last decade for cross-sectional TEM specimen preparation. However, an inevitable result of the FIB preparation process is the formation of amorphous damage layers on both sides of the milled TEM membrane. These reduce the quality of high-resolution imaging and limit the minimal useful specimen thickness. Understanding the thickness of the damage layers is very important because it provides an estimate of the thickness of the undamaged material in such specimens. Although FIB-induced damage has been studied over the last decade a wide range of thicknesses, as determined by various experimental techniques, has been reported for the side-wall damage layer in, for example, silicon induced by a 30 kV $Ga^+$ ion beam, for example: 20 nm [1], 25 nm [2], 28 nm [3, 4]. Although it is well known that penetration (and amorphisation) depth of ions increase with increases in their energy, it was recently reported that the thickness of the amorphous damage layer in a silicon TEM specimen after 50 kV Ga FIB milling was only 22 nm [5].

In this work the thickness of the side-wall damage layer in silicon was measured using two independent techniques. Each method was designed to prevent subsequent alteration of the damage layers during specimen manipulation. A FEI xP200 FIB system with a gallium ion source operating at 30 kV was used for both damage formation in a crystalline Si specimen and subsequent TEM specimen preparation. In the first method damage layers were formed in a silicon substrate using the FIB by milling rectangular trenches with an average size 10x10 $\mu m^2$ and a depth around 1μm using a range of beam currents. The beam currents used in this study ranged from 11 pA to 6600 pA. Next, the specimens were sputter coated with thick (~100 nm) Au protective film. The samples were placed back in the FIB and 1μm-thick Pt strips were deposited on the top of the milled trenches. The Au protective film ensured that the damage layer around the trench was not affected during deposition of the Pt strip or other specimen preparation steps [6]. Finally, cross-sectional TEM specimens were prepared using methods described elsewhere [7]. These samples contain cross-sections of damage layers that are clearly visible between Au protective layer and crystalline silicon substrate in TEM images (Fig. 1). In second method an electron transparent TEM membrane was prepared using FIB milling via standard techniques [7]. Next a set of FIB cuts was performed normal to the membrane plane using the same ion beam current range described above. The membrane of this pre-prepared TEM sample already contains damage cross-sections from prior FIB cuts (Fig. 2) and the damage is clearly visible between the edge of the cut and crystalline undamaged silicon substrate (Fig. 3). It can be also noted from a low magnification TEM image of the membrane (Fig. 2) that the slope angles (θ) of the cross-sections of the FIB cuts depend on the ion beam current which is generally acknowledged to exhibit a Gaussian-shaped profile of current-density. However, the thickness of the amorphous damage layers was found to be independent of the Ga ion beam current and the angle of incidence (slope angle). In both techniques the thickness of the side-wall damage was found, within experimental error, to be the same and was measured to be 28±3 nm. Unlike other methods of measurements (for example using of argon milling [5]) these two techniques do not introduce any alteration in the damage layers during subsequent TEM sample preparation and such measurements therefore provide an accurate value of the thickness of the amorphous wall-side damage layers in the FIB prepared TEM silicon samples.



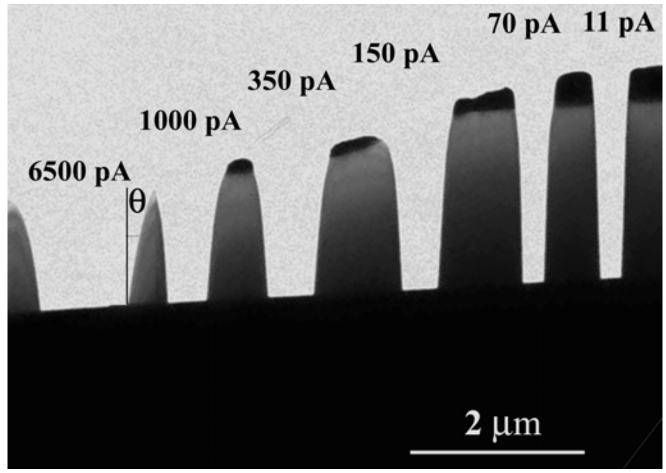




FIG. 1 TEM image of the side-wall damage layer of the trench milled with a 1000 pA ion beam current.

FIG. 2 TEM image of the FIB cuts milled normal to the original thinned membrane.

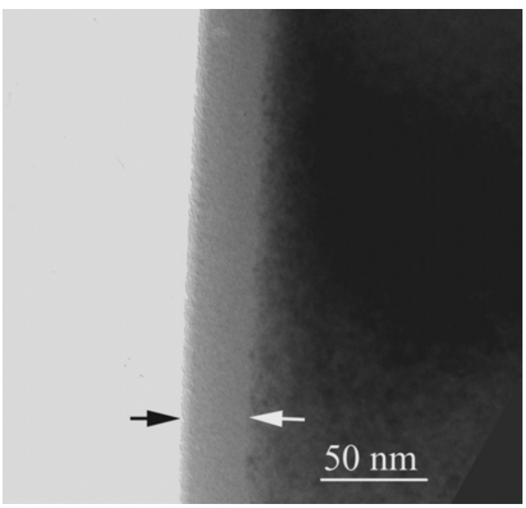



FIG. 3 TEM image of the side-wall damage layer on the edge of the cut milled using a 70 pA beam current.

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