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doi:10.1017/S1431927618006086

Microsc. Microanal. 24 (Suppl 1), 2018

Influence of SEM Deposited Protection Layers on FIB Induced Amorphous Damage of TEM Lamella Prepared by ExSolve WTP

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Motivation: Semiconductor devices are shrinking fairly consistent with Moore's Law. In order to investigate these smaller devices, it is necessary that transmission electron microscope (TEM) lamella be prepared progressively thinner by FIB. The FIB imparts some amount of damage at the surface of these lamellae which must be reduced to enable analysis of the features within the crystalline core of the lamella to enhance signal/noise for precise metrology. This paper investigates the influence of SEM deposited protective deposition layers on the damage layer thickness present after 2kV and 1kV final FIB clean mill, prepared using the fully automated Thermo Scientific™ ExSolve™ 300mm wafer dual beam.

Procedure: TEM lamellae were prepared on bare 300mm Si wafers using a fully automated TEM preparation process. The thinned window of the original lamellae were protected using different SEM deposited materials (~100nm) to prevent further ion beam damage. Subsequent lamella were then prepared orthogonal to the original lamella, to capture a thinned cross section of the original lamella thinned window in the second lamella, in a process called XTEM conversion (fig 1a). For the 1kV final thinned process, we investigated three chemistries for protective deposition by SEM: carbon, TEOS (Tetra-Ethyl-Ortho-Silicate), and tungsten. For the 2kV final thinned process, we investigated two chemistries for protective deposition, SEM deposited: TEOS and tungsten. The thickness of the XTEM lamella window was minimized to reduce the influence of projection artifacts (~45nm thick as measured by EELS) during TEM imaging. TEM lamellae were prepared and converted to XTEM without removing the wafers from the chamber to minimize oxidation of the thinned window. We imaged the XTEM lamella using a Cs Corrected Thermo Scientific Metrios™ (S)TEM. For each XTEM lamella, six HR-STEM images were captured at a series of depths from the wafer surface, using a 50nm field of view so as to image the amorphous layer present from the wafer surface to a depth of 300nm (indicated by the black square in fig 1a). The amorphous layer thickness metrology was performed on the images using Metrios Recipe Editor software employing 10nm wide edge-finders placed at 10nm increments along both sides of the lamella cross section (fig 1b). Each edge finder sampled a 10nm region, whose output was the average thickness of amorphous damage. For each XTEM lamella, 60 measurements were possible (30 per side).

Results: A Box Plot of the amorphous layer measurements and associated average values is shown in Figure 2. The 1kV final thinned process exhibited a greater than 50% reduction of the observed amorphous layer when compared to a 2kV final clean mill of the thinned window for both SEM TEOS and SEM W deposited protection materials respectively. EDS mapping shown in Figure 3 revealed a carbon and oxygen rich layer present at the a-Si/SEM tungsten protection interface while the carbon/oxygen are more evenly distributed in the SEM TEOS deposition, contributing to the measured amorphous layer thickness. For 1kV final thinned lamella, SEM carbon protective deposition resulted in the smallest amorphous layer observed.

Conclusion: Of the 3 chemistries investigated, SEM carbon protection produced the smallest damage layer, measuring at 1.28nm. 1kV final thinning resulted in a > 2x reduction in amorphous damage over 2kV thinning for each respective SEM protection chemistry.

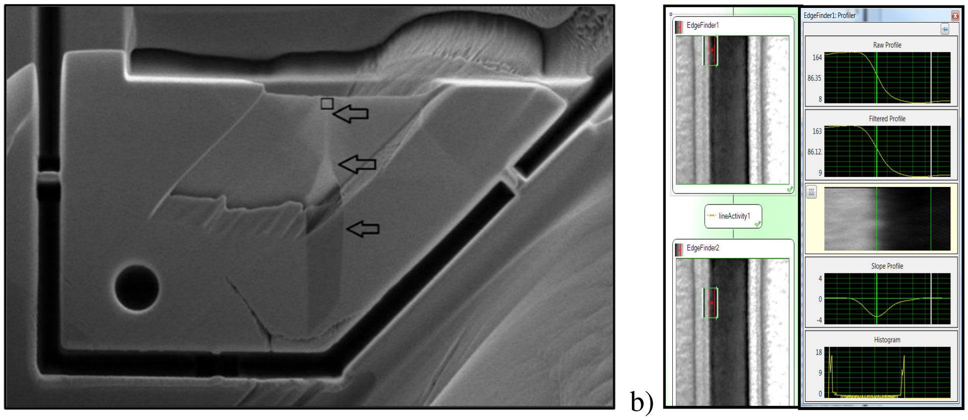
a)  b)

Figure 1: a) XTEM lamella with arrows indicating the original thinned lamella. The box indicates the 50nm^2 area imaged in HRSTEM for damage. b) Edge finder metrology of boxed region to determine the thickness of the amorphous layer.

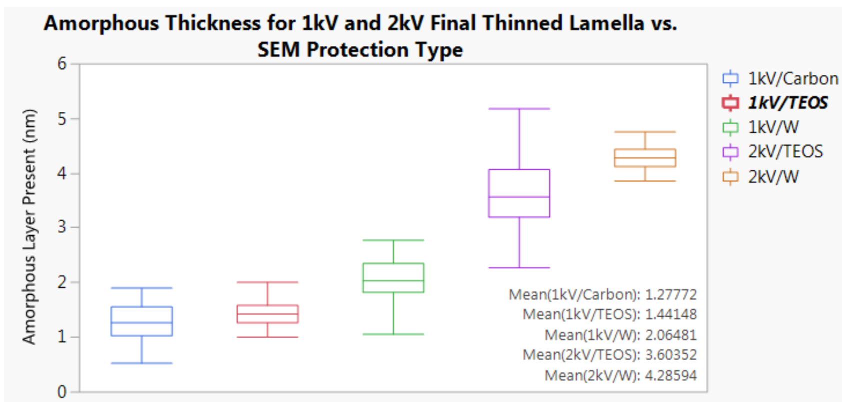


Figure 2. Box plot of the amorphous layer measurements for 1kV and 2kV final thin processes for SEM tungsten, SEM TEOS, and SEM carbon capping chemistries. All of the 1kV processes exhibited less damage than the 2kV processes. *2kV SEM C capping was not measured.

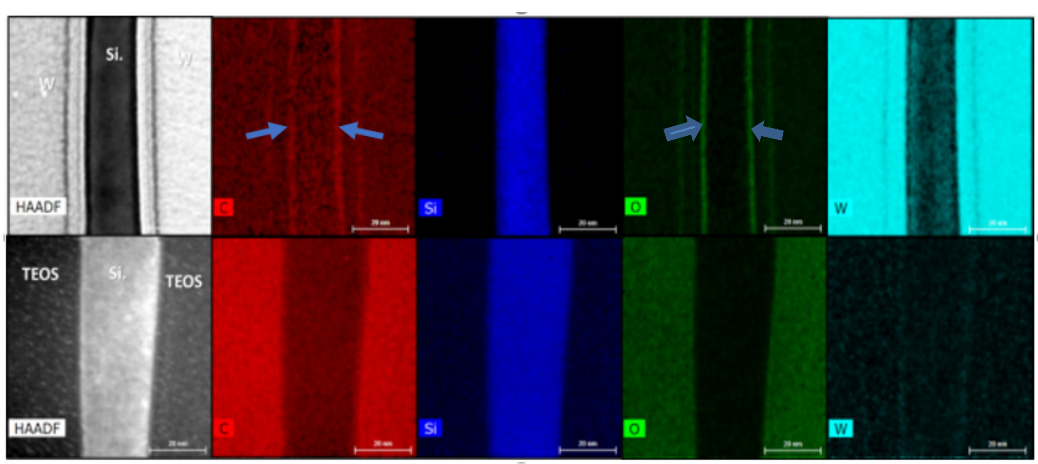


Figure 3. EDS map of SEM W (top) protected XTEM sample and SEM TEOS (bottom) protected sample. SEM W deposition leaves a thin layer of carbon and oxygen (arrows) contaminating the observed amorphous layer whereas the SEM TEOS has the carbon and oxygen contribution more evenly distributed.

https://doi.org/10.1017/S1431927618006086 Published online by Cambridge University Press