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Automatic End-point Detection for Ar^+ Milling of FIB *in situ* and *ex situ* Lift-out Specimens from Semiconductor Devices

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Transmission electron microscopy (TEM) is a critical characterization method for the semiconductor industry given the decreasing device size. TEM specimens are typically prepared using a focused ion beam (FIB) system because it provides accuracy and site-specificity for thinning and extraction [1]. Frequently used techniques are *in situ* lift-out (INLO) and *ex situ* lift-out (EXLO) [2]. With both techniques, artifacts such as surface damage and ion-implanted layers are present on the specimens due to Ga^+ from FIB ion milling. Previous studies on low energy (< 1 keV), small spot (<1 µm) Ar^+ milling of both INLO and EXLO FIB specimens [3, 4] have improved TEM specimen quality by removing Ga^+ ion-induced damage. Here, we present Ar^+ milling with automated end-point detection capability to prepare electron-transparent INLO and EXLO TEM specimens from semiconductor devices and remove Ga^+ ion implantation artifacts. Such work is highly relevant due to the high-throughput requirements of the semiconductor industry.

Intel processor and Intel solid state drive (SSD) cross-section specimens were prepared in a FIB [Thermo Fisher]; the processor specimens were milled at 30 keV, followed by 5 keV and made into INLO specimens; the SSD specimens were milled at 30 keV and made into EXLO specimens. All specimens were thinned in an Ar^+ ion beam milling system with in situ detectors – a secondary electron detector (SED) and a scanning transmission electron microscope (STEM) detector – that are used for end-point detection [Fischione Instruments]. The intensity value from the area of interest was noted prior to milling. A user-defined threshold value (a percentage of the initial intensity value) was entered before milling operations commenced. Milling was automatically terminated when the intensity value reached the user-defined threshold value. Small threshold values and decreasing energies (700 and 500 eV) were used for subsequent milling steps, followed by targeted milling steps at lower energy of 300 eV. TEM characterization was performed before and after milling.

Figure 1 shows the change in intensity at the area of interest that was detected by the ion milling system, which resulted in automatic termination of milling. The thickness of the INLO and EXLO specimens was reduced after Ar^+ milling based on the acquired STEM and TEM images in Figure 2. The qualitative thickness reduction with decreasing image intensities will be evaluated by measuring the specimen thickness of Si INLO and EXLO specimens processed in the ion milling system and analyzing the acquired image intensities. The effect of the carbon support on the detected intensities during automatic end-point milling of the EXLO specimens will be evaluated. Furthermore, the removal of Ga^+ ion implantation damage on the INLO and EXLO specimens will be shown. [5]

References:
[1] LA Giannuzzi and FA Stevie, Micron **30** (1999), p. 197.
[2] LA Giannuzzi in "Introduction to Focused Ion Beams: Instrumentation, Theory, Techniques and Practice", ed. LA Giannuzzi and FA Stevie, (Springer, New York City) p.201.

[3] P Nowakowski et al., Microscopy and Microanalysis **23** (2017), p. 300.
[4] CS Bonifacio et al., Microscopy and Microanalysis **23** (2017), p. 268.
[5] The authors thank Kevin McIlwrath of JEOL USA for STEM image acquisition.

INLO

EXLO

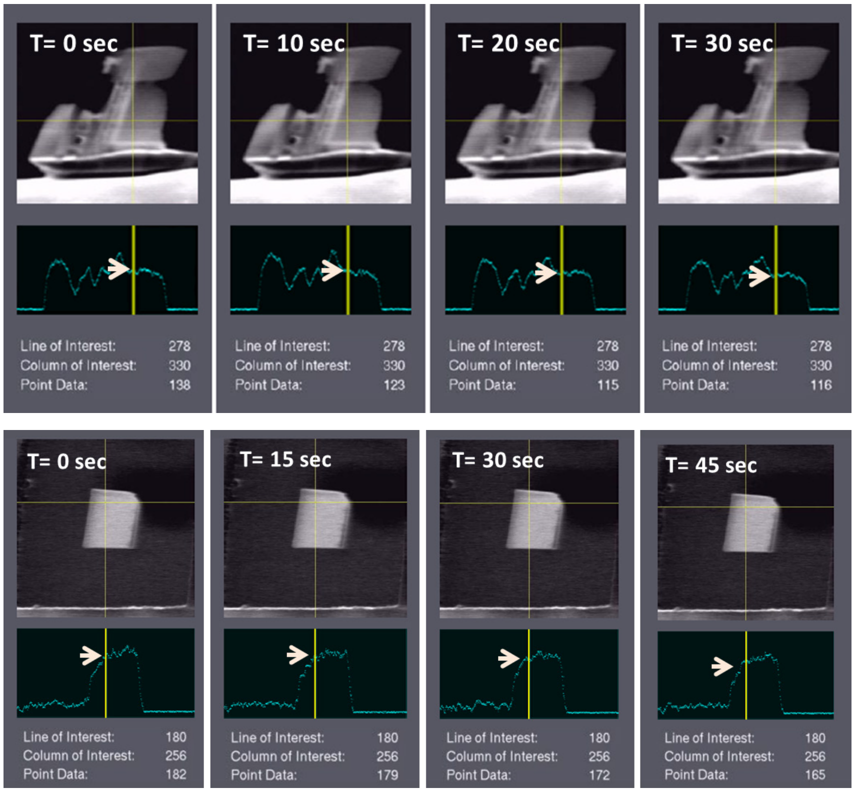

Figure 1. Screen captures from the ion milling system's in situ SED imaging during 700 eV milling of the specimens. The decreasing intensity at the area of interest is shown (indicated by both the arrows and the decreasing value of "Point Data").

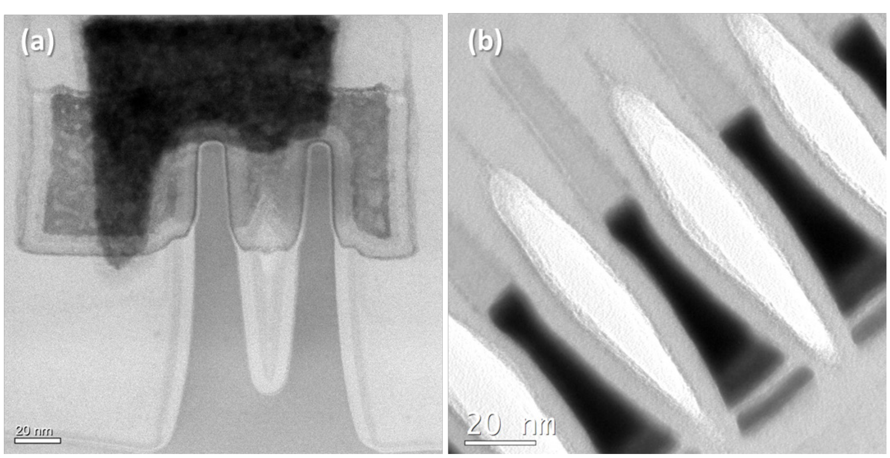

Figure 2. Bright field STEM image (**a**) and TEM image (**b**) of the INLO and EXLO specimens after ion milling with automatic end-point detection. The metal gate over the fin and TiAl grains of the FinFET structure are pronounced and distinct in (**a**). No curtaining is evident on the airgaps and W wordline structures in the memory device after Ar^+ milling (**b**).