Narrow-beam argon ion milling of ex situ lift-out FIB specimens

Fischione, P.[1], Campin, M.[1], Bonifacio, C.[1] and Giannuzzi, L.[2]

[1] E.A. Fischione Instruments, Inc., United States, [2] EXpressLO LLC, United States

Focused ion beam (FIB) tools are frequently used to prepare transmission electron microscopy (TEM) specimens due to the site specificity and accuracy of specimen thinning and extraction that it provides [1, 2]. In addition, FIB ex situ lift-out (EXLO) TEM specimen preparation is employed due to its higher throughput and flexibility when compared to in situ FIB preparation [3]. TEM specimens can be attached to carbon-supported mesh grids, which is a common EXLO method used by the semiconductor industry to improve throughput [4]. Unfortunately, the carbon support presents problems if the lamella needs to be thinned further for high-resolution TEM analysis or when attempting to isolate specific features within the lamella. Further thinning of the TEM specimen mounted on a thin carbon support with a Ga ion beam is limited due to the deleterious milling of the carbon support, which can result in loss of the specimen. In addition, high energy Ga ion milling causes artifacts, such as surface damage and ion-implanted layers, which limits analytical and high-resolution electron microscopy. In contrast, low energy (< 1 keV) Ar ion milling has been shown to improve specimen quality and remove Ga implantation [5-6]. We present targeted, narrow-beam (< 1 micrometer diameter) Ar ion milling as a method of improving specimen quality and removing gallium damage on carbon-supported EXLO TEM specimens.

EXLO FIB TEM specimens from patterned semiconductor wafers were FIB prepared and transferred to several types of carbon-supported TEM grids (Figure 1a). Narrow-beam Ar ion milling was performed using a tool which rasters the beam within a milling box placed over the area of interest. In order to gradually reduce the milling rate, Ar ion energies were reduced as the thickness of the lamella decreased. TEM and energy-dispersive X-ray spectroscopy (EDS) were performed for thickness evaluation and chemical analysis before and after ion milling.

Specimens were observed in situ in the ion milling system (Figure 1) using both a secondary electron detector (SED) and a scanning transmission electron microscope (STEM) detector to track thickness reduction of the specimens by contrast change. Thickness reduction of the carbon support and the TEM lamella were observed using the live imaging capability of the integrated electron column. Tests to determine the optimum ion milling conditions were performed. The sub-micrometer beam size, precise ion beam positioning, and low current densities of the argon ion milling system allowed thinning of the lamella with minimal damage to the supporting carbon foil. TEM images showed a reduction in specimen thickness (Figure 2) with no curtaining and EDS analysis shows a reduction of Ga after Ar ion milling (Figure 1). Quantification of the amount of sample thinning and Ga implantation reduction for EXLO lamella on various supporting grids is ongoing.

References:

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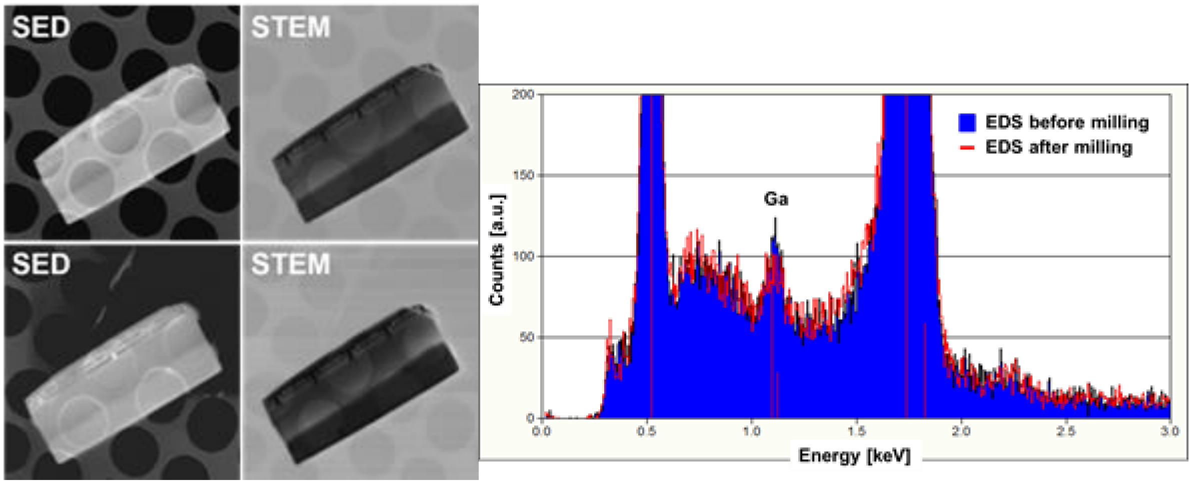

Figure 1. SED and STEM images (left) from the argon ion milling system showing an intact TEM lamella after milling. EDS data (right) acquired before (red) and after (blue) argon ion milling show a reduction in the amount of Ga.

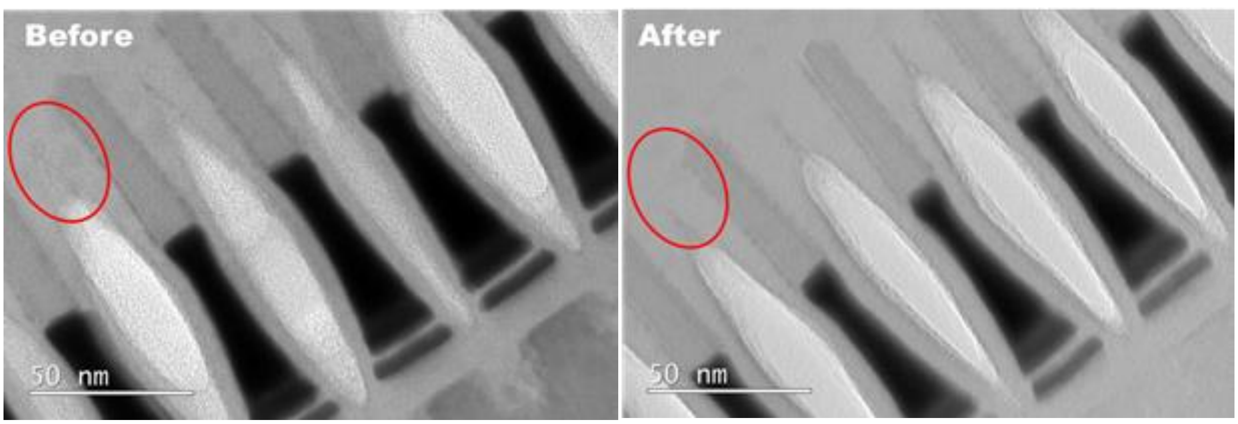

Figure 2. TEM images taken before Ar ion milling have poor delineation between features and contain variations in contrast within the inter-layer dielectric (ILD) regions (red circle). TEM images taken after argon ion milling show a show significant improvement in the contrast of features and uniform contrast within the ILD regions.