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Warp Free TEM Sample Preparation Methods Using FIB/SEM Systems

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Introduction

Systems that incorporate both a gallium based focused ion beam (FIB) and a scanning electron microscope (SEM) are commonly used in the semiconductor industry for the preparation of transmission electron microscopy (TEM) samples [1], [2]. These systems can capture patterned features at specific locations with sample thicknesses of less than 20nm [3]. Furthermore, skilled operators can frequently prepare a sample in roughly one to two hours depending upon the complexity of the sample and with the advent of auto TEM sample preparation systems, this time can be reduced to approximately 45 minutes per sample [4]. However, the conventional fabrication approach with FIB/SEM systems leaves at least one side of the sample too thin to provide structural support. This issue leads to warping and limitations on what can effectively be captured in a TEM sample [5]. For example, these limitations can severely impact or even prevent the preparation of back-end-of-line (BEOL) plan view (PTEM), large front-end-of-line (FEOL) PTEM or multilayer cross-section TEM (XTEM) samples. In this paper two methods are presented that overcome these limitations by enabling FIB/SEM operators to prepare both PTEM and XTEM samples where the thinned region is surrounded by thick supporting structures on all four sides. In addition, the reduction in sample warpage benefits TEM analysis by eliminating the need to perform multiple stage alignments when imaging different features in a sample.

Horizontal Oxide Bracing Method

For both PTEM and XTEM sample preparation the method of depositing horizontal oxide braces is performed by implementing conventional process steps up to the completion of the first side of the sample. At this stage the sample is still thick. Consequently, the sample has yet to warp. Furthermore, since the first side of the sample is now complete the need to expose this side of the sample to the ion beam no longer exists. Thus, one is now free to modify the first side of the sample in a way that would block the ion beam so long as the modification does not impact the region of interest. The needle of a gas injection system (GIS) is then inserted, and electron-beam-induced deposition is used to deposit horizontal oxide braces above the region of interest in the original cap and below the region of interest as shown for the PTEM sample in Figure 1. The horizontal width of each brace must exceed the width of the mill pattern used when thinning the second side of the sample. After brace deposition is complete, the substrate side of the sample is thinned by conventional TEM sample preparation techniques.

Oxide is used for the braces because the minimal overspray that occurs normally does not impact TEM analysis. However, if the oxide overspray for a particular application does pose a problem, then it can be removed by FIB sputtering at a reduced beam energy after loading the sample horizontally into the FIB/SEM. This step should be performed once the second side of the sample is complete. The overspray from the deposition of metals such as platinum or tungsten would most likely degrade TEM analysis, and therefore, is never used to form the horizontal braces. Brace deposition time is greatly decreased by increasing the current of the electron beam. For the braces shown in Figure 1 an electron beam current of 13nA was used. Beam alignments and focusing are never performed on the sample at such a high current to avoid sample damage. This concern is magnified when depositing braces on XTEM samples where the delicate ILD layers are easily damaged by the intense electron beam. One final note regarding this process is that frequently live beam shifts must be performed during brace deposition to counteract drift.

Crossing FIB Box Method

The crossing FIB box method also achieves the goal of producing thick supporting structures on all four sides of the sample with the added benefit of eliminating the use of a GIS. However, this method is significantly more time consuming and requires a higher skill set than needed to perform conventional TEM sample preparation. Thus, this method should only be used for cases when oxide overspray cannot be tolerated and the risk of ion beam damage from FIB sputtering is too great. This method has only been applied to PTEM sample preparation, but in principle could also be applied to XTEM sample preparation with precautions taken to mitigate curtaining. When thinning the first side of the sample a FIB pattern only slightly wider than the region of interest is used. The FIB pattern must leave thick regions of the sample to the left and the right of the pattern. Once the desired layer is reached the sample is removed from the grid and reattached so that the trench produced by the first side FIB pattern is horizontally oriented. Side 2 is now thinned to the desired layer using a FIB pattern that again leaves thick regions of the sample to the left and the right of the pattern. The process to remove and reattach the sample is too complex to describe here. Both sides of a completed BEOL PTEM sample are shown in Figure 2. Note that the side one mill box is now oriented horizontally in this image. Thus, only where the two mill boxes cross is the sample thin.

Conclusions

The horizontal oxide bracing method can be used to prepare effectively warp free PTEM and XTEM samples on normally configured FIB/SEM systems by operators trained to perform conventional sample preparation. Furthermore, the time required to deposit the braces is only a few minutes. The crossing FIB box method also enables the fabrication of effectively warp free FEOL and BEOL PTEM samples and eliminates the overspray generated by the horizontal oxide bracing method.

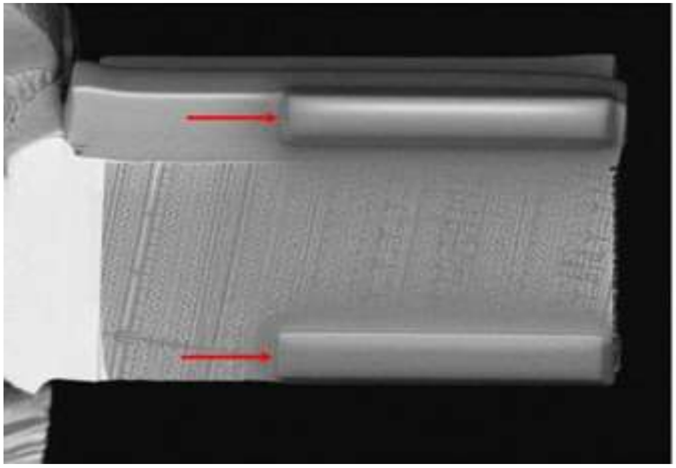

Figure 1. Figure 1: The red arrows in this figure point toward horizontal oxide braces that were deposited using electron-beam-induced deposition.

Figure 2. Figure 2: This figure shows a SEM image taken from the first side of a completed BEOL plan view TEM sample prepared using the crossing FIB box method.

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