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**Meeting-report**

# Artifact-Free Preparation of Plan View TEM Specimens and Its Application to MRAM Devices

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Transmission electron microscopy (TEM) specimens are prepared in a focused ion beam (FIB) tool in either cross-section or planar TEM specimen configurations. The former is a common method of TEM specimen preparation, while the latter preparation method is used infrequently. Even so, there are many advantages in plan view TEM specimen preparation. For example, one plan view sample can yield many repeating features [1], which can generate increased statistics from the large field of view (as compared to a cross-section specimen). Also, a plan view specimen allows for feasibility of direct correlation of microscale properties by scanning electron microscopy (SEM) methods [2]. Here, we describe post-FIB Ar concentrated ion beam (CIB) milling preparation of plan view TEM specimens; neither mechanical treatment [3] nor the addition of a protective block prior to FIB preparation [4] are necessary. We apply this novel, controlled, and artifact-free plan view TEM specimen preparation method to a fully fabricated magnetic random access memory (MRAM) device to achieve atomic resolution imaging and analysis of grain boundary structure in MgO thin films. MgO thin films comprise the ultra-thin tunnel barrier layer that is sandwiched between a multilayer stack in an MRAM device.

A spin-transfer torque MRAM device (STT-MRAM) [28 nm eMRAM, Samsung] was depackaged and from which plan view specimens were prepared using a FIB system [Scios, Thermo Fisher Scientific]. Post-FIB Ar concentrated ion beam (CIB) milling [PicoMill® TEM specimen preparation system, Fischione Instruments] was performed using the high-tilt method as described in a previous work [5]. This TEM sample preparation method is controlled and reproducible. FIB plan view specimen preparation followed by CIB polishing of the STT-MRAM specimens prevented exposure of the tunnel barrier layer, which can be damaged easily by the Ga beam of the FIB system when preparing cross-section specimens.

Determination of the layer thickness within the multilayer stack was performed by preparing a cross-section TEM specimen in the FIB system; the specimen was subsequently polished by the CIB system. Figures 1a-b show TEM images of the cross-section specimen after CIB milling. Each layer of the magnetic tunnel junction (MTJ) was revealed: the free layer, the tunnel barrier with the MgO layer, the reference layer, and its interface. The MgO layer thickness was measured as 2 nm. Figure 2a-b shows the plan view TEM specimen after FIB system preparation (Fig. 2a). Part of the protective Pt layer was milled off, which exposed the Cu metal line during thinning in the FIB system. Fig. 2b shows an electron-transparent specimen after CIB Ar milling. Multiple areas with MgO grains (Fig. 2c) were resolved and the $SiO_2$ layers in between the device structure were free of redeposition. This indicated that the sample preparation technique successfully attained the region of interest, the MgO layer, with a significant number of areas viable for grain analysis. Further fast Fourier transform analysis of the possible MgO layer on the specimen is ongoing. Details of the plan view FIB and CIB specimen preparation method and elemental analysis will be presented.

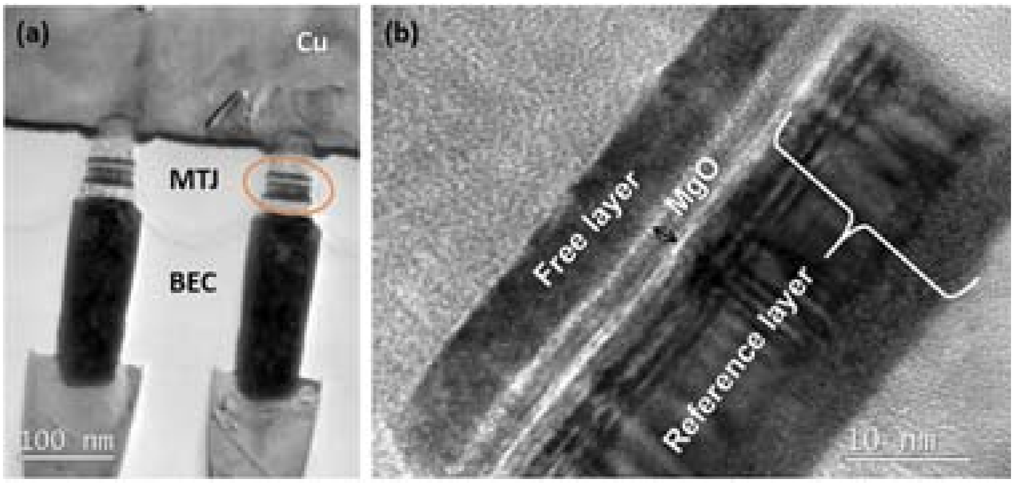


**Fig. 1.** Low magnification TEM image of the STT-MRAM cross-section specimen (**a**) after concentrated Ar ion milling shows the bottom electrode contact (BEC), magnetic tunnel junction (MTJ) and top Cu line of the STT-MRAM device. A high resolution TEM image of the MTJ (**b**) reveals the individual layers: free layer, tunnel barrier with MgO layer, and reference layer.

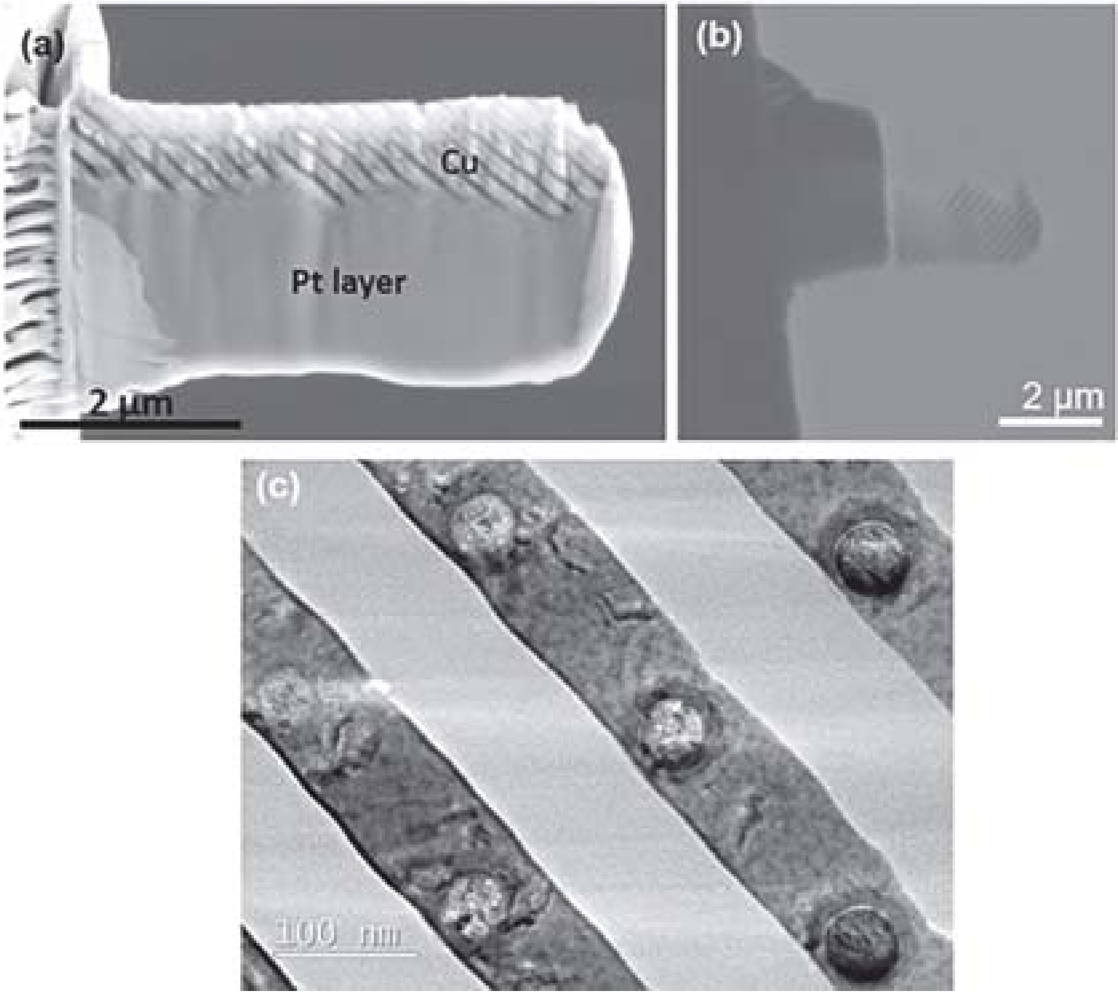


**Fig. 2.** Scanning electron microscopy images of a spin-transfer torque magnetic random access memory (STT-MRAM) device after plan view focused ion beam system preparation (SED image, **a**) and after concentrated Ar ion milling (STEM image, **b**). Subsequent condensed ion beam milling achieved an electron-transparent specimen from which a high magnification transmission electron microscopy image (**c**) was obtained. Multiple areas with resolved MgO grains were revealed.

## References

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