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Investigation of Layer Composition and Morphology in Perpendicular Magnetic Tunnel Junctions

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As traditional complementary metal–oxide semiconductor (CMOS) technology approaches its limit, alternative technologies such as magnetic tunnel junctions (MTJs) are being explored to replace CMOS-based devices for memory and logic applications. MTJs have advantages such as nonvolatility, low power consumption, and high densities [1]. These features have enabled application in technologies such as magnetic random access memory (MRAM), static random access memory (SRAM), and spin-transfer torque MTJs (STT-MTJs).

MTJs harness spin-dependent tunneling through a tunnel barrier (e.g., Al_2O_3 or MgO) that is placed between ferromagnetic electrodes. MgO-based perpendicular MTJs (p-MTJs) also exhibit perpendicular magnetization, which enables high density and scalability [2]. Three application criteria for p-MTJs are thermal stability and high values of tunneling magnetoresistance (TMR) and perpendicular magnetic anisotropy (PMA), and thus significant research has been devoted to improving these parameters.

A strategy to increase the TMR and PMA of CoFeB/MgO/CoFeB p-MTJs is to incorporate various heavy metals as capping and buffer layers. Tantalum has been widely used, but recently, other metals such as hafnium [3] and molybdenum [4] have been reported. We recently demonstrated that p-MTJs with Mo retain high values of TMR and PMA after annealing at 400°C, in contrast to their Ta analogues [5]. However, the structural basis for this performance has been unknown.

Here, we present scanning transmission electron microscopy (STEM), energy-dispersive X-ray spectroscopy (EDX), and electron energy-loss spectroscopy (EELS) data that characterizes the various layers in Mo- and Ta-based p-MTJs. Several features of interest are elemental mixing between layers, crystallinity, and interfacial roughness. Figure 1 shows characterization of cross sections of unannealed and annealed Ta samples. Figures 1(a,b) show high-angle annular dark-field (HAADF) and bright-field (BF) STEM images, respectively, of an unannealed Ta-based p-MTJ, and Figure 1(c) shows HAADF-STEM and EDX data displaying the elemental compositions of the layers of an annealed Ta-based MTJ. The data presented here provides insights into how the sample microstructure is related to device performance. STEM imaging and STEM-EDX experiments were conducted using an aberration-corrected FEI Titan G2 60-300 (S)TEM equipped with Super-X EDX and Gatan Enfinium ER spectrometers, operated at 200 kV [6].

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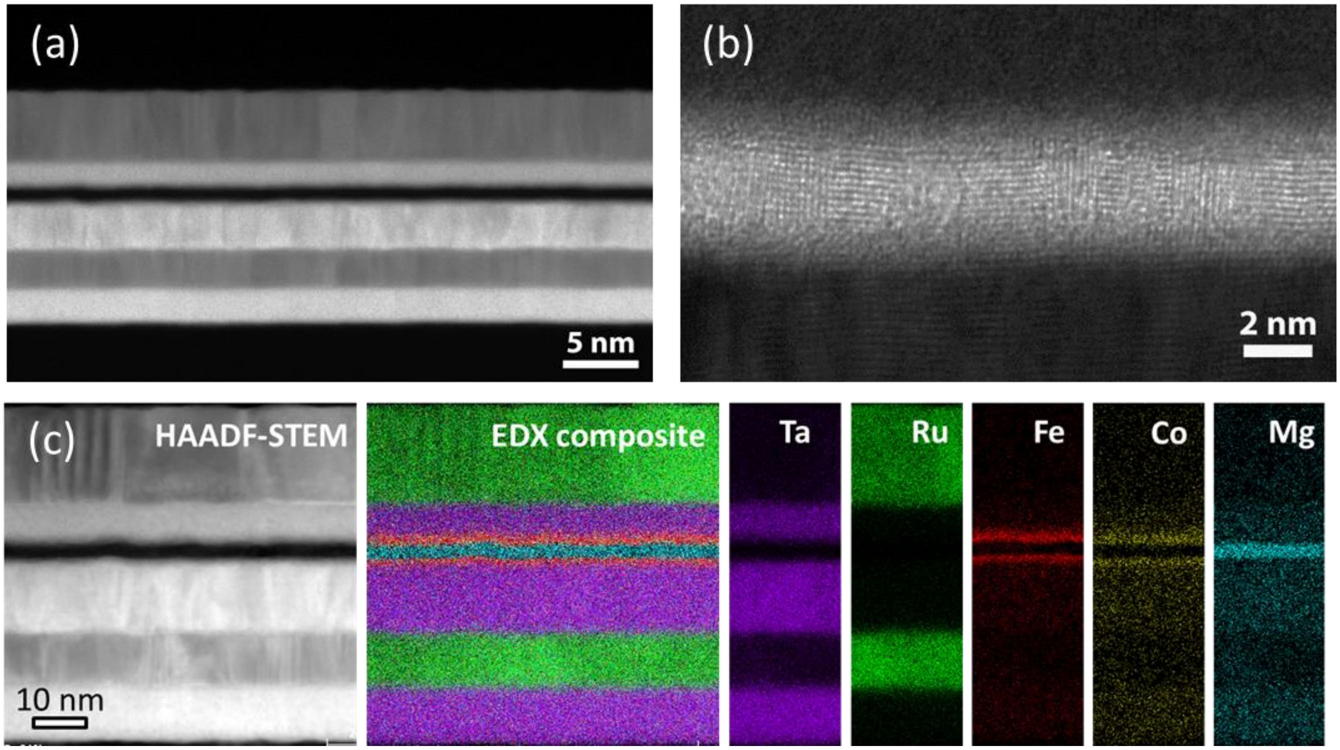

Figure 1. Characterization of Ta-based MTJs. (a) HAADF-STEM image and (b) BF-STEM image of an unannealed Ta-based sample. (c) HAADF-STEM image and EDX maps of an annealed Ta-based sample.