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Tunneling Magnetoresistance and B Diffusion in CoFeB/MgO/CoFeB Magnetic Tunnel Junctions Characterized by STEM-EELS

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Magnetic tunnel junctions (MTJs) are an essential component in both magnetic random access memories (MRAMs) and read-head sensors. Achieving a high tunneling magnetoresistance (TMR) ratio is especially crucial for MRAMs. Since the theoretical prediction of over 1000% TMR [1], MgO-based MTJs became an excellent candidate for non-volatile memory devices and have been extensively studied, resulting in large TMR values up to 472% at room temperature [2]. The steady increase in TMR has already led to a commercial MRAM 4 Megabit memory [3].

Despite the remarkable experimental progress, there is a discrepancy between the theoretical predictions and the experimental results. Theoretically, the high TMR value is attributed to a slowly decaying, coherent tunneling pathway available only to a majority spin state, which is made possible by lattice-matching the interface between the MgO barrier and the ferromagnetic electrodes [1]. Experimentally however, RF-sputtered MTJs, whose MgO/electrode interface is not precisely controlled, produce high TMR values [4]. Moreover, using an amorphous CoFeB electrode and annealing the device afterward is found to produce even higher TMR values. With the CoFeB electrodes, we observe that a significant amount of B diffuses into the RF-sputtered MgO barrier and becomes oxidized [5]. These observations suggest that the tunneling mechanism through the MgO layer cannot be fully accounted for by the current theoretical model [1].

To further investigate the effect of B (in the MgO layer) on TMR, we examined MgO-based MTJs with different thicknesses of the MgO layer and varying amounts of B in the CoFeB electrodes. The MTJs consist of a Si/SiO_x substrate / seed layer / 25 nm IrMn / 4nm CoFeB / MgO / 3nm CoFeB / capping layer (Figure 1). The capping layer is 8 nm Ta / 7nm Ru and the seed layer is four repeating layers of 5 nm Ta / 20nm CuN. We measured TMR values and RA products of the devices and characterized the devices using EELS in STEM mode. A TMR value of 180% is observed after annealing at 350 C for 90 minutes. We report the relative concentration of B in the MgO layer with respect to the O content at the center of the MgO layer (Figure 2). We will discuss our TMR results and correlate them with the amount of B found in the MgO layer.

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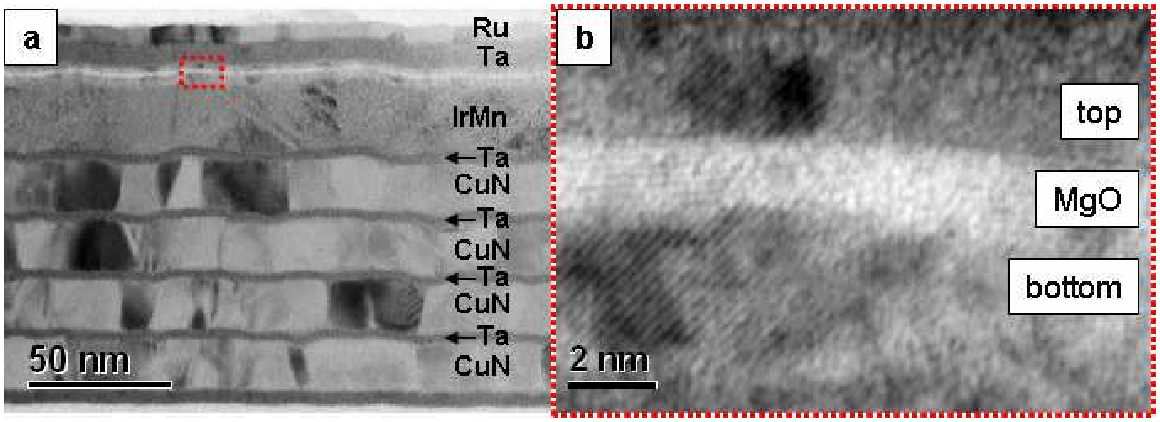

Figure 1. STEM-BF images of CoFeB/MgO/CoFeB magnetic tunnel junction (MTJ) structure after annealing. **a)** A low magnification image shows the structure of the device - seed layer/ IrMn/ CoFeB/ MgO/ CoFeB/ capping layer. **b)** A high magnification image shows that MgO is not uniformly crystalline. Also the electrodes contain regions that are crystalline.

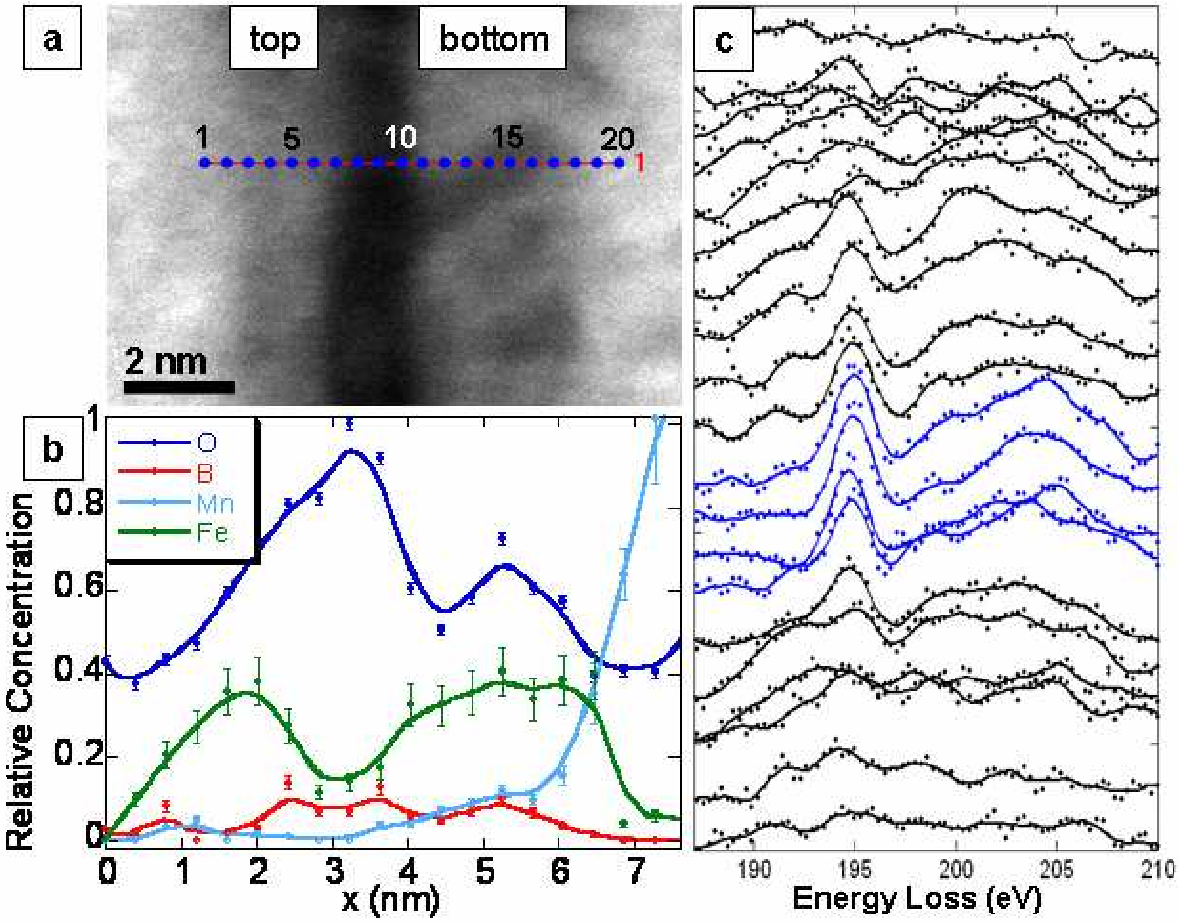

Figure 2. EELS characterization of a MgO-MTJ device. **a)** 20 point-spectra (blue dots) are taken across the tunnel junction. **b)** Concentration profile of various species in the tunnel junction. Approximately 10% of B is found in the MgO layer when the O concentration is normalized to 1 in the MgO layer. **c)** B-K edge across the junction. B found in the MgO layer is oxidized, as indicated by the strong π^* at ~ 195 eV.