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A TEM Structural Study of the Origin of Perpendicular Magnetic Anisotropy in Ultra-thin CoFeB Film

Zhi-Peng Li, Shaoping Li, Yuankai Zheng, Jianxin Fang, Lifan Chen, Liang Hong, Haifeng Wang

Western Digital Corporation, 44100 Osgood Road, CA 94539, USA.

Perpendicular magnetic anisotropy (PMA) at ferro-magnetic transition metal/insulator interfaces has attracted intensive interest in the context of developing various spintronic devices. Magnetized out-of-plane magnetic tunnel junctions (p-MTJ) are now developed for spin transfer torque (STT) magnetic random access memories (STT-MRAM) applications where the strong perpendicular anisotropy originating from the CoFe/MgO interface allows to maintain the thermal stability of the storage layer magnetization down to at least 20nm technological node. MTJ stack possessing ferromagnetic layer with a large PMA is expected to provide novel features such as high thermal stability and low switching energy consumption. Ultra-thin CoFeB (CFB) films in contact with MgO show a large PMA, which is originated from the interface integration, and have been recently studied in MTJs' stack [1]. Several studies tried to optimize the PMA and to study its dependence on the thickness of CFB layer [1], on the buffer layer [2] as well as the oxidation condition at the interface and the annealing temperature. Although PMA has been widely studied, the origin of its very large value in CFB/MgO system has not yet been fully unveiled. In this work, we have conducted a detailed TEM characterization for experimentally clarifying the PMA origin in ultra-thin CFB layer on the top of MTJs. Such study would certainly deepen our understanding of the mechanism of PMA in CFB thin film in MTJ stacks.

Two samples with similar structure (Fig. 1a) were fabricated on Si substrates using an ultrahigh vacuum magnetron sputtering. The films were then annealed at 270°C for 5 hours in ultra-high vacuum. Thereafter, TEM cross-sections of the two film stacks are made with almost identical conditions. There is no obvious difference from either the cursory view of film stacks (Figs. 1b and 1c) or the high resolution imaging (Fig. 1d and 1e). The magnetization (M-H) curves of the samples were measured by vibrating sample magnetometer (VSM) with perpendicular and in-plane magnetic fields. Figure 2 shows the magnetization curves measured with in and out-of-plane magnetic field for the 20Å-CFB layer sample and 10Å-CFB one, clearly demonstrating the PMA effect in the ultra-thin 10Å-CFB sample. Figure 3 presents STEM EELS comparisons of the two samples. It is difficult to distinguish the B distribution in 10Å-CFB (Fig. 3a) due to the small amount of B, while it can be noticed that B is mainly accumulated at the CFB/MgO interface in the 20Å-CFB sample (Fig. 3b). According to EELS fine structure comparison of Fe L2,3 peaks (Fig. 3c), the significant difference between Fe L2/L3 white line ratio can be detected. Since the L2,3 white lines were originated from the core electrons excited into well-defined empty states, the L2/L3 intensity ratio change can be used as fingerprint to interpret the local element environment. This is a clear evidence of the Fe bonding difference in 10Å-CFB layer compared to that in 20Å-CFB which is normal Fe EELS structure. Other structural study shows that more dislocations can be observed in thick 20Å-CFB sample, leading to more relaxed epitaxial layer formation in that film stack. However, more strain contrast can be noticed in 10Å-CFB sample. Therefore, the experimental findings support that the large PMA in CFB/MgO is an interface effect, which could be attributed to the interface strain relax resulting in possible lattice distortion along z-axis, and a hybridization between interfacial Fe-3d and O-2p, leading to the bonding environment change there.

References:

[1] S Ikeda *et al*, Nature Mater. **9** (2010), p. 721.
[2] D Worledge *et al*, Appl. Phys. Lett. **98** (2011), p. 022501.

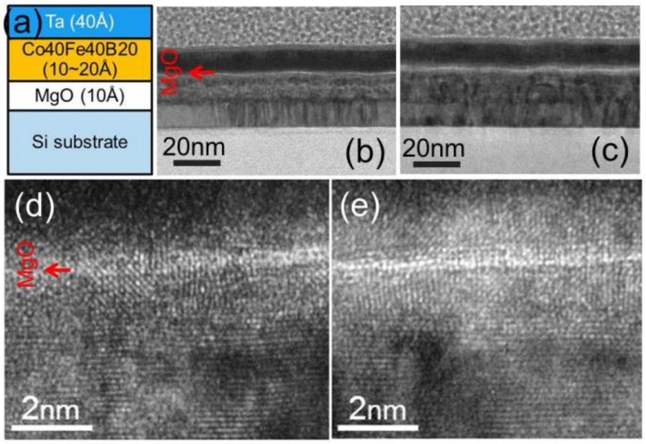

Figure 1. (a) Schematic structure of thin film stacks; TEM overview of (a) 10Å-CoFeB and (b) 20Å-CoFeB samples. HRTEM images of (d) 10Å-CoFeB and (e) 20Å-CoFeB sample, separately.

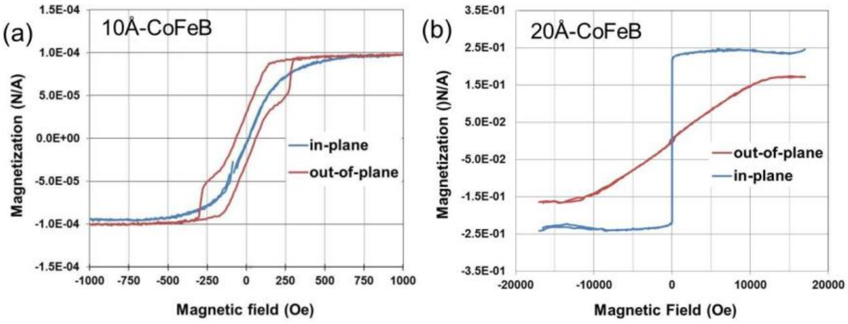

Figure 2. The easy and hard M-H loop comparisons of CoFeB layer in the two samples.

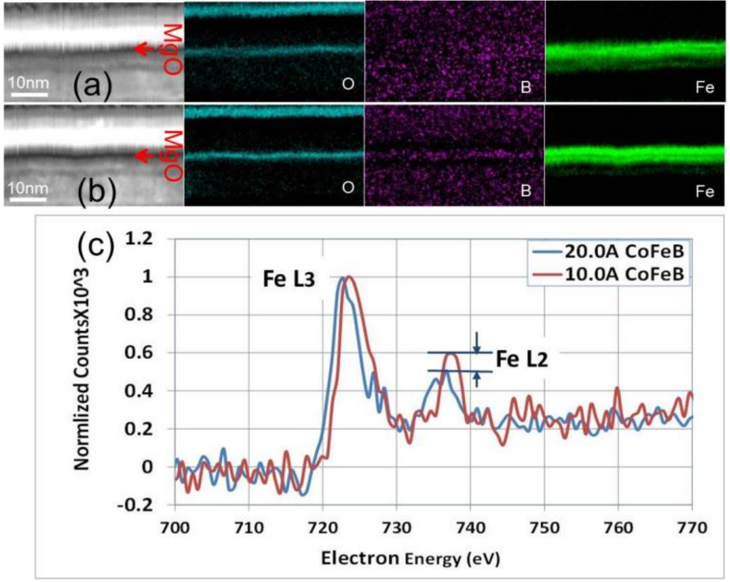

Figure 3. STEM EELS mapping of (a) 10Å-CoFeB sample and (b) 20Å-CoFeB with selected elements. (c) the comparison of Fe L2,3 fine structure shows the difference between the two samples.