Perpendicular magnetic anisotropy of polycrystalline Fe/MgO interfaces induced by W buffer and Tb capping layers

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The CoFeB/MgO layered structure is one of the most popular ferromagnetic metal/oxide systems possessing interface perpendicular magnetic anisotropy (PMA). Perpendicularly magnetized CoFeB/MgO-based magnetic tunnel junctions (MTJs) have been developed by using a sputter-deposition technique which is suitable for commercial productions, with the PMA energy density of 0.21 MJ/m^3 after the post annealing of amorphous layers [1]. The boron dopants presumably play a key role crystallized CoFeB/MgO interface with significant interfacial PMA. On the other hand, the large PMA in the Fe/MgO interface was often discussed based on the hybridization between Fe $3d_z{}^2$ and O $2p_z$ states [2] and a PMA energy density of 1.4 MJ/m^3 was achieved in a molecular beam epitaxy (MBE)-grown single crystalline Fe/MgO bilayer [3], suggesting that the Fe-based interfaces are preferable to obtain the large PMA characteristics. To our knowledge, however, Fe/MgO-based perpendicular MTJs have never been fabricated by sputter-deposition processes. In this study, by using the specific buffer and capping layers, we attempt to fabricate sputter-deposited Fe/MgO layered structures with large PMA energy densities.

Multilayered stacks of W-buffer(3nm)/Fe(0.85-2nm)/MgO(2nm)/Tb(2nm)/W(1nm) were deposited on thermally oxidized Si substrates using an rf sputtering method as shown in the inset of Fig.1. After the depositions at an ambient temperature, in-situ post-annealing was performed at 550°C. Magnetic properties were measured using a vibrating sample magnetometer (VSM) in the in-plane and perpendicular-to-plane directions. To evaluate the element-specific spin and orbital magnetic moments, as demonstrated for the MBE-grown Fe/MgO interfaces [4], x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) measurements were performed for Fe $L_{2,3}$-edges and Tb $M_{4,5}$-edges.

By optimizing the Fe layer thickness and the post-annealing temperature, we succeeded in the growth of the samples with PMA energy as much as that of CoFeB/MgO [1]. Fig.1 shows Fe layer thickness dependence of PMA energy density. The saturation magnetization M_s in our samples is much lower than that in Fe/MgO structures fabricated by an MBE technique [3]. From the Fe layer thickness dependence of M_s, we found that a 0.63-nm-thick Fe dead layer is formed presumably by mixing with the W buffer layer. Since a 3-nm-thick W buffer layer deposited on the Si/SiO_2 substrate at room temperature forms an amorphous structure [5], the Fe layer is also grown as an amorphous without boron dopants. After the annealing, the Fe layer can be crystallized from the interface with MgO through the process of solid-state epitaxy. The analysis of XMCD deduces the anisotropic orbital magnetic moments in Fe, while no XMCD signals are observed in Tb, suggesting that Tb does not directly contribute to the PMA in Fe/MgO interface. Therefore, the role of Tb layer can be regarded as absorbing the excess oxygen in the Fe/MgO interfaces, which suggests a new route to synthesize the interfacial PMA in sputter-depositied Fe/MgO without boron dopants.

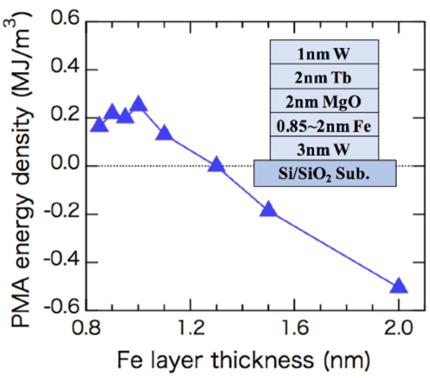

Fig. 1. Fe layer thickness dependence of PMA. Inset shows the layer structure.

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