PERPENDICULAR MAGNETIC ANISOTROPY OF AN Fe/MgO INTERFACE INDUCED BYW BUFFER AND Tb CAP LAYERS

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I. INTRODUCTION

Interface perpendicular magnetic anisotropy (PMA) of ferromagnetic metal/oxide layered structures is an important topic in perpendicularly magnetized magnetic tunnel junctions (MTJs), which are employed as a main element of magnetoresistive random access memory (MRAM) devices that can realize both low power consumption and high density integration in computing systems. The PMA energy density is a crucial physical quantity that determines thermal stability of magnetization states of the MTJs. Considering the volume of the ferromagnetic layer for spin transfer torque MRAMs with a perpendicular easy axis, PMA energy density of 1 MJ/m^3 is required to hold the data for 10 years.

CoFeB/MgO is the most popular layered structure in obtaining interface PMA of ferromagnetic metal/oxide systems. A perpendicularly magnetized CoFeB/MgO-based MTJ was developed by using a sputter-deposition technique suitable for commercial productions, and it exhibits a PMA energy density of 0.21 MJ/m^3 in the CoFeB layer [1]. On the other hand, ab initio calculations predict that the PMA energy in Fe/MgO interfaces is larger than that in Co/MgO interfaces [2]. This large PMA is often discussed based on the hybridization between Fe $3d_z{}^2$ and O $2p_z$ states [2,3]. In a corresponding experiment, PMA energy density of 1.4 MJ/m^3 was achieved in a molecular beam epitaxy (MBE)-grown Fe/MgO bilayer [4], suggesting that pure Fe based interfaces are preferable to obtain large PMA characteristics. However, Fe/MgO based perpendicular MTJs have never been fabricated by sputter-deposition processes, since boron presumably plays a key role to form a CoFeB/MgO interface with significant interface PMA.

In this work, by using specific buffer and cap layers, we tried to fabricate sputter-deposited Fe/MgO layered structures with perpendicular magnetization.

II. EXPERIMENT

Multi-layer stacks of W-buffer(3nm)/Fe(0.85-2nm)/MgO(2nm)/Tb-cap(2nm) were deposited on thermally oxidized Si substrates using an rf sputtering method (Figure 1). After completing all the depositions, in-situ annealing treatment was performed at 550˚C for 1 hour. Magnetic properties were measured using a vibrating sample magnetometer (VSM) for in-plane and perpendicular-to-plane directions. PMA energy densities were determined from the area surrounded by the two M-H curves. To evaluate the element-specific spin and orbital magnetic moments, x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) measurements were performed for Fe $L_{2,3}$-edge and Tb $M_{4,5}$-edge.

III. RESULTS

By choosing an optimized Fe layer thickness, we succeeded in the growth of the samples with PMA energy as much as that of CoFeB/MgO [1]. Figure 2 shows magnetization curves of W/Fe(0.9nm)/MgO/Tb, from which the PMA energy density (K_{eff}) is evaluated to be 0.22 MJ/m^3. Figure 3 shows Fe layer thickness dependence of K_{eff}. The saturation magnetization in our samles is much lower than that in Fe/MgO interfaces fabricated by an MBE technique [3]. A 0.63 nm thick Fe dead-layer was found to be

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formed, which can cause the low value of saturation magnetization.

The role of W buffer and Tb cap layers were considered from a structural point of view. When a 3 nm W layer is deposited on the Si/SiO_2 substrate at room temperature, it forms an amorphous structure [5]. Therefore, Fe is also grown as an amorphous structure, even though the Fe layer does not contain boron. When it is annealed, Fe layer can be crystallized from the interface with MgO. When Tb is not inserted, the easy magnetization axis aligns along the in-plane direction, and the saturation magnetization decreases. 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 Fe/MgO interfaces.

This study was partly supported by JSPS KAKENHI Grant Nos. 16H06332 and 15H03562.

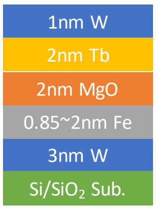

Fig. 1. Schematic of sample structures of W(3nm)/Fe(0.85-2nm)/MgO(2

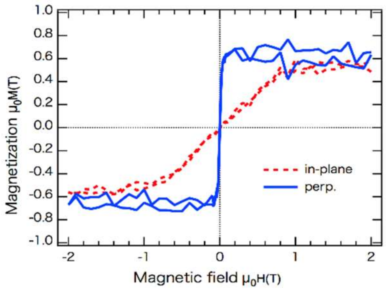

Fig. 2. Magnetization curves of a W/Fe(0.9nm) /MgO/Tb layered structure in the in-plane and perpendicular-to-plane directions

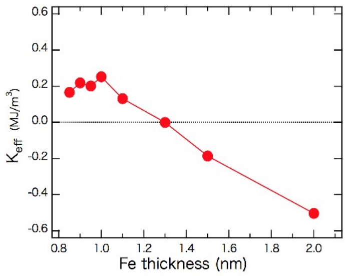

Fig. 3. Fe layer thickness dependence of PMA energy density K_{eff}.

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