Perpendicular magnetic anisotropy in as-deposited La/CoFeB/MgO layered structures

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Perpendicular magnetic anisotropy (PMA) is one of the most important issues to develop perpendicular magnetic tunnel junctions (p-MTJs). In the case of CoFeB that is widely used for p-MTJs, interface PMA with MgO plays an important role, since it does not show PMA in a bulk form [1]. Despite the continuous efforts to improve the PMA characteristics in CoFeB/MgO heterostructures, the mechanism of PMA has not fully been understood. First-principles calculations show that the hybridization of Fe-3d_{z^2} and O-2p_z states plays a crucial role in the occurrence of the interface PMA [2], where O atoms are positioned just above Fe atoms at the interface. Such an atomic-scale interface structure is likely essential, which is supported by the fact that PMA energies are dramatically increased by post-annealing in most of Fe-based alloy/MgO heterostructures [3-6]. On the other hand, interface PMA can also be observed even for the as-deposited CoFeB/MgO layered structures, depending on the underlayer materials [3,7]. In this study, we investigated PMA in as-deposited La/CoFeB/MgO layered structures, since the PMA in as-deposited layered structures was obtained depending on underlayer materials with a small electronegativity such as Ta or Zr. Note that La also exhibits a typical small electronegativity material that is likely to cause interatomic charge transfer, as well as to be easily oxidized.

CoFeB (t_{CFB})/MgO (2nm) bilayer structures with a 2-nm-thick La underlayer were prepared by rf sputtering on a W-buffered thermally oxidized Si substrates. The whole stacking structures are Si/SiO_2-subs.//W-buffer(3nm)/La(2nm)/CoFeB(1nm)/MgO(2nm)/W-cap(1nm) which are grown at room temperature. The thickness of CoFeB layer, t_{CFB}, was varied ranging from 0.8 nm to 1.4 nm. No annealing process was performed in the sample preparation procedures. Magnetic properties were examined by a vibrating sample magnetometer, and x-ray magnetic circular dichroism (XMCD) was measured for the element-specific characterization.

Figure 1 shows the areal PMA energy density $K_{eff}t_{CFB}$ as a function of t_{CFB}. Around t_{CFB} = 1.0 nm, definite PMA is obtained for the as-deposited La/CoFeB/MgO layered structures. The PMA energy density reaches $K_{eff}t_{CFB}$ = 0.2 mJ/m^2 (K_{eff} = 0.2 MJ/m^3). In the XMCD measurements, it was found that the normal component of the orbital magnetic moment in Fe is slightly larger than the in-plane one, being qualitatively the same as the results in a previous XMCD study for a monocrystalline Fe/MgO layered structure [8]. This suggests that the anisotropy of the orbital magnetic moment brings about the interface PMA even in the as-deposited and therefore presumably amorphous CoFeB layer.

To further investigate the correlation between PMA and the sample structures, La/CoFeB/La and MgO/CoFeB/MgO were prepared. Interestingly, these structures did not show PMA. This means that each interface does not contribute to the occurrence of PMA independently. It is inferred that there is a certain interplay of the roles of under- and over-layers for CoFeB. One possible mechanism would be that the La underlayer works as an excess oxygen absorber to the well-oriented MgO overlayer. However, such a simple idea would not explain the entire results obtained in this study. Internal electric field generated at the La/CoFeB interfaces locally due to the large difference in electronegativity might influence the observed PMA.

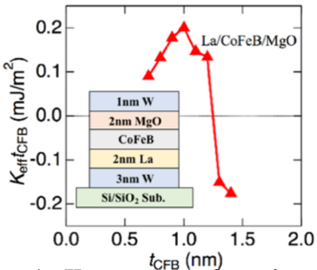

Figure 1, $K_{eff}t_{CFB}$ as a function of t_{CFB} in La/CoFeB/MgO layered structures. Inset shows the sample structure.

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