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Perpendicular magnetic anisotropy in ultrathin Fe film on MgO studied by x-ray magnetic circular dichroism

Jun Okabayashi[1*], Jungwoo Koo[2], Hiroaki Sukegawa[2], and Seiji Mitani[2]
[1]*Research Center for Spectrochemistry, The University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2]*National Institute for Materials Science (NIMS), Tsukuba 305-0047, Japan*

Perpendicular magnetization is one of the crucial issues in spintronics research field because it has benefits for thermal stability enhancement and the low current magnetization switching, which are very important for the development of spintronics devices. MgO-based magnetic tunnel junctions have been developed by exploiting the strong perpendicular magnetic anisotropy (PMA) at the interfaces between MgO and CoFeB transition metal alloys, measuring 2.1×10^5 J/m^3 [1], which is comparable to PMA in Co/Pt multilayers. As a fundamental understanding of PMA induced at the interface between ferromagnetic layer and MgO barrier layer, the electronic and magnetic structures of interfaces between ultrathin Fe layer and MgO have to be clarified explicitly [2]. It brings the understanding for the origin of FeCo alloys on MgO [3]. In order to investigate PMA energy (K), it is necessary to evaluate the orbital magnetic moments along parallel and perpendicular directions to the surface. Here, we report the anisotropic orbital moments of Fe/MgO by using x-ray magnetic circular dichroism (XMCD).

Samples were grown by electron-beam evaporation methods on MgO substrates. The 0.8-nm-thick Fe layer was deposited on Cr buffer layer and MgO layer was also grown on thin Fe layer. Post annealing at 450 ℃ was performed to enhance PMA, which was estimated to be 1.4 MJ/m^3 by vibrating sample magnetometer (VSM) at room temperature [2]. XMCD measurements were performed at KEK-PF BL-7A under the conditions of room temperature and normal incidence (NI) setup. A magnetic field of 1.2 T was applied along the incident polarized soft x-ray, which is enough to saturate the magnetization along magnetically easy axis direction. The total electron yield mode was adopted.

Figure 1 shows Fe L-edge x-ray absorption spectra and XMCD. Clear metallic peaks in absorption spectra reveal no mixing with oxygen atoms. Hysteresis loops at Fe L_3-edge photon energy shown in the inset of Fig. 1 clearly display the easy axis direction in the PMA. For the hard-axis direction, saturation magnetic field of 3 T is needed [2]. Asymmetry in XMCD spectrum reveals that the large orbital moments are induced. Using magneto-orbital sum rules, the orbital magnetic moments of 0.22 μ_B for sample surface normal direction are estimated. Considering the Bruno relationship; $K=(\xi/4)\Delta m_{orb}$, where ξ is spin-orbit coupling, we obtain K=0.9 MJ/m^3, which is comparable to the results obtained by VSM without the diamagnetic contribution. Therefore, element specific XMCD measurements become a unique technique for probing ultrathin magnetic layer on MgO.

Considering above results, the origin of PMA in Fe/MgO interface can be understood by the anisotropic orbital moments induced by spin-orbit interaction at the interface. Fe $3d_{z2}$ states are pushed up above the Fermi level through the hybridization with O $2p_z$ orbitals [4] and large perpendicular orbital moments are induced. Therefore, we conclude that anisotropic orbital moments in Fe $3d$ states are the origin of large PMA in Fe/MgO interface [5].

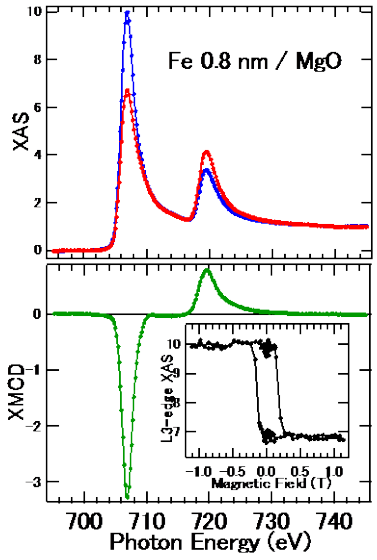

Fig. 1. X-ray absorption spectra and XMCD in Fe 0.8 nm/MgO. Inset shows the hysteresis curve at L_3-edge photon energy.

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*jun@chem.s.u-tokyo.ac.jp