BL-7A, BL-16A/2013G195

Observation of perpendicular magnetization in Cu layer inserted between Co and Pt layers revealed by x-ray magnetic circular dichroism

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Perpendicular magnetic anisotropy (PMA) in magnetic multilayers is strongly desired for the developments of high-density magnetic recording media. Co/Pt layers become one of the candidates possessing the PMA using the large spin-orbit interaction of Pt atoms and spin moments of Co atoms, which collaborates to enhance the PMA through the proximity effects at the interfaces. Recently, ultrathin Co/Pt layers have been also studied for the electronic-field modulations of magnetic properties [1]. On the other hand, the Co/Cu multilayer structures possessing the in-plane anisotropy derived from the shape anisotropy have been investigated extensively for the giant magneto-resistance devices [2]. The Cu spacer layers bring the RKKY-like oscillatory behavior in the magnetoresistance through the exchange coupling between the Co layers [3]. Combining these previous works, our objectives consist of the following two ideas; (i) the insertion of the Cu layer as an inserted layer between Co and Pt in order to separate the proximity between them and (ii) the induction of PMA in Cu spacer layer. In order to achieve these properties, we consider the stacked structures of Co/Cu/Pt thin films with different Cu layer thicknesses. In this paper, we investigate the element-specific spin and orbital moments of Co and Cu in the Co/Cu/Pt stacked structures using XMCD with the element-specific hysteresis curves in order to discuss the origin of the proximity-effect-driven PMA in the Cu inserted layer.

Samples prepared by rf-sputtering method consist of the stacked structures: MgO (2 nm)/Co (0.4 nm)/Cu (*t* nm)/Pt (2 nm)/Ta buffer layer deposited on the Si substrates with various Cu layer thicknesses (*t*). Samples of *t*=0.4 and 2.0 nm show the PMA and in-plane anisotropy, respectively. X-ray absorption spectroscopy (XAS) and XMCD measurements for Co and Cu *L*-edges were performed at BL-7A and 16A in Photon Factory (KEK). Photon helicity was fixed and a magnetic field of ±1.2 T was applied along the incident polarized soft x-ray. All measurements were carried out at room temperature in the total electron yield mode.

By inserting the Cu layer between Co and Pt layers, remanent magnetization (m_r) decreases rapidly at the threshold of 0.6-nm-thick Cu layer, suggesting that the proximity effects for PMA are weakened by the insertion of Cu layers. For less than 0.6 nm Cu thicknesses, the m_r slightly decreases. Near the threshold thickness, square shapes become broad and m_r decreases. For more than the threshold layer thickness, in-plane magnetization of Co derived from the demagnetization field in the films contributes to the magnetic anisotropy. These systematic changes confirm the abrupt interface formations without the intermixing.

Figure 1 displays the XAS and XMCD of Co and Cu *L*-edges in Co /Cu /Pt stacked sample showing PMA. In Co *L*-edge spectra, clear metallic XAS line shapes and XMCD can be observed. Quite small XMCD intensities in the Cu *L*-edges are detected as shown in Fig. 1 (b), which suggests that the XMCD signals are induced from the magnetic Co atoms with the same sign directions corresponding to the parallel alignments. Broad satellite structures in Cu $L_{2,3}$ edges are also observed corresponding to the transition from 2*p* to 4*s* states.

The element-specific hysteresis curves taken at the photon energies of Co and Cu L_3-edges clearly display the PMA (not shown). Here, we emphasize that the hysteresis curve of Cu displays the out-of-plane magnetization. PMA in the Cu layer is clearly observed which is induced by the proximity effects from both Co and Pt. In case of Co/Cu multilayers [3], in-plane induced magnetization in Cu is observed. Therefore, the PMA in Cu is derived not only from Co but also Pt spin-orbit interactions.

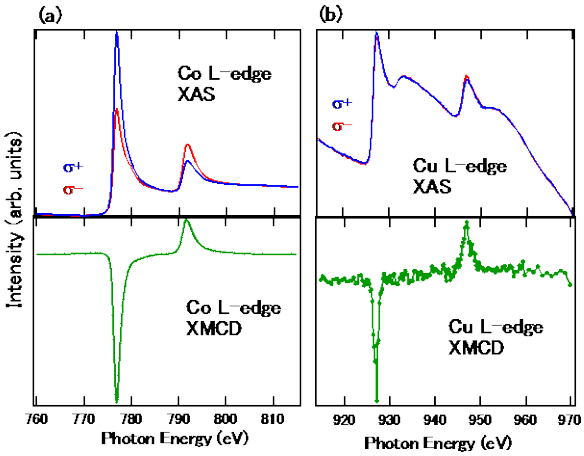

Fig. 1, XAS and XMCD of Co and Cu *L*-edges in Co /Cu /Pt stacked structure.

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