BL-7A/2021G069

Intrinsic Magnetic proximity effect at the $Co_xFe_{3-x}O_4$/Pt interface studied by XMCD

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The charge-to-spin current conversion phenomena via spin-orbit interactions have been intensively investigated in the field of spintronics. In particular, the spin Hall effect using heavy metal (HM) elements can directly convert a charge current into a spin current, and various useful phenomena have been reported in bilayers with ferromagnetic insulators (FMIs) through angular momentum exchange at the HM/FMI interface. The magnetic proximity effect (MPE), which induces ferromagnetism in a nonmagnetic HM through interfacial exchange interaction, also need to be investigated for interfacial materials designing [1]. The induced ferromagnetism has been examined in terms of the anomalous Hall effect and an anisotropic magnetoresistance effect in the HM layer. One significant issue with the MPE is the difficulty of experimentally detecting induced magnetic moments of HMs.

X-ray magnetic circular dichroism (XMCD) is a powerful tool for investigating this induced magnetism. Significant Pt magnetic moment signals cannot be detected by XMCD in the $Y_3Fe_5O_{12}$/Pt [2] and $CoFe_2O_4$/Pt systems [3]. Previous XMCD reports of $CoFe_2O_4$/Pt grown by pulsed laser deposition (PLD) found alloying at the interface in Pt deposited at high temperatures (400°C). Since this magnetic signal originates not from the MPE but from the alloying at the interface, the appearance of induced magnetic moments in Pt largely depends on the interfacial structures. This suggests that the MPE depends on the growth temperature and growth mode such as molecular beam epitaxy (MBE), PLD, or sputtering deposition. This arises from the difference in kinetic energies, with atoms deposited by MBE having lower kinetic energies than those deposited by sputtering, which suppresses the diffusion of atoms at the interfaces. Therefore, in this study, we employ MBE for the growth of CFO/Pt bilayers to understand the MPE.

Sample structures were MgO (001) substrate/ MgO (20 nm)/ NiO (5 nm)/ $Co_xFe_{3-x}O_4$ (CFO) (50 nm)/ Pt (t_{Pt} nm). MgO substrates. For Co and Fe L-edges, XAS and XMCD were performed at BL-7A in the Photon Factory. The photon helicity was fixed, and a magnetic field of ±1.2 T was applied parallel to the incident polarized soft x-ray beam to obtain the absorption signals, defined as $\mu+$ and μ- spectra. Total elections yield (TEY) mode was adopted, and all measurements were performed at room temperature.

Figure 1(a) shows the XAS and XMCD of CFO/Pt after the annealing at 500°C for the Fe and Co L-edges. The XAS intensities of Co are suppressed owing to the composition ratio of 1:10, resulting in a composition of $Co_{0.27}Fe_{2.73}O_4$ with x=0.27. The CFO with low Co composition exhibits perpendicular magnetic anisotropy (PMA) [4,5]. The XAS and XMCD line shapes for Fe L edges show distinctive features due to three kinds of Fe states (Fe^{3+} in O_h, Fe^{3+} in T_d, and Fe^{2+} in O_h). For the Fe L edges, although the difference in XAS is small, clear differential XMCD line shapes are detected. The Fe^{3+} state with T_d symmetry exhibits an opposite sign, which is common for spinel-type ferrite compounds. The XMCD hysteresis curves taken at the Fe^{3+} (O_h) peak photon energy are also displayed. The shapes of hysteresis curves are different between 500 and 600°, which is consistent with the SQUID measurements. The XMCD at Pt L-edges is also performed and interpreted consistently. Large XMCD signals in the Co L edge correspond to contribution of the orbital moment through the distorted Co^{2+} ($3d^7$) O_h site, which might be also related to the MPE [6].

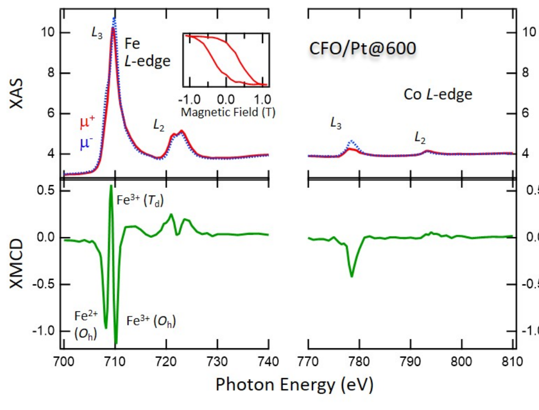

Fig. 1, XAS and XMCD of $Co_{0.23}Fe_{2.77}O_4$ facing on Pt layer after annealing at 600°C. Inset shows the hesteresis curve at Fe^{3+} (O_h) site.

References

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