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Origin of Perpendicular Magnetic Anisotropy in $Co_xFe_{3-x}O_{4+\delta}$ Thin Films Studied by X-ray Magnetic Circular and Linear Dichroisms

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Spinel-type oxide compounds such as Co-ferrites ($CoFe_2O_4$: CFO) epitaxial thin films are one of the candidates for spintronics application because of their insulating advantages as spin-filtering, high-frequency performance, and magneto-strictive properties. Recent development appends further functionality of large perpendicularly magnetic anisotropy (PMA) in CFO in the order of 10^6 J/m^3 by tuning the Co compositions [1]. Structural and magnetic properties in the CFO thin films can be controlled by the cation vacancies and anti-phase boundaries. Recent theoretical and experimental investigations for CFO thin films suggest that the tensile strain into CFO layer produces the PMA [2]. Although the PMA in CFO is strongly demanded for spinel-type oxide spintronics and spin-orbitronics by controlling the orbital states, the microscopic origin of the PMA appearing in the low Co compositions of CFO has not been clarified yet. In this study, we performed the x-ray magnetic circular and linear dichroism (XMCD/XMLD) measurements for CFO to understand the PMA microscopically.

The 13-nm-thick $Co_xFe_{3-x}O_{4+\delta}$ (001) samples (x=0.2 and 0.6) were prepared by pulsed laser deposition on the MgO (001) substrates. The case of x=0.2 and 0.6 exhibits the PMA and in-plane anisotropy, respectively [1]. The XMCD and XMLD were performed at BL-7A and 16A in the Photon Factory (KEK). For the XMCD measurements, a magnetic field of ±1.2 T was applied, by fixing photon helicities, parallel to the incident polarized beam. The total electron yield mode was adopted, and all measurements were performed at room temperature. In the XMLD measurements, the remnant states magnetized to PMA were adopted.

Figures 1 (a)-(c) show the XAS and XMCD of $Co_{0.2}Fe_{2.8}O_{4+\delta}$ for Fe and Co L-edges at the normal incidence setup. XAS and XMCD line shapes for Fe L-edges show distinctive features due to the three kinds of Fe states (Fe^{3+} in O_h, Fe^{3+} in T_d, and Fe^{2+} in O_h). Large XMCD signals in Co L-edge correspond to the saturated magnetized states. Figures 1 (d)-(e) show the **E** vector polarization dependent XAS, where the electric field **E** is parallel and perpendicular to the out-of-plane magnetization direction. Because of small difference in XAS by the horizontal (parallel) and vertical (perpendicular) beams as shown in the inset of Fig. 1(e), XMLD intensities are also suppressed and displayed in the different scales. For Fe L-edge XMLD, the overlapping of three kinds of components brings complex differential line shape. We note that the integrals of the XMLD line shapes are proportional to the charge asphericity within the XMLD sum rule. With both XMCD and XMLD combined, it can be concluded the in-plane tensile strain triggers the changes of charge distribution along in-plane direction, resulting in the large out-of-plane m_{orb} and the PMA [3].

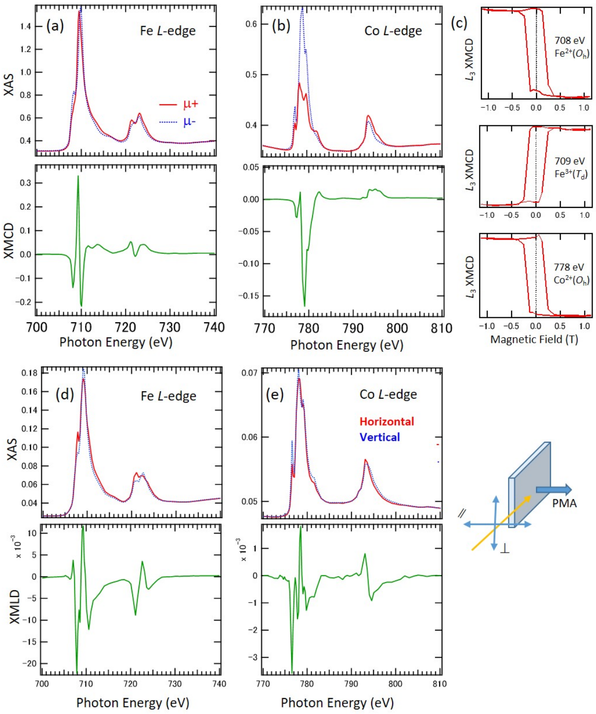

Fig. 1, XAS and XMCD of $Co_{0.2}Fe_{2.8}O_{4+\delta}$ film for (a) Fe and (b) Co L-edges. (c) Magnetic-field dependence at each fixed photon energy; 708, 709, and 778 eV corresponding to Fe^{2+} (O_h), Fe^{3+} (T_d), and Co^{2+} (O_h) peaks, respectively. (d,e) XAS and XMLD taken at the geometry illustrated in the inset.

References

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