Origin of Perpendicular Magnetic Anisotropy in $Co_xFe_{3-x}O_4$ Film Studied by Magnetic Circular and Linear Dichroisms

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Since the discovery of ferrite compounds by Prof. Yogoro Kato in 1930, the cobalt-ferrite ($CoFe_2O_4$; CFO) has been extensively investigated as the soft and hard magnets. Recently, CFO has been applied to the spintronics devices using the advantages such as insulating, highly anisotropic, and magneto-elastic properties. Further, large perpendicular magnetic anisotropy (PMA) in CFO was discovered in the thin film form, which opens up the researches and applications of spin filtering and current-free spintronics using spin waves. Squareness of out-of-plane hysteresis curves are tuned by Co composition [1]. However, the origin of the PMA in low Co compositions has not been clarified yet. X-ray magnetic circular and linear dichroisms (XMCD / XMLD) are powerful tools to detect the element-specific spin and orbital states with asphericity. Until now, although the XMCD and XMLD for CFO with in-plane anisotropy were reported [2], the investigations for the PMA in CFO have not been pursued. In this study, we aim to clarify the origin of PMA in CFO from the viewpoint of element-specific spin and orbital states using XMCD and XMLD.

The samples $Co_xFe_{3-x}O_{4+\delta}$ were prepared by pulsed laser deposition on the MgO (001) substrates [1]. The 13-nm-thick CFO layer with Cu capping layer was deposited for various Co compositions (x). Oxygen vacancies are also described as δ. The X-ray absorption spectroscopy (XAS) and XMCD/XMLD were performed at BL-7A and 16A in the Photon Factory (KEK). The total-electron-yield mode was adopted, and all measurements were performed at room temperature.

XAS and XMCD line shapes for Fe and Co L-edges show distinctive features in CFO with differential line shapes due to the three kinds of Fe sites (Fe^{3+} in O_h, Fe^{3+} in T_d, and Fe^{2+} in O_h) and Co^{2+} in O_h sites. For the PMA case, large XMCD signal is detected compared with that of in-plane case, which brings the PMA because of large orbital magnetic moments in the d^7 system due to the orbital degeneracy. The Co L-edge XMLD at the remanent magnetic states with oblique incident geometry is also different from the in-plane case [2]. Small amounts of Co doping govern the PMA with large orbital magnetic moments in Co, which can be explained by the single-ion model [3]. XMCD and XMLD line shapes are reproduced by the ligand field model calculations. Element-specific hysteresis curves at Fe (O_h, T_d sites) and Co L-edges also exhibit the PMA.

In the presentation, we discuss the element-specific spin and orbital states with the local structural displacement obtained by extended X-ray fine structure analysis at Co K-edge.

References

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