1A, 16A2/2003S1-001, 2004G-051

Magnetoelectric X-ray Scattering in $GaFeO_3$ and Fe_3O_4

Masakazu MATSUBARA*[1], Jong-Hoon JUNG[2], Yoshiaki SHIMADA[1], Taka-hisa ARIMA[2], Hiroshi SAWA[3], and Yoshinori TOKURA[1]
[1]Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan
[2]ERATO-JST, c/o AIST, Tsukuba, Ibaraki 305-8562, Japan
[3]KEK-PF, Tsukuba, Ibaraki 305-0801, Japan

Introduction

The linear magnetoelectric (ME) effect can be observed in magnetically ordered crystals whose magnetic group does not contain the space inversion operation, i.e., where time reversal *R* and space inversion *I* operations are broken simultaneously. In optical or x-ray region, the novel nonreciprocal magneto-optical phenomena, termed magnetochiral or optical ME effect, are expected to show up in such a crystal as characterized by a different optical response (absorption or refraction) depending on light propagation direction ***k***. Spectroscopy of this nonreciprocal effect is important to clarify the microscopic mechanism of the ME effect which is attracting renewed interest also from the viewpoint of the application to spin-electronics.

In this study, we have investigated resonant ME x-ray scattering (MEXS) in a polar ferrimagnet $GaFeO_3$ and a spinel-type ferrimagnet Fe_3O_4. Here, we propose that present element-specific resonant MEXS would be a unique probe of the magnetic state with broken centrosymmetry.

Experimental

The samples used in this work were $GaFeO_3$ and Fe_3O_4 single crystals grown by a floating-zone method. The measurements of magnetic x-ray scattering were carried out at BL-1A and 16A2. An incident beam was injected on the (010) and (111) surface for $GaFeO_3$ and Fe_3O_4, respectively, and a modulated magnetic field was applied perpendicular to the incident beam, namely in Voigt configuration. The modulated magnetic and/or ME scattering intensity $\Delta I(f)$ was recorded as the ratio of spin-dependent to spin-independent scattering intensity $\Delta I(f)/I$ with a lock-in amplifier.

Results and Discussions

First, we describe the results in a polar ferrimagnet $GaFeO_3$. For the (020) and (040) Bragg reflections, we have observed a change in the scattering intensity with reversal of the magnetization direction near the Fe *K* pre-edge [1]. In Fig. 1, we show the magnetic-field modulation spectra $\Delta I(f)/I$ for the (020) and (040) Bragg reflections, respectively. One can see a large energy-independent component for (020) and resonant peaks for both reflections. The energy-independent component is assigned to the well-known conventional magnetic x-ray scattering (MXS) from the viewpoint of the spin structure of $GaFeO_3$. On the other hand, the resonant signal near the pre-edge is possibly related to MEXS, which is sensitive not only to the magnetism but also to the breaking of the inversion symmetry [2]. Actually, we certainly observed, that the MEXS signal is reversed in sign when the sample (spontaneous polarization) was reversed, which evidences our expectation (Fig. 1).

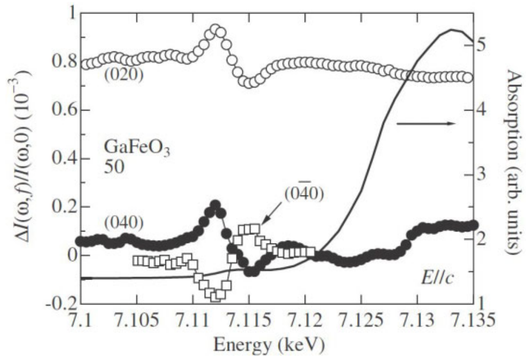

Figure 1: Magnetic field modulation spectra of Bragg reflections at 50 K for (020) (open circles), (040) (solid circles), and (0$\bar{4}$0) (open squares). The absorption spectrum around the Fe *K*-absorption edge of $GaFeO_3$ is also shown by a solid line.

Next, we describe the results of a spinel-type ferrimagnet Fe_3O_4. Although *I* symmetry is globally restored, it is locally broken at the tetrahedral A site. It is possible to detect the local ME scattering at noncentrosymmetric site as the nonreciprocal effect, due to the possibility of adjusting phase factors, even in systems where the *I* symmetry is globally restored. At the (222) Bragg reflection with a specific structure factor, in fact, resonant magnetic component was observed around the pre-edge region of Fe *K*-absorption. As compared with the (333) and (444) Bragg reflections, we deduced that the resonant structure observed at the (222) Bragg reflection is due to MEXS at the spinel A site with locally broken inversion symmetry (T_d).

References

[1] T. Arima, J. H. Jung, M. Matsubara, M. Kubota, J. P. He, Y. Kaneko, and Y. Tokura, J. Phys. Soc. Jpn. **74**, 1419 (2005).
[2] M. Kubota, T. Arima, Y. Kaneko, J. P. He, X. Z. Yu, and Y. Tokura, Phys. Rev. Lett. **92**, 137401 (2004).

* m-matsubara@aist.go.jp