BL-7A, 16A/2019G028

Detecting quadrupole: a hidden source of magnetic anisotropy in $Mn_{3-\delta}Ga$

Jun Okabayashi[1*], Kazuya Suzuki[2], and Shigemi Mizukami[2]
[1] *Research Center for Spectrochemistry, The University of Tokyo, Bunkyo, Tokyo113-0033, Japan*
[2] *WPI-Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan*

Perpendicular magnetic anisotropy (PMA) is desired for the development of high-density magnetic storage technologies. Recently, research interests using PMA films have focused on not only magnetic tunnel junctions toward the spin-transfer switching magneto-resistive random-access memories but also antiferromagnetic or ferrimagnetic devices. To design PMA materials, heavy-metal elements that possess large spin-orbit coupling are often utilized. However, the design of PMA materials without using the heavy-metal elements is strongly desired and an important subject in future spintronics researches.

Mn-Ga binary alloys are a candidate that could overcome these issues. $Mn_{3-\delta}Ga$ alloys with PMA satisfy the conditions of high spin polarization, low saturation magnetization, and low magnetic damping constants. Tetragonal $Mn_{3-\delta}Ga$ alloys are widely recognized as high PMA, ferromagnetic, or ferrimagnetic properties depending on the Mn composition. Two kinds of Mn sites, which couple antiferromagnetically, consist of $Mn_{3-\delta}Ga$. The $L1_0$-type Mn_1Ga ordered alloy possesses a single Mn site. With increasing the Mn concentration, ferrimagnetic coupling occurs. To investigate the mechanism of PMA and large coercive fields in $Mn_{3-\delta}Ga$, site-specific magnetic properties must be investigated explicitly. In this study, we performed the x-ray magnetic circular and linear dichroism (XMCD/XMLD) measurements for $Mn_{3-\delta}Ga$ to understand the PMA microscopically.

The samples 3-nm-thick $Mn_{3-\delta}Ga$ layers were prepared by magnetron sputtering on a 30-nm-thick $Co_{55}Ga_{45}$ buffer layer using MgO (001) substrate [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.

The Mn L-edge XAS and XMCD for Mn_1Ga with a single Mn site (MnI) are shown in Fig. 1(a). With increasing Mn concentrations (decreasing δ), the intensities of XAS increased and the those of XMCD decreased because of the increase of antiparallel components. The element-specific magnetization curve at Mn L_3-edge is also shown in the inset, showing PMA. The orbital magnetic moment values deduced form XMCD sum rules are too small to explain stabilizing the PMA because of the large magnetic crystalline anisotropy energy of the order of 10^6 J/m^3. Then, the magnetic dipole term (m_T) also stabilizes the PMA.

To determine the effect of m_{T_z}, we performed XMLD measurements. Figure 1(b) shows the linear polarization dependent XAS, where the directions are perpendicular and horizontal to the sample magnetization as shown in the inset. The XMLD were detected by grazing incident beams tilted 60° from the incident beam. We note that the integrals of the XMLD line shapes are proportional to quadrupole Q_{zz} along the sample surface normal direction. We confirmed that the integral converges to a positive value, deducing that the sign of Q_{zz} is positive with the order of 0.01 by applying the XMLD sum rule in the notation of $m_{Tz} = -Q_{zz}\langle S\rangle$; that is, $3z^2 - r^2$ orbitals are strongly coupled with the incident beam and are elongated to an easy-axis direction. These suggest the orbital polarization of Mn $3d$ states along z-axis direction forming the cigar-type prolate unoccupied orbital orientation, which causes the PMA in $Mn_{3-\delta}Ga$ [2]. These results are also reproduced from the density-functional-theory calculation.

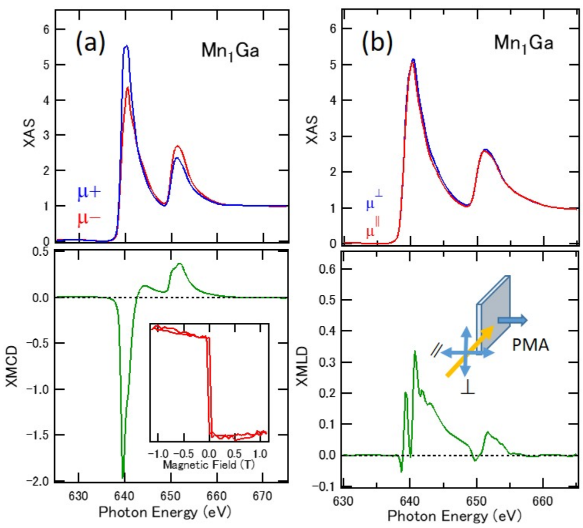

Fig. 1, (a) XAS and XMCD of $Mn_{3-\delta}Ga$. The insets show the magnetic field dependence of the hysteresis curves taken by fixed L_3-edge photon energy. (b) XAS and XMLD of $Mn_{3-\delta}Ga$. The inset shows an illustration of the XMLD measurement geometry.

References

[1]K.Z. Suzuki, *et al.*, Sci. Rep. **6**, 30249 (2016).

[2]J. Okabayashi *et al.*, Sci. Rep. **10**, 9744 (2020).

*e-mail: jun@chem.s.u-tokyo.ac.jp