

Interfacial Exchange Coupling in FeCo/MnGa Studied by X-ray Magnetic Circular Dichroism

Jun Okabayashi,^{1*} Kazuya Suzuki,² and Shigemi Mizukami²

¹Research Center for Spectrochemistry, The University of Tokyo, 113-0033 Tokyo, Japan

²WPI-Advanced Institute for Materials Research, Tohoku University, Sendai 980-8579, Japan

Magnetic ordered alloys have attracted significant attention for use as spintronics materials because they are highly likely to exhibit perpendicular magnetic anisotropy (PMA). As promising spintronics materials, tetragonal L_{10} -type and D_{022} -type Mn_3Ga compounds have been extensively investigated originating from their ferrimagnetic properties that cause antiferromagnetic coupling at the different Mn sites; thus, they have high potentials for use in magnetic tunnel junctions integrated in tunnel magnetoresistance (TMR) devices.

Using the advantage that $Mn_{3-\delta}Ga$ is a hard magnetic film, the deposition of other ferromagnetic materials on $Mn_{3-\delta}Ga$ layers can be used to induce perpendicular exchange coupling through exchange interactions without the use of heavy metal elements. Ultrathin $Fe_{1-x}Co_x$ layers deposited on $Mn_{3-\delta}Ga$ couple ferromagnetically or antiferromagnetically, depending on their compositions [1]. Antiferromagnetic coupling has been demonstrated in high-Co-concentration regions, while low-Co-concentration regions have been shown to exhibit ferromagnetic coupling. However, the abruptness and element-specific magnetic properties at the interfaces between $Mn_{3-\delta}Ga$ and $Fe_{1-x}Co_x$ layers must be clarified explicitly. Here, X-ray magnetic circular dichroism (XMCD) is employed to investigate the element-specific magnetic properties at an $Fe_{0.4}Co_{0.6}/Mn_{1.5}Ga$ interface. In particular, we discuss the interfacial coupling, which may be ferromagnetic or antiferromagnetic depending on the annealing of the samples.

The samples were prepared by magnetron sputtering on MgO substrates. On the 30-nm-thick MnGa, 1-nm FeCo were deposited at room temperature and capped by 2-nm MgO. We prepared two samples of as-grown and annealed at 350 C after the growth. The X-ray absorption spectroscopy (XAS) and XMCD were performed at BL-7A in the Photon Factory (KEK). The total-electron-yield mode was adopted, and all measurements were performed at room temperature and the geometries were set to normal incidence configuration.

Figure 1 shows the polarization dependences of the XAS and XMCD results for the Mn, Fe, and Co $L_{2,3}$ -edges after the annealing. By comparing these spectral line shapes with those in the as-grown case, it is evident that the XAS intensity ratios between Mn

and FeCo are modulated, which suggests that the Fe and Co atoms diffuse chemically into the MnGa layer within the probing depth of approximately 5 nm. Opposite XMCD signs are observed in Fe and Co as shown in Fig. 1 because of the anti-parallel coupling between FeCo and MnGa layers.

We can discuss the magnetic properties at the interfaces before and after the annealing in terms of three aspects: the exchange coupling at the interfaces, the PMA at the FeCo/MgO interface, and the chemical reactions at the interfaces. When parallel coupling is dominant, the strong perpendicular magnetization in the FeCo layer is induced by exchange coupling with $Mn_{1.5}Ga$ accompanied by the large coercive fields of the Fe and Co hysteresis curves. By annealing, anti-parallel exchange coupling becomes dominant through the interfacial layer, that separates the two magnetic layers. The annealing causes interfacial secondary phase formation with in-plane anisotropy, which is not observable in a transmission electron microscopy image but clearly detected by the XMCD line shapes and element-specific hysteresis curves. Heusler-type alloys such as Mn_2CoGa might be stabilized. Although the annealing process at 350°C is necessary to obtain a high quality FeCo/MgO interface, it inevitably produces an interfacial layer at the $Mn_{1.5}Ga/FeCo$ boundary, which contributes slightly to the TMR properties.

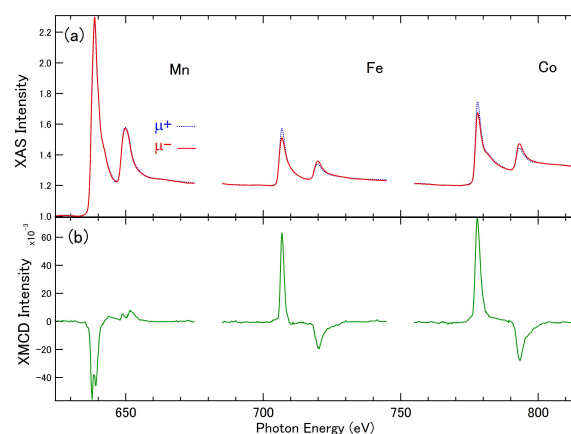


Fig. 1. (a) XAS spectra of Mn, Fe, and Co L -edges in $Fe_{0.4}Co_{0.6}/Mn_{1.5}Ga$, 350°C annealed sample. (b) XMCDs of Mn, Fe, and Co L -edges.

[1]Q. L. Ma et al., Phys. Rev. Lett. **112**, 157202 (2014).

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