BL-7A/2019S2-003

Depth-resolved x-ray magnetic circular dichroism study of the Fe/MgO interface

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1 Introduction

The Fe/MgO interface is one of the most important systems in spintronics as it exhibits giant tunneling magnetoresistance (TMR) and strong interfacial perpendicular magnetic anisotropy (PMA) simultaneously [1]. Both effects are determined by the interfacial electronic and magnetic structures, and therefore, it is essential to characterize the interfacial spin and orbital magnetic moments of Fe to understand and enhance TMR and PMA.

In this study, we performed depth-resolved x-ray magnetic circular dichroism (XMCD) measurements on an epitaxial V/Fe/MgO trilayer and revealed that both spin and orbital magnetic moments are enhanced at the Fe/MgO interface.

2 Experiment

The V/Fe/MgO trilayer was grown on a single-crystalline MgO(100) substrate by molecular beam epitaxy. The schematic sample structure is shown in Fig. 1(a). The substrate was annealed at 800 °C for 10 min before the deposition. A 5-nm-thick MgO seed layer and a 30-nm-thick V buffer layer were grown at room temperature and subsequently annealed at 500 °C for 30 min to obtain a flat surface. The 0.7-nm-thick (5 monolayers thick) Fe layer and a 2-nm-thick MgO overlayer were then grown at room temperature. Magneto-optical Kerr effect measurements confirmed that the trilayer showed PMA with perfectly square magnetic hysteresis curves, as shown in Fig. 1(b).

The depth-resolved XMCD measurements [2] were performed at the beamline BL-7A at room temperature. The sample was placed such that the sample surface was perpendicular to the incident x-rays and magnetized by a permanent magnet put close to the sample before the measurements. Photoelectrons emitted with various angles were detected separately by a microchannel plate detector with a phosphorus screen. This detection-angle dependence of XMCD signals can be converted to probing-depth dependence and thus yields the depth profiles of spin and orbital magnetic moments.

3 Results and Discussion

Figures 1(c) and 1(d) show the detection-angle (θ_d) dependence of the spin and orbital magnetic moments of Fe deduced using the XMCD sum rules. Here, θ_d = 0 corresponds to the electron emitted parallel to the sample surface or perpendicular to the incident x-rays. The effective probing depth can be simply expressed as $\lambda_e \sin(\theta_d)$, where λ_e denotes the escaping depth of Auger electrons. The smaller the detection angle θ_d is, the shallower the effective probing depth is. Both the spin and orbital magnetic moments decrease as θ_d increases, suggesting that they are larger at the Fe/MgO interface than at the Fe/V interface.

In order to be more quantitative, we fit the following expression, the weighted average of the magnetic moment of each layer, to the data shown in Figs. 1(c) and 1(d).

$$m(\theta_d) = \frac{\sum_{i=1}^{5} m_i \exp\left(-(i-1)d/\lambda_e \sin\theta_d\right)}{\sum_{i=1}^{5} \exp\left(-(i-1)d/\lambda_e \sin\theta_d\right)},$$

where $m(\theta_d)$ denotes the spin or orbital magnetic moment as a function of θ_d, m_i denotes the spin or orbital magnetic

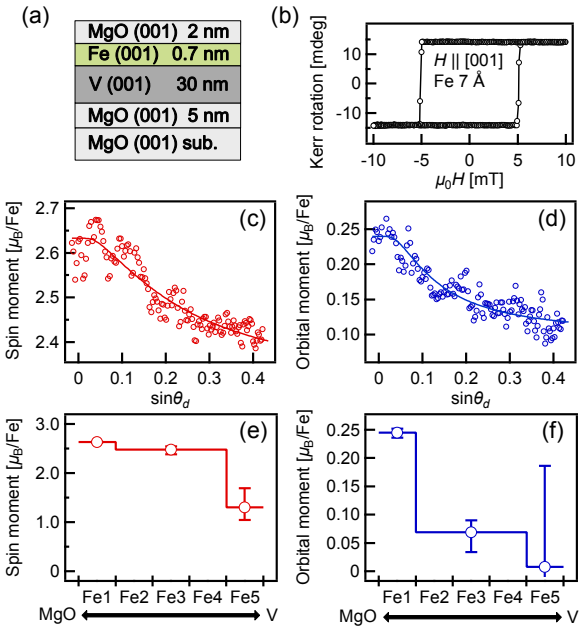

Fig. 1: (a) Schematic sample structure. (b) Out-of-plane magnetic hysteresis curve measured using magneto-optical Kerr effect. (c) and (d) Detection-angle dependence of the spin and orbital magnetic moments. (e) and (f) Depth profiles of the spin and orbital magnetic moments

moment of Fe at the *i*-th layer, *d* (=1.42 Å) is the interlayer distance. Upon fitting, we assumed that the magnetic moments of inner layers are the same (m_2=m_3=m_4) to reduce the number of free parameters and that λ_e = 12 Å, which is a typical mean free path of electrons in the relevant energies of ~700 eV [3]. The fits reproduce the data well, as shown by the solid curves in Figs. 1(c) and 1(d).

Figures 1(e) and 1(f) show the deduced depth profiles of the spin and orbital magnetic moments. As mentioned above, both the spin and orbital magnetic moments are enhanced at the Fe/MgO interface while they may diminish at the Fe/V interface. Interestingly, the orbital magnetic moment enhancement is found much more drastic than the spin magnetic moment enhancement. The origin of the spin magnetic moment enhancement can be attributed to the band narrowing caused by electron localization at the Fe/MgO interface. While this mechanism can enhance the orbital magnetic moment, the lower crystal symmetry and suppressed crystal-field quenching can further increase the orbital magnetic moment. The present findings are important for deeper understanding of various phenomena that emerge at the Fe/MgO interface.

Acknowledgement

This work was supported by JSPS KAKENHI (Nos. JP18H03880, No. JP20K15158), and the Spintronics Research Network of Japan (Spin-RNJ). We thank T. Higo and S. Nakatsuji of the University of Tokyo for magneto-optical Kerr effect measurements. We thank M. Tsujikawa and M. Shirai for discussion.

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