BL-7A/2021G069

Magnetic structures at Co/oxide interface for voltage-controlled magnetic anisotropy effect studied by XMCD

Jun Okabayashi[1*] and Tomohiro Nozaki[2]

[1] *Research Center for Spectrochemistry, The University of Tokyo, Bunkyo-ku, Tokyo113-0033, Japan*

[2] *National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568, Japan*

Electric-field control of magnetism has attracted significant attention because it can realize ultralow-power spintronics devices. The voltage-controlled magnetic anisotropy (VCMA) effect is a high-speed spin manipulation technique with excellent compatibility with magnetoresistive random access memory. VCMA effects in bcc-Fe-(001)-based stacks have been investigated extensively and a VCMA coefficient of 350 fJ/Vm has been achieved using high-quality epitaxial films [1]. However, further improvement in the VCMA coefficient is demanded. The VCMA effect was also investigated for fcc-Co-(111)-based stacks because of a large VCMA coefficient of 230 fJ/Vm [2]. However, in fcc-Co-based stacks, systematic studies of the VCMA effect have not been conducted and the understanding is still in its infancy compared with that of bcc-Fe-based stacks. In fcc-Co-based stacks, a particularly large VCMA effect, including voltage-controlled coercivity (H_c) (VCC), has been reported at interfaces with surface oxidation of Co, suggesting the significant role of surface oxidation [3]. However, the reasons for the improvement in VCC by post-annealing remain unclear.

Pt/Co/AlOx trilayers have long been focused on the studies of large interface PMA, strong Rashba effect, and Dzyaloshinskii-Moriya interaction. The effect of the oxidation conditions on the interface PMA was examined in detail using Pt/Co/post-oxidised Al trilayers [4]. The PMA at the Co/oxide interface was maximised under appropriate oxidation conditions with the Co-O bonds at the interface and enhanced by post-annealing. To investigate the interfacial oxidation and chemical states, we employed x-ray magnetic circular dichroism (XMCD) to probe the spin and orbital magnetic moments (m_{orb}). In this study, to understand VCMA effect at fcc-Co (111)/oxide interfaces, we systematically investigated the dependence of the VCC in the Pt/Ru/Co/CoO/TiOx structure on Co film thickness and annealing temperature.

The samples were grown by molecular beam epitaxy and sputtering. The sample structures consist of SiO_x sub./Ta (5 nm)/Ru (10 nm)/Ta (5 nm)/Pt (10 nm)/Ru (0.2 nm)/Co wedge (t_{Co} nm)/TiO_x (2 nm) as shown in Fig. 1a. XAS and XMCD were performed at BL-7A in the Photon Factory (KEK-PF). For XAS and XMCD measurements, the photon helicity was fixed, and a magnetic field of ±1.2 T was applied parallel along the incident polarised soft X-ray beam to obtain signals defined as $\mu+$ and $\mu-$ spectra. The total-electron-yield mode was adopted and all the measurements were performed at room temperature.

The Co L-edge XAS and XMCD spectra of as-deposited and 350°C-annealed samples are shown in Fig. 1. The XAS signals comprised metallic Co (777.0 eV) and chemically shifted CoO (Co^{2+}) components (778.0 eV). Metallic Co components of the XAS and XMCD signals increased with an increasing t_{Co}. Note that while the spectra after annealing appeared as a single peak of metallic Co component, the spectra contain the CoO component; the peak at 777.0 eV broadened compared with that of metallic Co, suggesting the partial reduction of the CoO layer owing to post-annealing. Despite the reduction in CoO, no significant increase in XMCD signals was observed; the sample with t_{Co}=2.0 nm showed an XMCD intensity comparable to that of the as-deposited sample. The sample with t_{Co} = 1.5 nm showed an XMCD intensity smaller than that of the as-deposited sample. These can be attributed to the decrease in Co owing to the diffusion of Co atoms into the Pt layer. By using the magneto-optical sum rules, the post-annealing induced increase in m_{orb}/m_{spin}, which corresponds to the increase in the H_c and VCC and may occurs at the Co/oxide upper interface.

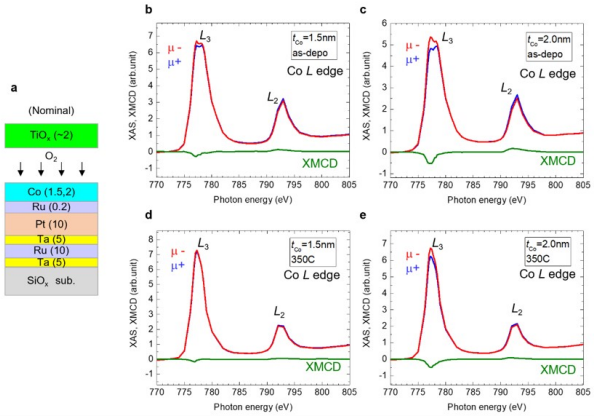

Fig. 1, (a) Sample structures, (b-e) XAS and XMCD of Co L-edge for as-deposited and 350°C-annealed samples for t_{Co}=1.5 and 2.0 nm.

[1]T. Nozaki *et al.* APL Mater. **8**, 011108 (2020).
[2]T. Hirai *et al.*, Appl. Phys. Lett. **112**, 122408 (2018).
[3]T. Nozaki *et al.*, Sci. Rep. **11**, 21448 (2021).
[4]C. Nistor *et al.* Phys. Rev. B **84**, 054464 (2011).

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