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Perpendicular Magnetic Anisotropy at Fe/NiO (001) Interface Studied by X-ray Magnetic Circular Dichroism

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Interfacial perpendicular magnetic anisotropy (PMA) is one of the crucial issues in the spintronics research field because of thermal stability enhancement and low current magnetization switching. MgO-based magnetic tunnel junctions have been exploited toward an ultrahigh tunnel magnetoresistance through the large interfacial PMA between MgO and transition-metal alloys. The PMA of 1.4 MJ/m^3 at the Fe/MgO interfaces has been achieved through the chemical bonding between Fe $3d_{z2}$ and O $2p_z$ orbitals. Further, theoretical prediction implies that the PMA energy depends on the amounts of interfacial oxygen [1]. As an another candidate to enhance the interfacial PMA, we focus on the antiferromagnetic NiO layer which possesses the same lock-salt crystalline structure as MgO and exhibits Néel temperature of 523 K. Since the interfacial structure and geometry in Fe/NiO are similar to those in Fe/MgO, the PMA through the *p-d* hybridization is anticipated. Further, the spins at the Ni sites aligned to in-plane direction couple with the Fe at the interface, which provides the unique spin and orbital structures at the Fe/NiO interface region.

In the previous studies, the oxygen stoichiometry (δ) dependence in $NiO_{1-\delta}$ has been extensively investigated. The uncompensated Ni spins appear depending on the oxygen pressure during the NiO film growth [2]. The lattice constant and magnetic properties also depend on the amounts of oxygen. In this study, we aim to investigate the PMA in the Fe/NiO interface by x-ray absorption and magnetic circular dichroism (XMCD) to elucidate the element-specific spin and orbital magnetic moments (m_{orb}) of Fe and Ni sites.

The samples were grown by rf-sputtering on the MgO (001) substrates. Thick NiO buffer layer and 0.6-nm-thick Fe layer were deposited epitaxially with 2-nm-thick Cr capping layer. The precise δ dependence was examined and the PMA appears by tuning δ to an appropriate condition.

XMCD measurements were conducted at BL-7A, Photon Factory. A magnetic field of ±1.2 T was applied along the incident polarized beam by switching the magnetic field directions. The total electron yield mode was adopted. The geometry between sample surface normal and incident beam directions are changed by changing the sample position from normal incidence to oblique incidence of 60°. All measurements were performed at room temperature.

Figure 1 shows Fe and Ni *L*-edge x-ray absorption spectra and XMCD. Clear metallic line shapes in Fe suggest no mixing with oxygen atoms. Hysteresis loops at Fe L_3-edge photon energy shown in Fig. 1(c) clearly display the easy axis direction in the PMA. Asymmetry in XMCD spectrum reveals that the large orbital moments are induced in the perpendicular components. These features are quite similar to the case of Fe/MgO [3]. As shown in Fig. 1(b), there are no XMCD signals at the Ni *L*-edge because antiparallel spins at Ni sites are compensated completely although quite small differential signal appears, originating from applying the magnetic field along the perpendicular direction during the measurements. We note that the case of the amounts of oxygen concentration for less than stoichiometry exhibits in-plane magnetic anisotropy and the perpendicular component of m_{orb} is supressed.

Considering above results, the origin of PMA in Fe/NiO interface can be understood by the anisotropic orbital moments induced by spin-orbit interaction at the interface. Although the role of Ni is recognized as independent on the PMA at the Fe-O hybridization, the *interfacial super-exchange interaction* among Fe-O-Ni units can be considered to stabilize the PMA.

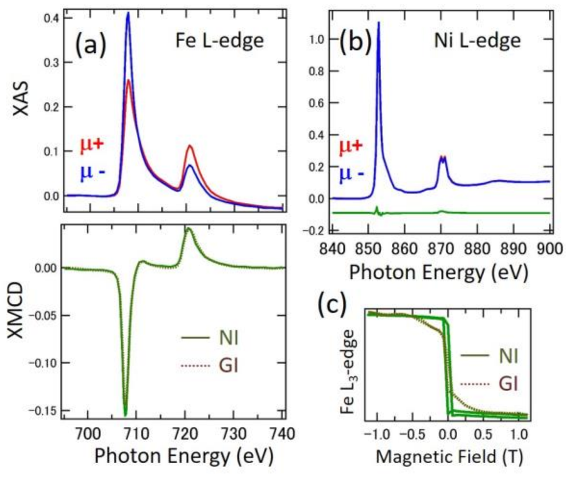

Fig. 1, XAS and XMCD in Fe/NiO interface. (a) XAS and XMCD at Fe *L*-edge using normal incident (NI) setup. In XMCD, normalized grazing incidence (GI) case is also shown. (b) XAS and XMCD at Ni *L*-edge. (c) Hysteresis curve taken at Fe L_3-edge.

References
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