Angle-Resolved Longitudinal- and Transverse-Geometry X-ray Magnetic Circular Dichroism in Two-Dimensional Magnetic Systems

T. Koide[1], K. Mamiya[1], T. Sekine[1], Y. Ishida[2], Y. Osafune[2], A. Fujimori[2], Y. Suzuki[3,4], T. Katayama[4], and S. Yuasa[4]

[1]Photon Factory, Institute of Materials Structure Science (IMSS), High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan

[2]Department of Complexity Science and Engineering, University of Tokyo, Kashiwa, Chiba 277-8561, Japan

[3]Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

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

Magnetism of low-dimensional systems, such as ultrathin films, superlattices, and supported nanoclusters, has attracted much scientific and technological interest, because studies of those systems could provide new insights into the evolution of magnetism from 0-dimensional atoms to 3-dimensional solids and because they are promising candidates applicable to new magnetic devices. The reduced symmetry affects the orbital part of the electron wave functions, resulting in enhanced anisotropy of an orbital magnetic moment (m_{orb}) and a magnetic dipole moment (m_{T}) as well as in an enhanced spin magnetic moment (m_{spin}). Thus, it is very important to quantitatively study those magnetic moments.

Angle-resolved soft x-ray magnetic circular dichroism (XMCD) in the longitudinal (L) and transverse (T) configurations allows an element-specific, valence-orbital-selective, separate determination of such enhanced anisotropic magnetic moments [1]. We report on the results of angle (?)-resolved XMCD measurements in the L ($\boldsymbol{B} \parallel h$) and T ($\boldsymbol{B} \perp h$) arrangements for ultrathin Fe and Co films, where $\boldsymbol{B}$ and h represent the external magnetic field and the photon helicity, respectively. A huge tunnel magnetoresistance has been observed in Fe/MgO(001)/Fe magnetic tunnel junctions [2]. A possibility of an hcp/bcc transition has been indicated for ultrathin Co films on Au (001) with decreasing Co thickness (t_{Co}) [3]. To clarify the origin of those phenomena, we have studied the microscopic magnetic states of Fe atoms in Fe(1 ML)/MgO(001) and of Co atoms in Co(2 = t_{Co} = 11 ML)/Au(001) by angle-resolved XMCD measurements at the Fe and Co $L_{2,3}$ edges in both the L and T arrangements. No multiplet features, characteristic of iron oxides, were observed in the Fe $L_{2,3}$-edge XAS and a strong L-geometry Fe $L_{2,3}$-edge XMCD was observed in Fe/MgO, showing no oxidation of Fe atoms [4] and an enhanced spin magnetic moment. We detected angle dependence in the L-geometry XMCD and a small, but clear, T-geometry XMCD in Fe/MgO. An extraordinarily strong T-geometry XMCD was observed at the Co $L_{2,3}$ edges in Co/Au(001) for t_{Co} = 4 ML. This result is supported by a remarkable increase of angle dependence in the L-geometry $L_{2,3}$-edge XMCD for t_{Co} = 4 ML. Sum-rule analyses of the L- and T-geometry XMCD in both systems gave values of enhanced spin, anisotorpic in-plane and out-of-plane orbital, and non-zero in-plane and out-of-plane magnetic dipole moments. The physical implication of the results is discussed in relation to the huge tunnel magnetoresistance and magnetic anisotropy.

[1] T. Koide et al., Phys. Rev. Lett. **87**, 257201 (2001).

[2] S. Yuasa et al., Nature Materials **3**, 868 (2004); S. S. P. Parkin et al., ibid. **3**, 862 (2004).

[3] T. Katayama et al., J. Magn. Magn. Mater. **156**, 171 (1996).

[4] K. Miyokawa et al., Jpn. J. Appl. Phys. **44**, L9 (2005).