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Magnetic compton profiles of Pd/Fe multilayers

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Abstract

Magnetic Compton profiles are measured on Pd/Fe multilayers. The measurements show that wavefunctions of the Pd/Fe multilayers have the isotropic character. The origin of isotropic character comes from the nearly spherical distribution of the Fe 3d states.

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1. Introduction

Recent nano-structured multilayers are expected to show interesting properties due to modifications of wavefunctions. Pd/Fe multilayers have been reported to have an FCC Fe phase and an enhanced Fe magnetic moment with 2.7 μ_B, when the Fe layer thickness is less than 2 nm [1]. These characteristic Fe are of importance not only for a fundamental science but also industrial applications such as a data storage media. However the electronic structures of the Pd/Fe have not been clear.

A magnetic Compton profile (MCP) measurement is a good candidate to probe wavefunctions. The MCP, $J_{\rm mag}(p_z)$, is expressed by the following equation:

$$J_{\rm mag}(p_z) = \int (n_{\rm maj}(\mathbf{p}) - n_{\rm min}(\mathbf{p}))\, {\rm d}p_x\, {\rm d}p_y, \qquad (1)$$

$$n(\mathbf{p}) = \left|\Psi(\mathbf{p})\right|^2, \Psi(\mathbf{p}) = \iiint \Psi(\mathbf{r}) e^{-i\mathbf{p}\cdot\mathbf{r}}\, {\rm d}x\, {\rm d}y\, {\rm d}z. \qquad (2)$$

Here, $\boldsymbol{p}(=(p_x, p_y, p_z))$ denotes a momentum of a electron in a solid, $n(\boldsymbol{p})$ denotes charge density in the momentum space, $\Psi(\boldsymbol{p})$ and $\Psi(\boldsymbol{r})$ denote

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wavefunctions of the momentum space and the real space respectively. The sub-indexes, maj and min, denote the majority spin and the minority spin, respectively. From the Eq. (1), the MCP represents spin density distribution in the momentum space, which reflects the symmetry of momentum wavefunctions in the crystal.

Although the MCP has been recognized as a useful technique to probe wavefunctions [2–4], there are few MCP measurements of thin films. That is because scattering photons from the film substrates are rather strong than from the films. Recently we have suggested a novel and convenient technique to reduce the strong background scattering from the substrates, of which the film sample is deposited on a thin substrate, such as a PET (polyethylene terephthalate), and have succeeded the first observation of anisotropy of magnetic Compton profiles in Pd/Co multilayers [5,6]. In this paper we report on anisotropies of MCPs in Fe/Pd multilayers and discuss on the anisotropy of the wavefunctions and electronic structures.

2. Experimental

Three kinds of multilayers, [Pd(1.6 nm)/Fe (0.8 nm)], [Pd(1.6 nm)/Fe(1.6 nm)] and [Pd(1.6 nm)/Fe(4.0 nm)], were fabricated by the R.F. sputtering method. The base pressure prior to sputtering was 1×10^{-5} Pa, and the Ar pressure during sputtering was 1.0 Pa. The deposition rate was 0.08 nm/s for Fe and Pd. A film thickness of multilayers was 1 μm. The multilayers were grown on the PET (polyethylene terephthalate) substrate with a thickness of 4 μm.

An Fe film on PET substrate with the thickness of 1 μm was measured as a reference sample.

Crystal structure and multilayered structure were confirmed by θ–2θ X-ray diffraction measurements with the Cu-$K\alpha$ radiation. These results are discussed in the next section. Magnetization measurements show soft magnetic properties when applied fields were on an in-plane configuration (applied field was parallel to the sample surface). The magnetizations were hard to saturate when applied fields were on an out-of-plane configuration (applied field was perpendicular to the sample surface). However, magnetization saturation field was below 2 T in both the configuration.

MCPs were measured at the AR-NE1A1 beamline of KEK-PF, Japan. (High Energy Accelerator Research Organization, Institute of Materials Structure Science, Photon Factory). Circularly polarized X-rays were obtained from an elliptical multipole wiggler (EMPW) under the ring operation of 6.5 GeV and 50 mA with a typical lifetime of 16 h. The monochromatized X-ray energy was 59.8 keV.

A sample was set in a superconducting magnet with a magnetic field of 2 T. The applied field was the in-plane configuration and the out-of-plane configuration. The incidence X-ray was tilted by 10° against the applied field direction. Compton scattered X-rays were detected with a scattering angle of 160° by 10-segmented Ge SSD (solid state detector). The magnetic Compton profiles were measured with reversing the magnetic field of the superconducting magnet under the vacuum at R.T., using the fixed circular polarized X-rays. The degree of circular polarization was about 0.66. Typical measuring time for a multilayer was about 48 h in a configuration.

3. Results

Fig. 1 shows the θ–2θ X-ray diffraction pattern of the Pd/Fe multilayers and the Fe film on the PET substrate. A diffraction peak at $2\theta=26.5^\circ$ comes from the PET substrate. The Fe film in Fig. 1 shows diffraction peaks, which correspond to typical BCC Fe structure ($2\theta=45.0^\circ$ for (1 1 0), $2\theta=65.4^\circ$ for (2 0 0) and $2\theta=82.8^\circ$ for (2 1 1)). The Pd(1.6 nm)/Fe(0.8 nm) multilayer and the Pd(1.6 nm)/Fe(1.6 nm) multilayer have diffraction peaks around $2\theta=42.0^\circ$ and $2\theta=49.0^\circ$. They are assigned to (1 1 1) and (2 0 0) of FCC structure, which correspond to strained Pd ($2\theta=40.1179^\circ$ for (1 1 1) and $2\theta=46.6578^\circ$ for (2 0 0)) and/or FCC Fe at the multilayer interface. The prominent (1 1 1) diffraction peaks of these two multilayers suggest (1 1 1) textured structure. There is no diffraction peak from the BCC Fe in these two multilayers. On the contrary, the Pd(1.6 nm)/