BL-16A/2014G159

Resonant soft-x-ray scattering study of Co/Pt multilayers

Goro Shibata[1,*], Keisuke Ishigami[1], Yukio Takahashi[1], Shoya Sakamoto[1], Yosuke Nonaka[1], Atsushi Fujimori[1], and Tsuneharu Koide[2]
[1]Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan
[2]Photon Factory, Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan

1 Introduction

Transport and magnetic properties of metal and transition-metal-oxide thin films and multilayers have drawn much attention for years. Especially, novel physical properties induced by low dimensionality, interfacial effects, and epitaxial strain have been intensively studied [1]. In order to understand the origin of these physical properties specific to thin films and multilayers, it is of great importance to clarify the depth distribution of atoms, valences, and magnetic moments as fundamental information. So far, photoemission spectroscopy, x-ray absorption spectroscopy, and x-ray magnetic circular dichroism have been widely used to study depth-resolved electronic states by utilizing the fact that the escape depth of photoelectrons depends on the electron emission angle [2,3]. However, the spatial resolution along the depth direction and the probing depth are severely limited in these methods because of the small escape depth of the electrons (a few nm). Recently, an alternative method, in which the incident-angle dependence of the x-ray scattering intensity is measured, has been developed as a probe for the depth-dependent electronic structure [4]. We have been developing an apparatus for such experiments, namely resonant soft x-ray scattering (RSXS). In this paper, we report on the preliminary RSXS experiments of $[\mathrm{Co/Pt}\ (111)]_n$ multilayers, which are known to show perpendicular magnetic anisotropy with decreasing Co thickness [5].

2 Experiment

$[\mathrm{Co/Pt}\ (111)]_n$ multilayer samples with a total thickness of ~100 nm were grown on the glass substrate by the RF sputtering method. Prior to the growth of the Co/Pt multilayer, a 15-nm-thick Pt (111) buffer layer was deposited and the samples were annealed at 350 °C for 1 h. After the deposition of the Pt buffer layer, 4-monolayer (ML)-thick Co and 10-ML-thick Pt layers were alternatingly deposited, terminating with the Pt layer in order to protect the surface. X-ray diffraction confirmed that the periodicity of the superlattice almost agreed with the designed values. Details of the sample preparation are described in Ref. 6.

RSXS experiments have been performed at BL-16A of KEK-PF. The photon energy ($h\nu$) was adjusted to the Co L_3 absorption edge. Scattering profiles were taken at room temperature. A magnetic field of ~ 0.1 T was applied parallel to the incident x rays using permanent magnets. Signal was collected using a silicon diode detector. A slit of ~0.1 mm width was attached in front of the detector to achieve the angular resolution of ~ 0.05°.

3 Results and Discussion

Figure 1 shows the scattering profile of the $[\mathrm{Co}\ (4\ \mathrm{ML})/\mathrm{Pt}\ (10\ \mathrm{ML})]_n$ multilayer at the Co L_3 absorption edge ($h\nu$ = 775.6 eV) with a fixed sample angle (θ_{sample} = 16.15°) and a varying detector angle (θ_{det}). A sharp peak located at θ_{det} =32.3° and a broader peak located around θ_{det} =37° are observed. The sharp peak is identified as the specular reflection peak because the scattering angles nearly satisfy the θ-2θ relation ($\theta_{\mathrm{det}} \simeq 2\theta_{\mathrm{sample}}$). On the other hand, the broader peak is identified as the first-order superlattice reflection from the $[\mathrm{Co/Pt}]_n$ multilayer. The Bragg condition for the first-order reflection is given by $q_z = 2\pi/L$, where $q_z = k(\sin\theta_{\mathrm{sample}} - \sin(\theta_{\mathrm{det}} - \theta_{\mathrm{sample}}))$ is the momentum transfer and L is the superlattice period. From the scattering profile in Fig. 1, the momentum transfer for the broad peak is calculated to be $q_z \sim 2.5\ \mathrm{nm}^{-1}$, yielding L ~ 2.5 nm. On the other hand, the theoretical superlattice period of the $[\mathrm{Co}\ (4\ \mathrm{ML})/\mathrm{Pt}\ (10\ \mathrm{ML})]_n$ multilayer is estimated to be 2.590 nm, using the lattice parameters of hcp (0001) Co (1 ML = 0.2053 nm) and fcc (111) Pt (1 ML = 0.1769 nm). The experimental superlattice period is, therefore, consistent with the theoretical value. Furthermore, the peak width (half width at the half maximum) is estimated to be Δq_z ~ 0.1 nm^{-1}, corresponding to the total superlattice thickness of $2\pi/\Delta q_z$ ~ 60 nm. This is also consistent with the designed total thickness of ~ 100 nm, within the experimental errors due to the estimation of Δq_z. These

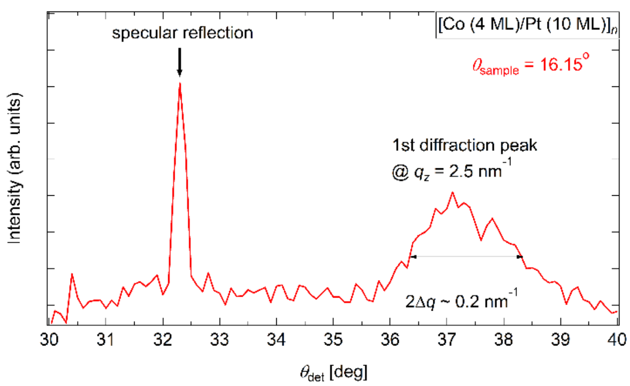

Fig. 1: Scattering profile of the $[\mathrm{Co}\ (4\ \mathrm{ML})/\mathrm{Pt}\ (10\ \mathrm{ML})]_n$ multilayer at the Co L_3 absorption edge ($h\nu$ = 775.6 eV) with fixed the sample angle (θ_{sample} = 16.15°) and the varying detector angle (θ_{det}).

estimations justify the assignment that the broad peak around θ_{det} =37° is the first-order superlattice reflection.

Thus we have succeeded in the observation of scattering peaks not only of the specular reflection but also of the superlattice reflection from the $[Co/Pt]_n$ multilayer. In the future, we are going to investigate the angular and photon-energy dependencies of the reflection intensity in order to probe the depth-resolved electronic and magnetic states.

References

[1] H. Y. Hwang *et al., Nature Mater.* **11**, 103 (2012).
[2] M. Sing *et al., Phys. Rev. Lett.* **102**, 176805 (2009).
[3] K. Amemiya *et al., Phys. Rev. B* **72**, 201404(R) (2005).
[4] E. Benckiser *et al., Nature Materials* **10**, 189 (2011).
[5] P. F. Carcia, *J. Appl. Phys.* **63**, 5066 (1988).
[6] N. Nakajima *et al*., *Phys. Rev. Lett.* **81**, 5229 (1998).

* shibata@wyvern.phys.s.u-tokyo.ac.jp