X-ray absorption spectroscopy study of Co structure in the epitaxial Co/Pt multilayers on Al_2O_3(11-20) substrates

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In this study, five epitaxial [Co(t nm)/Pt(1 nm)]$_{30}$ multilayer samples (t=0.16-1.07 nm) were studied using polarized X-ray absorption spectroscopy method. These samples were prepared on Mo(110)/ Al_2O_3(11-20) substrates by MBE technique. The results show that the Co layer is more like an fcc pseudomorphic structure for the Co thickness of less than 0.3 nm. For Co layer thickness of 1 nm, the first shell distance is 0.25 nm, which is very close to the Co-Co distance of bulk hcp Co. On the other hand, for Co layer of less than 0.3 nm, the in plane first shell distance is expanded by 4% and most of the neighboring atoms are Pt atoms. The fitting results of the Co/Pt multilayers seem to support a sharp boundary model rather than an interdiffusion model.

Keyword: X-ray absorption spectroscopy, Co/Pt multilayer

1. Introduction

The existence of large Perpendicular Magnetic Anisotropy (PMA) is of great interest for application in high-density magneto-optical devices. The PMA effect can exist in the ultra-thin multilayer as a consequence of symmetry breaking at the ferromagnetic and non-ferromagnetic interface. Therefore, understanding of the interfacial structure in multilayers is important for the PMA mechanism. For instance, it was predicted that the PMA for the transition metal-noble metal multilayer might be both strain and interfacial roughness related (Yamaguchi. *et al*., 1993). Previous works involved the study of MCD effect of Co/Pt thin film using soft X-ray absorption spectroscopy (Nakajima *et. al.*, 1998; Thiele *et al*., 1996), where an fcc pseudomorphic layer of 5 ML was reported and the PMA effect was found for Co less than 5 ML. Sato (1987) studied this thin film by changing the layer thickness between Co and Pt, where an fcc-like structure can be found if the Co layer is smaller than that of Pt. Galeotti *et al*. (1993) used X-ray photoelectron diffraction to examine the growth of thin Co on Pt(111) surface and found Co to have a fcc pseudomorphic structure. Previously, we also reported a synchrotron X-ray study of a [Co(t nm)/Pt(1 nm)]$_{30}$ multilayer on Al_2O_3(11-20) (Huang *et al.*, 1998; Lee *et al.*, 2000). The magnetic properties of these samples were studied by Kerr effect and vibrating-sample magnetometer. The magnetic moment of the multilayers was found to be perpendicular to the surface when the thickness of Co layer is less than about 0.5 nm. For the Co layer thicker than 0.5 nm, the magnetic moment is inclined or parallel to the interface plane. In order to understand the PMA effect in detail, it is important to probe the structure difference of Co/Pt multilayers with distinct Co layer thickness, especially those below 0.5 nm. It is also interesting to see how the 10% lattice mismatch between the Co and Pt is accommodated in these epitaxial multilayers.

In a previous synchrotron X-ray diffraction work on these samples (Lee *et al.*, 2000), we found that the Pt layer in the multilayer possesses a compressible strain of about 2-3.5 % along the Pt[1-10] direction. Samples with large in-plane mosaic (about 2.2 - 10.5 degrees) and small coherence length (about 2.0-2.8 nm) were also measured, indicating a plastic deformation of the Pt layer due probably to the lattice misfit between Co and Pt layers. However, no Co peak can be detected in any of the diffraction scans even for the sample with 1 nm of Co. The low intensity of Co is probably due to its low atomic scattering factor compared to Pt atom and the disorder of the Co layer. It is also possible that the Co layer forms an interfacial alloy with Pt and the measured peaks are actually the peaks of a surface Co_xPt_{1-x} alloy. However, no diffraction peak of any known CoPt alloy structure can be identified. Therefore, in this experiment, we adopted the polarized X-ray absorption spectroscopy technique which is an element-specific method capable of defining the structure of ultrathin Co layer. A similar technique has been applied on a highly textured Co/Pt multilayer sample with Si as substrate (Chung *et al.*, 2000). In this work, epitaxial Co/Pt multilayers with different Co thickness were studied.

2. Experimental

Epitaxial growth [Co(t)/Pt(1 nm)]$_{30}$ multi-layer was prepared on the Pt/Mo buffer layer on Al_2O_3(11-20) substrates in an MBE system under a base pressure of less than 10^{-9} Torr. The deposition rate is about 0.01 nm/s with the substrate temperature of about 470 K. We have prepared samples with a Co thickness from 0.16 to 1.07 nm in order to study the structure difference on the Co/Pt interface. The crystal orientation, strain, and interfacial roughness were measured using X-ray diffraction and X-ray reflectivity methods which were performed at the wiggler BL17B beamline of Taiwan Light Source (TLS). X-ray diffraction measurement confirmed that a twinned fcc Pt(111) buffer layer and multilayer can be grown epitaxially on the Mo(110) layer on the Al_2O_3 (11-20) substrate. In the in-plane direction, the Pt(1-10) closely parallels to the Mo(-111) and Al_2O_3 (0001); and Pt(-211) to the Mo(-211) and Al_2O_3 (1-100). The polarized X-ray absorption spectroscopy experiments were performed at wiggler BL17C beamline of TLS with energy resolution of 3 eV. To understand the structure of Co layer, both the in plane and plane normal polarization XANES and EXAFS were examined. In this

experiment, the Co Kα fluorescence emitted from the samples were detected by a Lytle detector and sample surfaces were rotated at an angle either parallel to or near perpendicular to the polarization of the synchrotron light. Reference spectra of the hcp-Co foil and CoPt and $CoPt_3$ alloy samples were also measured for comparison.

3. Results and discussion

Figure 1 shows several near edge X-ray absorption spectra around the Co K-edge. The deduced neighboring distance, coordination number of surrounding Pt atoms are shown in the Fig. 2-3 respectively. Fig. 1 reveals that the absorption spectra of both in-plane and plane normal directions are quite similar for samples with Co layer of less than 0.3 nm. This result leads to a speculation that the Co layer is more like an fcc pseudomorphic structure at thickness of less than 0.3 nm, because of its crystal symmetry along these two directions are the same. The data also show that, for the Co layer thickness of 1 nm, the spectra in both directions are separated apart and the spectra look closer to the bulk hcp Co. It is quite possible that a structural phase transition (from a cubic symmetry to a hexagonal symmetry with increasing Co thickness) occurs at Co layer of 0.3-0.4nm. This result is consistent with the previous report on thin Co layer by Nakajima *et al*. (1998), Thiele *et al.* (1996), Sato (1987), Galeotti *et al*. (1993), and Bulou *et al.* (1997). The X-ray absorption spectroscopy data of the Co/Pt multilayer with Co layer of about 1 monolayer is quite similar to the CoPt alloy with partial ordered

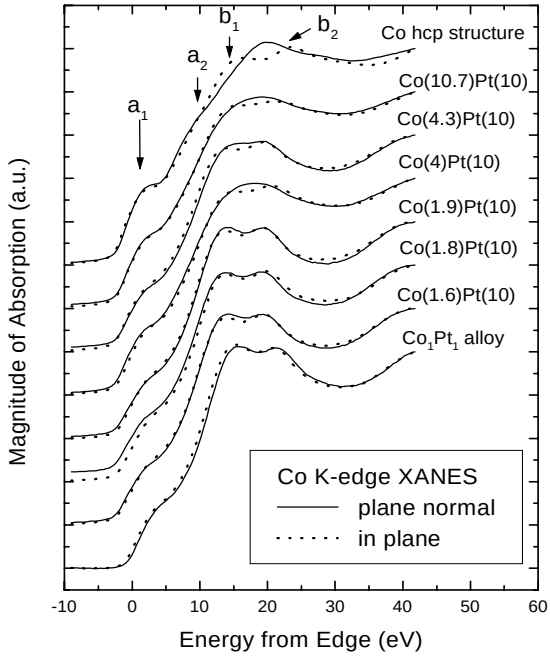

Figure 1

The result of X-ray absorption spectroscopy with the polarization direction perpendicular to the surface (solid line) and the polarization direction parallel to the surface (dash line).

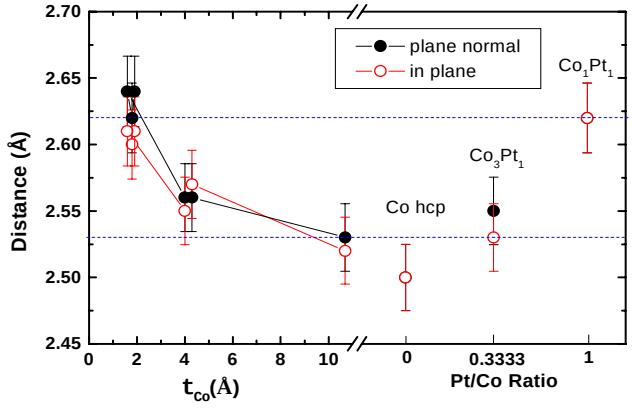

Figure 2

The nearest neighbor distance around the Co atoms deduced from the EXAFS data with the polarization direction perpendicular to the surface (filled circle) and the polarization direction parallel to the surface (open circle).

structure which also reveals significant PMA effect (Huang *et al.*, 1999). For Co layer of 1 nm, the bonding distances of the first shell is 0.25 nm (see Fig.2), which is very close to the Co-Co distance in the bulk hcp Co. On the other hand, for Co layer of less than 0.3 nm, the in plane first shell distance of Co is expanded by about 4 %. In comparison with the CoPt alloy with three different compositions, apparently, the atom distance in the multilayer does not follow the atomic distance of alloy. It is also showed that the epitaxial multilayer structure was formed in a non-mixed form viewed from the plane normal direction. Evidence can be found from the Pt coordination numbers around the Co atom. To understand the interface morphology, we assume two models (see Fig.3) —a sharp boundary model and a total interdiffusion model (alloy model). In the sharp boundary model, we assume half of the 12 coordinates neighbors are Pt atoms at the interface between Co and Pt layer. The averaged coordination number of Pt neighbors for different Co layer thickness is also plotted as a triangular line in Fig. 3a. In the total interdiffusion model, we assumed that the multilayer interface is a totally disordered alloy and the averaged coordination number of Pt neighbors is plotted as a reversed triangular line in Fig. 3a. From the experimental result, we can see that our sample fitted the sharp boundary model better than the total interdiffusion model. Note that the interfacial roughness determined from the X-ray reflectivity measurement is about 0.3-0.5 nm for all the samples. The relatively large interfacial roughness obtained from the X-ray reflectivity measurement does not contradict with our sharp boundary model because different in-plane length scales were probed by the X-ray reflectivity method and the EXAFS measurement. The data X-ray reflectivity is a lateral average over several μm of length scale, but the EXAFS data probe only the local distance no longer than few tenth's of nanometer. The sharp boundary indicates that the interfacial boundary is a jagged one

instead of an interdiffused one. The result also indicates that the phenomenon of interdiffusion at of Co/Pt interface is not severely taken place at this growth temperature (470K). This results is consistent with the recent thin film experiment (Lin *et al.*, 2000; Tsay *et al.*, 1997), where the interdiffusion of Co on Pt layer was found to be significant only at the growth temperatures higher than 550 K. We can also see that the near atom distances are in general follow the same trend for in-plane and out-of-plane directions. This implies that the Co/Pt multilayer samples are not Poisson materials in which the typical Poisson ratio in the bulk material is not applicable.

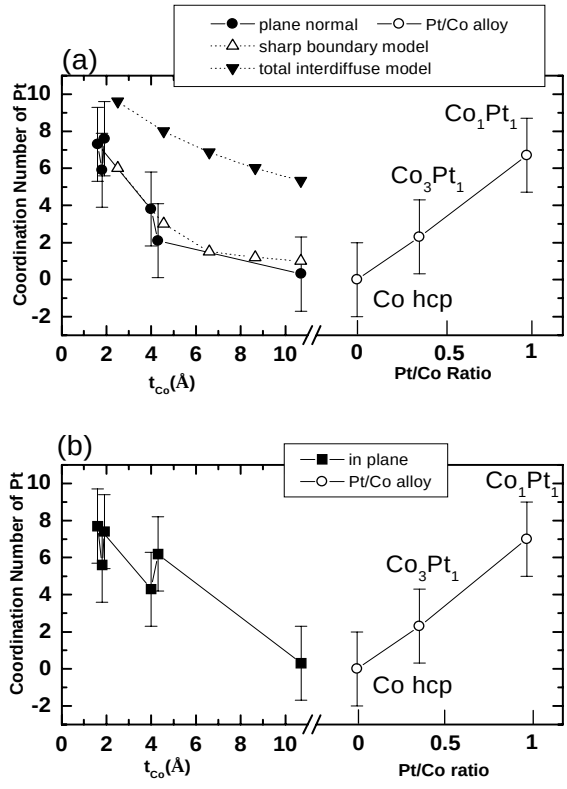

Figure 3
The coordination number of Pt atoms around the Co atom deduced from the EXAFS data with (a) the polarization direction perpendicular to the surface and (b) the polarization direction parallel to the surface. In the plane normal direction, the triangular line indicates the sharp boundary model and the reversed triangular line is the total interdiffusion model.

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References

Bulou,H.,Barbier,A., Renaud, G., Carriere, B., Baudoing-Savois, R., and Deville,J.P., (1997) *Surf. Sc*i. **277**, 377-379.

Chung, I. B., Joo, Y. M., Lee, J. M., (2000). *J. Appl. Phys*. **87**, 4205-4209.

Galeotti, M., Atrei,A., Bardi, U., Cortigiani, B., Rovida, G., and Torrini, M., (1993), *Surf. Sci*.**297**, 202-208.

Huang, J.C.A., Wu, L.C., Hsu, A.C., Hu, Y.H., Wu, T.H., and Lee, C.H., (1998), *Phys. Rev. **B*** **59**, 1209-1213.

Huang, J.C.A., Hsu, A.C., Lee,Y.H., Wu, T.H. and Lee, C.H., (1999), *J.Appl. Phys.* **85**, 5977-5979.

Lee, C.H., Wu, L.C., Yu, K.L., Huang, J.C.A., Jan, J.C., Cheng P.Y. (2000), *Physica B* **283**, 153-156.

Lin, T.M., Her, H.Y., Wu, Y.E., Shern, C.S., Ho, J.W., Kuo, C.C., Huang, H.L.,(2000), *J. Magn. Magn. Mater.* **209**, 211-213.

Nakajima, N., Koide, T., Shidara,T., Miyauchi, H., Fukutani, H., Fujimori, A., Iio, K., Katayama, T., Nyvlt, M., and Suzuki, Y. (1998), *Phys. Rev. Lett.* **81** , 5229-5232.

Sato, N., (1987), *J. Appl. Phys*. **61**, 1979-1982.

Thiele, J., Boeglin, C., Hricovini, K., and Chevrier, F.,(1996), *Phys. Rev. B* **53**, 11934-11938.

Tsay, J.S., Wu, Y.E. and Shern, C.S., (1997) *Chinese J. Phys.* **35**, 610-616.

Yamaguchi, A., Ogu, S., Soe, W.H., and Yamamoto, R. (1993), *Appl. Phys. Lett.* **62**, 1020-1022.