

# The electronic structure of a metastable ferromagnetic CoPt<sub>3</sub> film prepared by ion irradiation

G. S. Chang<sup>1</sup>, S. H. Kim<sup>1</sup>, J. H. Son<sup>1</sup>, S. W. Shin<sup>1</sup>, K. H. Chae<sup>1</sup>, A. Moewes<sup>2</sup>,  
E. Z. Kurmaev<sup>3</sup>, A.V. Ezhov<sup>3</sup>, and C. N. Whang<sup>1</sup>

<sup>1</sup>Atomic-scale Surface Science Research Center and Institute of Physics & Applied Physics,  
Yonsei University, Seoul 120-749, Korea

<sup>2</sup>Department of Physics and Engineering Physics, University of Saskatchewan,  
Saskatchewan S7N 5E2, Canada

<sup>3</sup>Institute of Metal Physics, Russian Academy of Science-Ural Division,  
620219 Yekaterinburg GSP-170, Russia

## INTRODUCTION

Strong efforts in the technologies of ferromagnetism have been devoted to study the magnetic and magneto-optical properties of ferromagnetic/non-magnetic multilayers and thin film alloys in order to develop magnetic data-storage media, sensors, and read heads [1]. As the size of those devices shrinks to sub-micron with ultrahigh storage density, the requirement for ferromagnetic materials with superior magnetic properties are increasing. In the case of *3d* transition metal/rare-earth metal systems, Co/Pt multilayers and Co-Pt alloy films have attracted a lot of attention due to their large magneto-optical (MO) Kerr rotation and perpendicular magnetic anisotropy which have been known to be strongly correlate with electronic structures of Co *3d* and Pt *5d* states and also with their chemical structures.

In this study, we apply the ion beam mixing method to ferromagnetic Co/Pt films to modify the electronic and chemical structures of Co-Pt alloy films. It has been reported that ion beam mixed (IBM) multilayered films show different electronic structure from those of thermodynamically stable alloys and that IBM multilayered films show a metastable disordered alloy phase, which is similar to that of a rapidly quenched alloy [2]. Therefore, it is expected that Co *3d* and Pt *5d* valence-band characteristics of ferromagnetic thin films are modified by ion beam mixing, which leads the change in magnetic properties and Co *L*<sub>3</sub> soft X-ray fluorescence (SXF) spectra and valence-band photoemission spectra of IBM CoPt<sub>3</sub> films are presented.

## EXPERIMENTALS

Co/Pt multilayered films with 8 periods of Co and Pt sublayers were prepared by alternating electron-beam evaporation on Si (100) substrates. The sublayer thickness of Co and Pt layers was chosen to 15 Å and 60 Å, respectively, to match the CoPt<sub>3</sub> composition. Ion beam mixing was carried out by using 80 keV Ar<sup>+</sup> beam at room temperature. Ion dose and beam current were fixed at 1.0×10<sup>16</sup> ions/cm<sup>2</sup> and 1.5 **nA**, respectively. The spectra of IBM CoPt<sub>3</sub> films were compared with those of pure Co, Pt, and stable CoPt<sub>3</sub> alloy films prepared by electron-beam evaporation.

SXF measurements of Co *L*<sub>3</sub> (valence *3d4s*→*2p*<sub>3/2</sub> transition) were performed at ALS on beamline 8.0. The spectrometer resolution in the first order of diffraction was 0.9 eV for Co *L*<sub>3</sub>. In

addition, the electronic valence-band structure was measured by photoemission spectroscopy (PES) at PLS, Korea. The incident photon energies were 100 eV for partial density of states of Co 3*d* and 50 eV for that of Pt 5*d*.

## RESULTS AND DISCUSSION

Figure 1 shows valence-band PES spectra of IBM CoPt<sub>3</sub>. It should be noted that a superposition in a ratio of 0.25 : 0.75 of the spectra of Pure Co and Pt was added in Fig. 1b for comparison. We chose the incident photon energies of 50 eV (Fig. 1a) that the relative ratio of Co 3*d* photoionization cross section to Pt 5*d* is minimized to distinguish the local density of states of Co 3*d* from that of Pt 5*d*. As seen in Fig. 1a, a valley at about 3 eV (arrow A) is a typical feature of the Pt 5*d* band, while the flattened spectral weight at the Fermi level ( $E_F$ ) is attributed to the photon energy-dependent cross-section effects at lower photon energies. In addition, the Pt 5*d* characteristic feature shifts slightly toward higher binding energy from pure Pt to CoPt<sub>3</sub> alloy. This reflects that the covalent interaction of Pt atoms changes under a variation of nearest neighbors surrounding the Pt site and the relative positions of Co and Pt *d* bands affect the Co 3*d* – Pt 5*d* hybridization and the valence-band width is increased in the Co-Pt alloys [3].

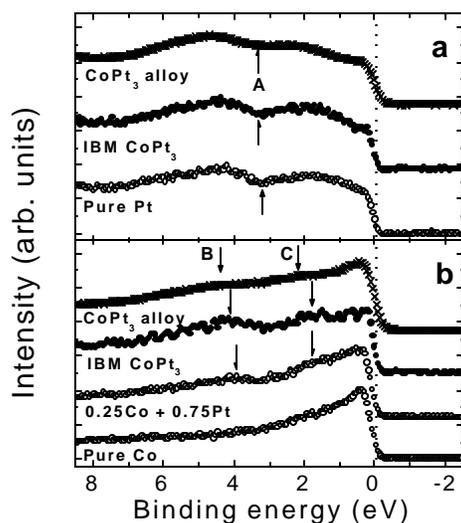


Fig. 1. Valence-band PES spectra of IBM CoPt<sub>3</sub>, stable CoPt<sub>3</sub>, pure Pt, and pure Co films.

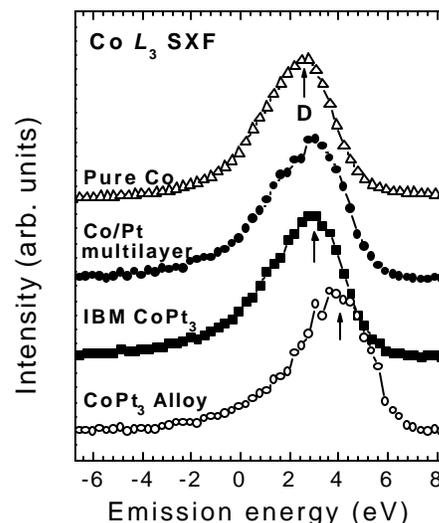


Fig. 2. Co  $L_3$  SXF spectra of Co/Pt multilayer, IBM CoPt<sub>3</sub>, pure Co, and stable CoPt<sub>3</sub> alloy films.

As indicated by Fig. 1b, the energy shift is more significantly observed in the spectra dominated by Co 3*d* states, even though the spectral weight from Pt states is very weak due to a small photoionization cross section of Pt 5*d* with respect to Co 3*d* states. However, the interesting feature is the contribution of Pt 5*d* to the spectrum of IBM CoPt<sub>3</sub> (arrow B and C), which does not resemble that of stable CoPt<sub>3</sub> alloy film but the superposed spectrum of pure Co and Pt with a factor of 0.25 and

0.75, respectively, which reflects that the Co  $3d$  and Pt  $5d$  electrons are in an isolated state of greatly weakened interatomic electronic interaction. During the ion beam mixing treatment, the independent motions of atoms activated by ion bombardment are quenched in a very short period of the order of  $10^{-11}$  s at the end of ion-solid interaction. Therefore, the rapid quenching process can induce the formation of a metastable  $\text{CoPt}_3$  phase with expanded volume and reduced coordination, which does not allow the electronic interaction between Co and Pt atom to be relaxed to an equilibrium state.

To clarify this implication, we measured the distribution of Co  $3d$  states using SXF, where the dipole selection rule enables us to extract information about the partial density of Co  $3d$  states from Pt  $5d$ . Figure 2 shows the Co  $L_3$  SXF spectra of the investigated samples which correspond to dipole  $3d4s \rightarrow 2p_{3/2}$  transition. As seen in Fig. 2, the spectral maximum of Co  $L_3$  (arrow D) shifts by about 1.6 eV from pure Co (780.8 eV) to the stable  $\text{CoPt}_3$  alloy (782.4 eV). Acker *et al.* reported that, in case of Fe-Pt and Co-Pt alloy phase, Fe and Co majority-spin states located at higher binding energy have a strong tendency to mix with Pt  $5d$  states, while much Fe and Co minority-spin characters positioned near and above  $E_F$  as an unoccupied virtual bound state are driven to move higher above  $E_F$  under the  $d$  resonance with Pt minority-spin states [4]. This means that, in case of SXF measurements of Co  $L_3$ , the emission energy of stable  $\text{CoPt}_3$  film is higher than that of pure Co. Furthermore, it is also natural that the spectrum of Co/Pt multilayered film is similar with that of pure Co, because the interfacial Co  $3d$  - Pt  $5d$  hybridization is overwhelmed by the metallic interaction between Co atoms in Co sublayer. However, IBM  $\text{CoPt}_3$  shows the same trend as in the PES measurements. The spectral maximum of IBM  $\text{CoPt}_3$  (781.1 eV) is close to that of pure Co with respect to stable  $\text{CoPt}_3$  alloy film, even though the sample was ion-beam-mixed to form a  $\text{CoPt}_3$  phase. As discussed above, this is a direct evidence of isolated Co  $3d$  states with greatly weakened interatomic electronic interaction with Pt  $5d$  states and, therefore, lower Co coordination in IBM  $\text{CoPt}_3$  film by the formation of metastable alloy phase than that of a stable one which is in thermodynamically equilibrium state.

The overall spectroscopic results provide the direct evidences of the isolated Co  $3d$  states with a weakened interatomic interaction due to the reduced coordination which is expected to play an important role in enhancing magnetic properties of ferromagnetic thin films.

## REFERENCES

1. R. L. White, J. Magn. Magn. Mater., **200**, 616 (1999).
2. K. H. Chae, Y. S. Lee, S. M. Jung, Y. Jeon, M. Croft, C. N. Whang, Nucl. Instrum. Methods, B **106**, 60 (1995).
3. S. Uba, L. Uba, A.N. Yaresko, A.Ya. Perlov, V. N. Antonov, R. Gontarz, Phys. Rev., B **53**, 6526 (1996).
4. J. F. van Acker, P. J. W. Weijs, J. C. Fuggle, K. Horn, H. Haak, and K. H. J. Buschow, Phys. Rev. B **43**, 8903 (1991).

This work was supported by the Brain Korea 21 Project and the Korea Science and Engineering Foundation through Grant No. 995-0200-003-2 and by the Russian Foundation for Basic Research (Project 00-15-96575).

Principal investigator: Gap Soo Chang, Atomic-scale Surface Science Research Center and Institute of Physics and Applied Physics, Yonsei University. Email: gschang@phya.yonsei.ac.kr. Telephone: 82-2-2123-4280.