Chemical short-range order and magnetic anisotropy in $CoPt_3$ alloy films

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Introduction

Co/Pt multilayers possess large perpendicular magnetic anisotropy (K_u), high coercivity, and a Kerr response to blue light. This combination of properties makes them ideal candidates for the next generation of magnetooptic media. Recent reports have indicated that thin alloy films of Co and Pt can be processed to have many of the same desirable properties as the Co/Pt multilayers [1]. This result is unexpected since bulk CoPt alloys do not show this behavior. From a technological standpoint, sputtered films are more attractive for high-volume processing than evaporated multilayers.

Studies of the growth of Co_xPt_{1-x} alloy films have shown an enhancement of the Curie temperature (T_C) and K_u with increasing substrate temperature peaking near 400° C for x = 0.25 and decreasing at higher temperatures [2]. Several researchers have studied the magnetic and structural properties of these films and have concluded that Co-rich clusters must exist to account for the enhanced T_C [2, 3]. Polarized extended x-ray absorption fine-structure (EXAFS) has been used to measure anisotropic short-range order in a 200 Å film of $Co_{0.28}Pt_{0.72}$ film grown at a substrate temperature of 300° C [3], however, direct correlation between local structural anisotropy and the magnetic properties has not been established, nor has a detailed description of the Co clustering been provided.

We have used polarization-dependent EXAFS to study the local environment of Co and Pt atoms in a series of $Co_{0.25}Pt_{0.75}$ alloys grown on (100) MgO via molecular beam epitaxy over a substrate temperature range of 200° C < T < 800° C across the miscibility gap.

Methods and Materials

The samples were epitaxial (100) Co_xPt_{1-x} films grown by electron beam co-evaporation on (100) MgO with x = 0.25 ± 0.02. The sample preparation and bulk structural characterization were previously reported [2]. The EXAFS data were collected at the Advanced Photon Source (APS) 20-ID-B using a fixed-exit Si(111) monochromator to scan across the Co-K and Pt-L_{III} absorption edges using the first and third harmonics of the undulator, respectively. Samples were mounted on a tilt stage at 5° ± 1° to the unfocused incident beam. A 6000 rpm sample spinner was used to minimize the effect of Bragg diffraction from the substrate and fcc film. The fluorescence was collected using a 200 mm x 200 mm x 10 mm gas ionization chamber flowing Ar placed normal to the incident beam direction in the polarization plane. Incident beam intensity was monitored using a 300 mm gas ionization chamber flowing He. Harmonic rejection was accomplished by detuning the second crystal of the monochromator to 40% of peak intensity and locking on this position with a PID feedback circuit. Four samples, grown at 200° C, 450° C, 600° C, and 800° C, were measured with the polarization in plane and out of plane, with respect to the substrate. Five scans at three seconds/point were collected from each of the samples.

The pre-edge background subtraction was performed using AUTOBK [4], and the resulting $\chi(k)$ were averaged before analysis. Theoretical phases and amplitudes were calculated using FEFF7 [5], and the data were fit in R-space using FEFFIT [4]. An adjustable overall scale factor S_0^2 was not used in the single data set fits because it was found to be too highly correlated with σ^2, N_{Pt}, and N_{Co} to be reliable. Instead, S_0^2 for Co and Pt were fixed to give a total coordination number of 12, consistent with the average fcc structure determined by x-ray diffraction (XRD) and with the values for S_0^2 obtained in constrained fits to both polarizations simultaneously. The results of the first-shell fit to the 450° C sample for both in- and out-of-plane polarization at the Co K-edge are shown in Figure 1, including the individual contributions from the Co and Pt neighbors around the central Co atoms.

Results

The results of the analysis of the first-neighbor EXAFS is summarized in Tables 1 and 2. With the exception of the number of in-plane Co-Co bonds for the sample grown at 450° C, the coordination and bond lengths for all of the data are consistent with disordered fcc $Co_{0.25}Pt_{0.75}$. The number of in-plane Co-Co bonds for the sample with the largest K_u is twice that of all other samples, confirming that the structural anisotropy is correlated with the magnetic anisotropy. Furthermore, the lack of any significant increase in out-of-plane Co-Co bonds in the 450° C sample suggests that the clustering is confined to one atomic plane. We do not see any variation in the number of out-of-plane near-neighbor Co-Pt bonds.

Discussion

Tyson *et al.*, [3] have suggested the possibility of anisotropic "plates" as well as one-dimensional "chains"of Co atoms. Our findings are consistent with this for the film grown at 450° C, however, our measurements can not distinguish these two geometries. Due to the lack of any significant increase in the number of Co-Co bonds out of plane, the EXAFS gives an estimate of the out-of-plane extent of the domains as one monolayer. However, the next-neighbor in-plane Pt atom beyond that substituted by Co is over 8 Å from the central Co atom, outside a reasonable

range for EXAFS analysis, and therefore we can make no conclusion about the lateral extent of the Co domains.

Acknowledgments

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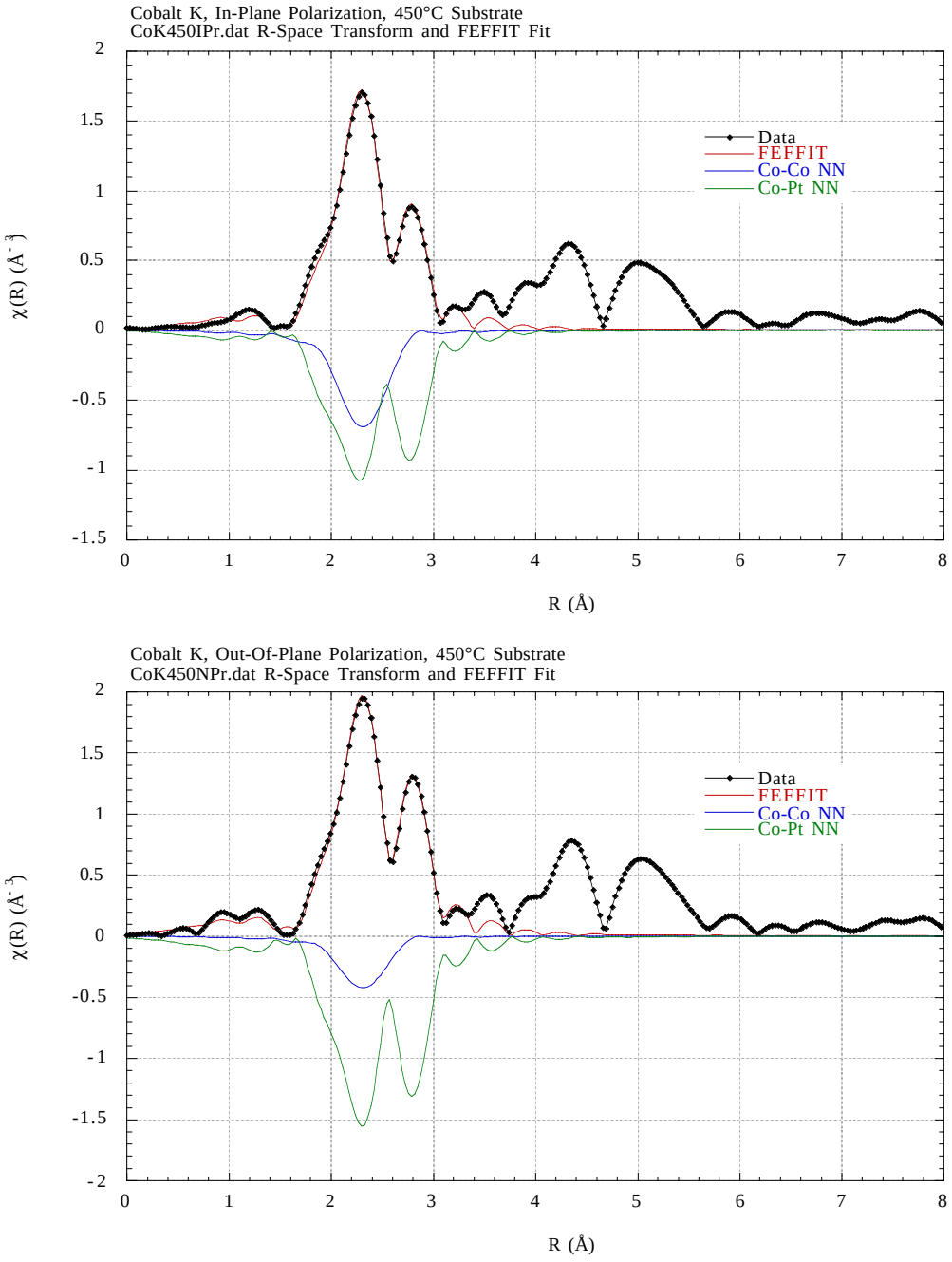

Figure 1: R-space Fourier transform and FEFFIT fits to the in-plane and out-of-plane polarized EXAFS from the film grown at 450° C. Contributions from the Co-Co and Co-Pt first-neighbor paths are shown on the $-\chi$ axis for clarity.

Table 1: EXAFS analysis results for Co K-edge data. Shown are the coordination numbers (N) and distances (R) for near neighbors of Co and Pt around the central Co atom for each growth temperature and orientation. A single mean-square-displacement (σ^2) was used for both bonds, and S_0^2 was fixed at 0.75. Estimated uncertainties in the fitted parameters are given in parentheses.

Growth T /	Co – Co		Co – Pt		
Orientation	N	R (Å)	N	R (Å)	σ^2 (Å^2)
200 / In	1.3 (0.3)	2.67 (0.01)	9.9 (0.5)	2.71 (0.01)	0.007 (0.001)
200 / Out	1.1 (0.5)	2.68 (0.04)	10.7 (1.2)	2.71 (0.01)	0.007 (0.001)
450 / In	2.7 (0.3)	2.68 (0.01)	8.4 (0.4)	2.69 (0.01)	0.008 (0.002)
450 / Out	1.5 (0.1)	2.65 (0.01)	10.5 (0.4)	2.69 (0.01)	0.007 (0.001)
600 / In	1.3 (0.2)	2.67 (0.01)	10.0 (0.5)	2.71 (0.01)	0.007 (0.001)
600 / Out	1.3 (0.5)	2.62 (0.03)	10.6 (1.3)	2.72 (0.01)	0.008 (0.001)
800 / In	1.0 (0.3)	2.67 (0.02)	10.4 (0.7)	2.72 (0.01)	0.007 (0.001)
800 / Out	1.2 (0.3)	2.66 (0.02)	10.3 (0.6)	2.71 (0.01)	0.007 (0.001)

Table 2: EXAFS analysis results for Pt L_{III}-edge data. Shown are the coordination numbers (N) and distances (R) for Co and Pt near neighbors around the central Pt atom for each growth temperature and orientation. S_0^2 was fixed at 0.70.

Growth T /	Pt – Co		Pt – Pt		
Orientation	N	R (Å)	N	R (Å)	σ^2 (Å^2)
200 / In	2.6 (0.3)	2.67 (0.01)	8/7 (0.7)	2.73 (0.01)	0.005 (0.001)
200 / Out	2.4 (0.2)	2.68 (0.02)	8.6 (1.0)	2.73 (0.01)	0.005 (0.001)
450 / In	2.5 (0.3)	2.67 (0.01)	7.5 (0.9)	2.73 (0.01)	0.005 (0.002)
450 / Out	3.1 (0.3)	2.67 (0.01)	7.0 (0.8)	2.72 (0.01)	0.005 (0.001)
600 / In	2.5 (0.3)	2.68 (0.01)	7.6 (0.7)	2.73 (0.01)	0.005 (0.001)
600 / Out	2.7 (0.2)	2.68 (0.02)	7.8 (0.8)	2.73 (0.01)	0.005 (0.001)
800 / In	2.8 (0.3)	2.68 (0.02)	7.7 (0.9)	2.73 (0.01)	0.005 (0.001)
800 / Out	2.7 (0.3)	2.68 (0.02)	7.8 (0.8)	2.73 (0.01)	0.005 (0.001)