The role of Ta and Pt in segregation within Co-Cr-Ta and Co-Cr-Pt thin film magnetic recording media

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Polarization dependent extended x-ray absorption fine structure (PD-EXAFS) and magnetic circular dichroism (MCD) measurements of CoCrTa and CoCrPt films, sputter deposited at varying substrate temperatures, were performed to investigate the average local structure and chemistry about the Ta, Pt, and Co atoms and the average magnetic moment of the Co and Cr atoms within these films. Results from the MCD measurements indicate the average net magnetic moment of the Cr atoms is opposite in direction and five percent in amplitude relative to the Co moments. Inspection of the Fourier transforms of the XAFS data from these samples shows an increase in structural disorder around the Ta and Pt atoms with increasing substrate deposition temperature. A further comparison between the Ta and Pt edge EXAFS results show that the temperature-dependent increase in structural disorder is greater around the Ta atoms in the CoCrTa system than it is around the Pt atoms in the CoCrPt system. [S0021-8979(96)09708-5]

I. INTRODUCTION

Compositional inhomogeneities have long been thought to play an important role in determining the magnetic properties of Co-Cr based magnetic thin films. Previous studies of CoCr-based thin films deposited at elevated temperatures indicated the presence of fine, periodic compositional variations within grains.[1] The addition of Ta has been shown to decrease the size of the Co enriched regions within these films, demonstrating the importance of the addition of Ta. Similarly, the addition of Pt has been shown to increase these films' coercivities. Previous studies have also proposed that nonmagnetic or paramagnetic Cr enriched regions[2,3] between the magnetic Co enriched regions aid in decoupling the magnetic domains within these films thus leading to higher storage density and lower noise media.

The films investigated in this study were sputter deposited on glass substrates at temperatures (T_s) of room temperature and 260 °C. The nominal composition of the films studied were $Co_{86}Cr_{12}Ta_2$, and $Co_{86}Cr_{12}Pt_2$. The thickness of the films was 300 Å. All films were capped with a 50 Å layer of Al to prevent any oxidation effects, and had a 1000-Å-Cr underlayer.

The average local structure around the Co, Ta, and Pt atoms in these films was investigated by using polarization-dependent extended x-ray absorption fine structure (PD-EXAFS), a local structural probe having both elemental and directional sensitivity. Analysis of this data shows a greater amount of structural disorder around the Ta and Pt atoms with increasing substrate deposition temperature. A further comparison between the Ta and Pt edge PD-EXAFS results shows that the temperature-dependent increase in structural disorder is greater around the Ta atoms in the CoCrTa system than it is around the Pt atoms in the CoCrPt system. Chemical segregation of Co-enriched regions within the films was confirmed also via PD-EXAFS at the Co absorption edge.

Magnetic circular dichroism (MCD) measurements were also made on these samples. MCD is an element-specific magnetic spectroscopic tool in which the difference in the absorption of left- and right-circularly polarized photons are measured at the absorption edges of the constituent elements. This difference in absorption cross sections, appropriately normalized, is a measure of the average magnetic moment of an atomic species at a given atomic site.[4,5] Results from this study show the existence of a small average net magnetic moment associated with the Cr atoms that is opposite in direction relative to the average net magnetic moment of the Co atoms. MCD therefore enables measurement of direction and magnitude of the average magnetic moment for each constituent atomic species within a sample. Thus, it is a very good technique to use to determine if there is a magnetic moment associated with the Cr atoms within these films.

II. DATA COLLECTION AND ANALYSIS

PD-EXAFS and MCD measurements were performed on four films deposited on glass with nominal compositions $Co_{86}Cr_{12}Ta_2$, and $Co_{86}Cr_{12}Pt_2$ and T_s equal to room temperature and 260 °C.

X-ray absorption spectra were collected on the Naval Research Laboratory's materials analysis beam line, X23B, and the National Institute of Standards and Technology XAFS beamline X23A2, at the National Synchrotron Light Source (Brookhaven National Laboratory, Upton, NY). The fine structure appearing above the Co K edge (7709 eV), the Ta LIII-edge (9881 eV) and the Pt LII edge (13273 eV) were

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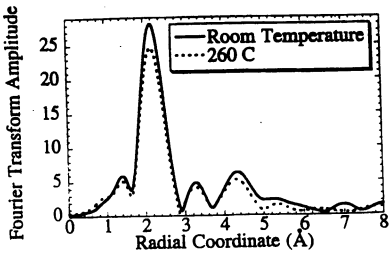

FIG. 1. Fourier transform of Ta EXAFS data on $Co_{86}Cr_{12}Ta_2$ films grown at substrate deposition temperatures of room temperature (solid line) and 260 °C (dotted line).

collected in electron yield mode[6] using normal and glancing angle (10° with respect to the film plane) incident radiation. Because the EXAFS signal originates with a $\cos^2$ angular dependence with respect to the electric-field vector of the incident radiation and the bond between the absorbing and backscattering atom, these orientations allow preferential sampling of the in-plane and out-of-plane structure, respectively. The EXAFS data were subjected to standard analysis procedures,[7] leading to the Fourier transformation of the data to radial coordinates. To obtain quantitative measurement of the average near neighbor environment around the Co atoms, Fourier transformed data of the first Fourier peak from the Co K-edge PD-EXAFS data were back-Fourier transformed to wave vector space and fitted using parameterized theoretical EXAFS spectra. The theoretical EXAFS spectra were generated using the FEFF codes developed by Rehr and co-workers.[8] This analysis allows the calculation of the average coordination number, radial distance, and Debye–Waller factors of atomic shells around each atomic species in both the parallel and perpendicular directions relative to the film surface.

MCD measurements were performed on these samples at beamline U4B and X13 at the National Synchrotron Light Source (Brookhaven National Laboratory, Upton, NY). MCD enables measurement of direction and magnitude of the average magnetic moment for each constituent atomic species within a sample. Thus, it is a very good technique to use to determine if there is a magnetic moment associated with the Cr atoms within these films. Measurements of the CoCrTa and CoCrPt films were made in the plane of the films while alternating the direction of the applied magnetic field (10 kOe) between parallel and antiparallel orientations at each energy throughout the scan. The thickness of the glass substrate prohibited absorption measurements by transmission, therefore absorption was determined from the x-ray fluorescence signal[9] as a function of incident energy and applied magnetic field. Since this study is only qualitatively addressing the existence of a magnetic moment associated with Cr, no fluorescence amplitude correction[10] was included in the analysis.

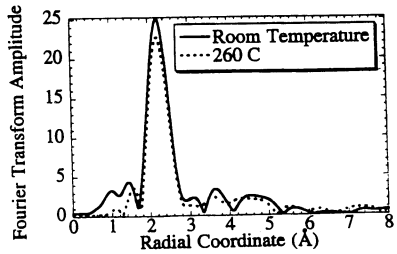

FIG. 2. Fourier transform of Pt EXAFS data on $Co_{86}Cr_{12}Pt_2$ films grown at substrate deposition temperatures of room temperature (solid line) and 260 °C (dotted line).

III. RESULTS AND DISCUSSION

For all films, qualitative analysis of the Fourier Transformed PD-EXAFS data from the Co K edge show that the Co atoms are incorporated into the films in a close-packed structure.[11,12] Results from a quantitative analysis of the filtered first shell data from the Co K-edge PD-EXAFS data indicate at least 95% of all the atoms surrounding the Co absorbing atoms are Co atoms. This is significantly larger than the 86% value expected had a solid solution of $Co_{86}Cr_{12}Ta_2$ or $Co_{86}Cr_{12}Pt_2$ had been formed. This illustrates the presence of Co-enriched regions within the films, and thus indirectly illustrates the presence of Cr-enriched regions.

Figures 1 and 2 are plots of the Fourier transformed Ta and Pt EXAFS data for T_s of room temperature (solid line) and 260 C (dotted line). The general characteristic shapes of these data suggests that, for both substrate deposition temperatures, both the Ta and Pt atoms are incorporated within the films' close-packed structure with a large amount of local structural disorder. Furthermore, the local environment of the Ta and Pt atoms is not bcc or fcc clusters as one might expect if the Ta or Pt atoms had phase separated. Further analysis of the first Fourier transform peaks for the Ta and Pt data shows that for an increasing T_s, the average total number of atoms surrounding Ta and Pt decreases while the EXAFS Debye–Waller term increases. (An increase in the EXAFS Debye–Waller term corresponds to a broader distribution of radial distances about their average distance.) This temperature-dependent trend however, is not seen around the Co atoms in the CoCrTa or CoCrPt films. These two trends are consistent with vacancies preferentially segregating to the Ta or Pt atoms thereby decreasing the diffusion of the Co or Cr atoms, and thereby refining the length scale of the Co-enriched regions. A further comparison between the Ta and Pt edge PD-EXAFS results shows that the temperature-dependent increase in structural disorder is greater around the Ta atoms in the CoCrTa system than it is around the Pt atoms in the CoCrPt system.

Figures 3 and 4 are the MCD spectra for the Co and Cr atoms in a 2000-Å-thick $Co_{86}Cr_{12}Ta_2$ film with T_s at room temperature. MCD measurements were made on this sample instead of the 300 Å film because it did not have a 1000-Å-Cr underlayer which would contaminated the Cr MCD signal. These figures represent the difference in absorption of circularly polarized photons parallel and anti-parallel to an external magnetic field (10 kOe) applied in the plane of the films. The amplitude of these signals are normalized to the relative numbers of Co and Cr atoms in the film. The figure depicting the Co MCD spectra (Fig. 3) shows a negative

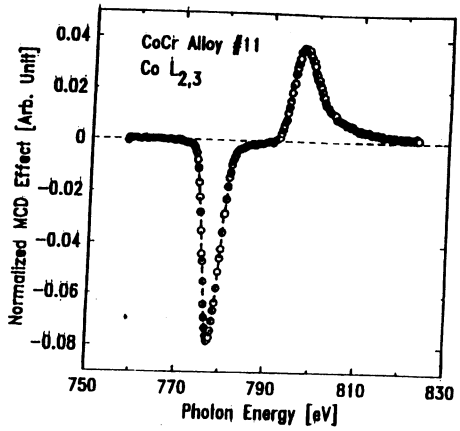

FIG. 3. MCD spectrum of the Co LIII and LII edges on the $Co_{86}Cr_{12}Ta_2$ film grown at room temperature.

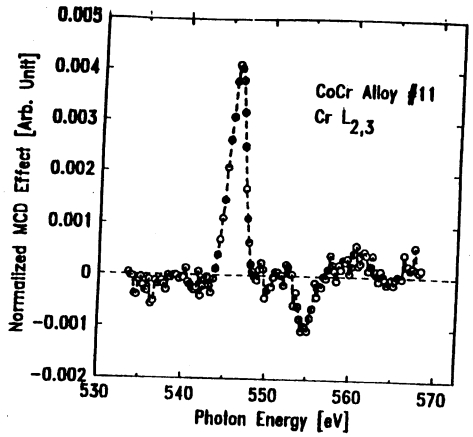

FIG. 4. MCD spectrum of the Cr LIII and LII edges on the $Co_{86}Cr_{12}Ta_2$ film grown at room temperature.

difference signal at the LIII edge step and a positive difference signal at the LII edge step. Conversely, the figure depicting the Cr MCD spectra (Fig. 4) shows a positive signal at the LIII edge step and a negative signal at the LII edge step. The ratio of the magnitudes of the MCD effect for the Co and Cr atoms is approximately 20:1. A similar ratio exists for the 2000-Å-CoCrTa film grown with a 260 C T_s. This ratio does not exhibit any substrate deposition temperature dependence. In all cases, the absolute magnitude of this effect has not been corrected for self-absorption effects. However, although self-absorption effects may cause the amplitude of the MCD effect to change, the existence of the effect and its direction will not change. Therefore, this demonstrates that

(1) there is a small net magnetic moment associated with the Cr atoms in the CoCrTa system,
(2) the moment associated with the Cr atoms is anti aligned relative to the Co atoms, and
(3) the ratio of the net Cr/Co magnetic moments is not temperature dependent.

IV. SUMMARY

In summary, we have used PD-EXAFS to verify that the local environments about the Co, Ta, and Pt atoms in $Co_{86}Cr_{12}Ta_2$, and $Co_{86}Cr_{12}Pt_2$ thin films are a close-packed structure. Results from analysis of the Co atoms' average first shell environments show Co-Co coordination numbers greater than that expected in a totally random case. This illustrates chemical segregation, within these films, into Co-enriched regions. Inspection of the Fourier transformed Ta edge and Pt edge PD-EXAFS data shows a change in the average local structure surrounding the Pt and Ta atoms in that there is a greater amount of structural disorder around these atoms with increasing substrate deposition temperature. A further comparison shows that the temperature-dependent increase in structural disorder is greater around the Ta atoms in the CoCrTa system than it is around the Pt atoms in the CoCrPt system. Results from the MCD measurements of these films at the Co and Cr LIII and LII edges show that the average net magnetic moment of the Cr atoms is opposite in direction and five percent in amplitude relative to the Co moments. The amplitude and direction of the net magnetic moment of Cr exhibits no dependence on substrate deposition temperature.

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