Direct observation of Cr magnetic order in CoCrTa and CoCrPt thin films

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Magnetic circular dichroism measurements of room temperature, sputter deposited $Co_{86}Cr_{12}Ta_2$ and $Co_{86}Cr_{12}Pt_2$ films were performed to investigate the local magnetic ordering of the Co and Cr atoms. The results demonstrate that the Cr has a net magnetic moment and that a small fraction of the Cr is magnetically oriented opposite to the Co moment. © 1997 American Institute of Physics. [S0021-8979(97)00502-1]

CoCr-based thin film alloys are a demonstrated technologically important system for perpendicular[1–3] and longitudinal[4,5] recording media. Numerous studies have demonstrated that these CoCr-based films can be grown in such a way as to produce compositionally inhomogeneous Co- and Cr-enriched regions.[6–12] Although significant work has been performed over the past decade, demonstrating that compositional and structural inhomogeneities play an important role in determining the magnetic properties of these materials,[3–5,10,11,13] the most significant control of the films' magnetic properties is achieved through tailoring the Co and Cr concentrations. Interestingly, although the Cr is paramount in prescribing the magnetic response, no *direct* measure of the magnetic role of the essential Cr has been performed.

Previous studies using indirect methods have suggested induced magnetic moments associated with the Cr atoms equal to 4.25 μ_B per atom in one study[14] and either 0 or 2 μ_B per atom in others.[15,16] More recently however, for these alloys, researchers have proposed citing other indirect evidence, that the Cr-enriched regions are present in a nonmagnetic or paramagnetic state.[3,11,13] This is particularly important since it is believed that the segregation of the nonmagnetic constituents results in less exchange coupling between and within the columnar microstructures, thus contributing to higher storage densities, lower noise, and higher coercivities of these materials.[3,17,18]

The major obstacle in directly ascertaining the magnetic behavior of the Cr is that traditional magnetism measurements are sensitive to the total magnetic response of the sample. For these materials, the large magnetic response of the ferromagnetic Co overwhelms any response from the less abundant Cr (Cr concentrations in these alloys are typically $<20\%$). Furthermore, if the magnetic behavior of the Cr is inhomogeneous, a likely scenario considering the evidence of compositional inhomogeneity of these films,[19] the magnetic response of the Cr is further diluted. To discriminate what is anticipated to be a small magnetic response of the Cr from the much larger Co response, we have employed soft x-ray magnetic circular dichroism.

Soft x-ray magnetic circular dichroism (MCD) is an element-specific magnetic spectroscopic tool where the difference in the absorption of left- and right-circular polarized photons is measured at the absorption edges of the constituent elements. Soft x-ray MCD is capable of determining the magnetic order of overlayers[20–22] and buried layers[23] with high sensitivity. Previous MCD measurements have been able to clearly identify the magnetic orientation of extremely small amounts of material [down to 0.25 monolayers of Cr deposited under ultrahigh vacuum conditions on a bcc Fe(001) surface].[21] In that case, the Cr moment was found to be small (0.6 ± 0.2 μ_B per atom) and shown to be antialigned to the Fe moment.[24] A similarly clear distinction of the Cr moment direction and size estimation should be possible for these alloys.

The nominal composition of the films studied are $Co_{86}Cr_{12}Ta_2$ and $Co_{86}Cr_{12}Pt_2$. The films were sputter deposited on glass substrates at room temperature and are 300 Å thick and capped with a 50 Å Al layer to retard oxidation
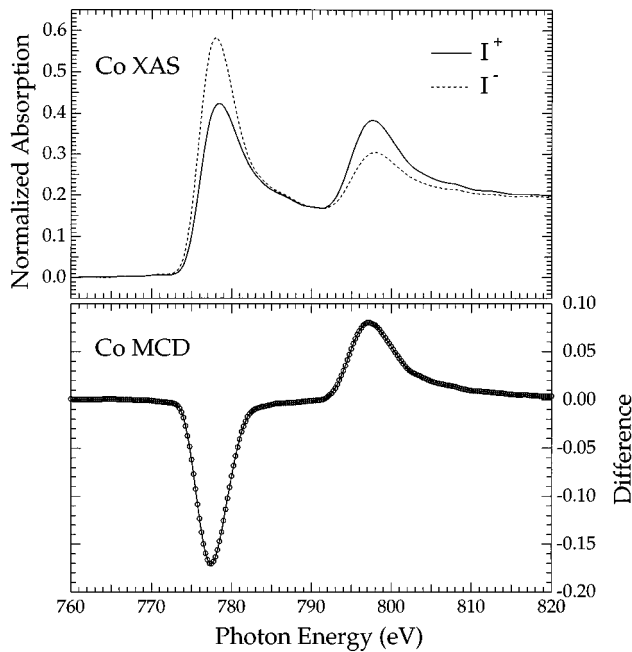
FIG. 1. Top–x-ray absorption spectra (XAS) for Co $L_{2,3}$ edges for positive (solid) and negative (dashed) helicity light. Bottom–difference spectra (MCD) for Co at the $L_{2,3}$ edges. All the spectra are corrected for the degree of polarization and the incident direction of the photon beam and are normalized.

FIG. 2. Top–x-ray absorption spectra (XAS) for Cr $L_{2,3}$ edges for positive (solid) and negative (dashed) helicity light. Bottom–difference spectra (MCD) for Cr at the $L_{2,3}$ edges. The vertical lines represent one standard deviation of the experimental data. All the spectra are corrected for the degree of polarization and the incident direction of the photon beam and are normalized.

after removal from the sputtering chamber. An initial Cr underlayer is usually deposited on the glass before deposition of the alloy to create an epitaxy between the Cr orientation and the CoCrX layer to create the correct texture and to achieve a smoother surface and consequently a better recording performance.[25] However, for these experiments, the Cr underlayer was not included so as to eliminate possible distortions of the Cr MCD absorption signal. Additional details of the film preparation and characterization are presented elsewhere.[4,12]

The MCD measurements were performed at the bending magnet beamline U4-B and at the elliptically polarized wiggler beamline X-13 at the national synchrotron light source. Characteristics of these beamlines have been described elsewhere.[26–29] The sample is placed in a 4 kOe magnetic field generated between the poles of a permanent magnet whose magnetization direction can be reversed by the mechanical motion of the ultrahigh vacuum compatible magnet assembly, leaving the sample/optical arrangement unchanged. The helicity-dependent x-ray absorption spectra is determined by monitoring the fluorescence yield and/or the total electron yield of the sample while holding the magnetization direction constant and reversing the helicity direction at 2 Hz while the photon energy is swept through the $L_{2,3}$ edges of Co (760–820 eV) and Cr (535–570 eV). In this manner, the two helicity dependent spectra are acquired in parallel, greatly reducing any background variation in the MCD spectra. Instrumental asymmetries are checked by reversing the magnetization direction and reacquiring the MCD spectra.
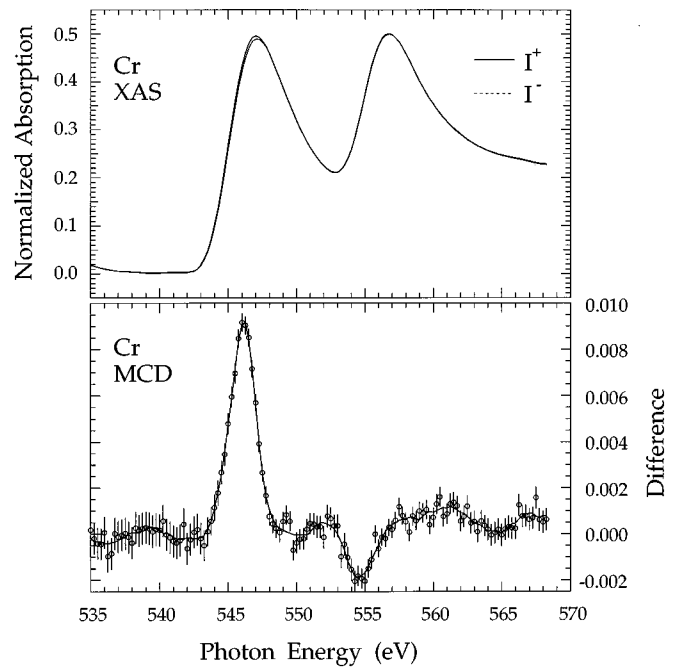
The Co $L_{2,3}$ absorption spectra x-ray absorption spectroscopy [(XAS) spectra] for positive (solid) and negative (dashed) helicity light for the $Co_{86}Cr_{12}Ta_2$ film are shown in the top panel of Fig. 1. The difference spectrum (MCD spectrum) is shown in the bottom panel. The data have been normalized to the incident photon flux as measured by the photocurrent from an in-line Cu grid and corrected to account for the degree of circular polarization (60%) and the incident direction (45°) of the photon beam. The spectra show a clear difference between the two absorption spectra and a large MCD effect, comparable to MCD spectra for bulk Co films.[30]

Figure 2 shows the same type of absorption (XAS) and difference spectra (MCD) for the Cr in the $Co_{86}Cr_{12}Ta_2$. The vertical lines in the MCD spectra depict the experimental error of the measurement. The presence of a difference in the helicity dependent XAS spectra immediately indicates that, contrary to previous assertions, the Cr possesses a net magnetic moment.[31] It must be stressed that this MCD signal represents the average response of all Cr atoms, but it clearly indicates that some net alignment of the Cr atoms occurs. (If the Cr were all antiferromagnetic, no MCD signal would be observed.) From an inspection of the relative strength of the absorption for the helicity dependent spectra in comparison to the Co spectra, it is also clear that the Cr moment is antialigned to the average Co moment. For the Co spectra, the negative helicity light is more strongly absorbing than the positive helicity light at the L_3 edge, whereas for the Cr the converse is true. Similar spectra and peak values are obtained for both the Co and Cr edges of the $Co_{86}Cr_{12}Pt_2$ films but are not shown due to space constraints.

By comparing the Cr MCD intensity for the $Co_{86}Cr_{12}Ta_2$ sample to the Cr MCD intensity for a 0.25 monolayer of Cr deposited on bcc Fe(001),[21] we can extract an average moment of $0.06 \pm 0.02 \mu_B$ for each Cr atom of the alloy. It must be remembered that this represents the average moment of the Cr in a likely scenario where the Cr is inhomogeneous both compositionally and magnetically. In the case that the Cr is present in only two magnetic phases, one with no overall net Cr moment, and one magnetically antialigned with the Co with a Cr atomic moment of $0.6 \mu_B$ per Cr atom, the extracted average moment of $0.06 \mu_B$ means that only 10% of the Cr is in this uncompensated, magnetically active state. Although this measurement cannot identify the location of these magnetic Cr atoms, it is possible that these magnetic Cr atoms are the small percentage of Cr in the Co-enriched regions of CoCr-based films as suggested in previous studies.[10–12,32] This would then mean that the Cr-enriched regions of the film are indeed nonferromagnetic. However, our results do not preclude the possibility that the Cr MCD signal is due, in part, to the Cr atoms in the Cr-enriched regions of the film.

In summary, we have shown that a significant fraction (at least 10%) of the Cr atoms in the $Co_{86}Cr_{12}Ta_2$ and $Co_{86}Cr_{12}Pt_2$ films have a net magnetic orientation antialigned to the ferromagnetic Co direction. A more thorough understanding of this behavior of the Cr magnetic moment and its inhomogeneous distribution in the alloy may improve our understanding and ability to predict the unique and technologically important properties of these promising systems.

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