Element Specific Magnetic Hysteresis of Gd and Co in Gd_xCo_{1-x} Ferrimagnetic Amorphous Alloys

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Introduction

Rare- earth – transition-metal (RE-TM) alloys are widely used in permanent magnets and magneto optical recording. The alloys combine the strong coupling of itinerant magnetism of the TM and the anisotropic and localized magnetic properties of the RE. The interaction of the localized and itinerant magnetism is not completely understood. Gd and Co form ferrimagnetic alloys in which the magnetic moments of neighbouring Gd and Co ions tend to be aligned antiparallel to each other. The moments are of different magnitudes so there is a net magnetization which depends upon temperature and composition. At the compensation temperature, $T_{comp,}$ the net magnetization is zero. We are interested in studying the magnetic coupling between the Gd and Co sublattices in amorphous alloys in which the composition has been adjusted to produce a T_{comp} close to room temperature. In our initial studies we have used X-ray magnetic circular dichroism.

XMCD measures the difference in the absorption coefficient ($\mu_{\uparrow\uparrow} - \mu_{\uparrow\downarrow}$) where the helicity of the incident x-ray beam is parallel ($\mu_{\uparrow\uparrow}$) and antiparallel ($\mu_{\uparrow\downarrow}$) to the net magnetization of the x-ray absorbing atom. The dichroic effect is large at L_3-edges. This has been used to advantage in the measurement of element specific magnetic hysteresis (ESHM) in which the height of the white line in the absorption coefficient has been recorded as a function of applied magnetic field [1]. At the Gd L_3-edge in ternary Gd-Ni-Co amorphous alloys the normalized signal $(\mu_{\uparrow\uparrow} - \mu_{\uparrow\downarrow})/ (\mu_{\uparrow\uparrow} + \mu_{\uparrow\downarrow})$ is ~ 7% at 10 K [2]. It decreases to zero as the compensation temperature is approached from below and switches sign above $T_{comp.}$ [2]. In our Gd_xCo_{1-x} alloys the compensation temperature was selected to be close to room temperature. Consequently the normalized XMCD signal at room temperature is small, the order of 1 % at the Gd L_3-edge and an order of magnitude smaller at the Co K-edge.

In this report we present XMCD and ESMH measurements at the Gd L_3- and Co K-edges for two amorphous Gd_xCo_{1-x} alloys (x= 0.227, 0.217). The results of Co K-edge ESMH are also compared to the hysteresis loops acquired by the surface magneto-optic Kerr effect, SMOKE.

Methods and Materials

XMCD measurements were made using the PNC-CAT undulator beamline, ID-20 [3]. The Si(111) double-crystal monochromator was detuned to 70% of the maximum intensity at the Gd L_3- and Co K-edges to reduce harmonic contributions. A diamond (111) wave plate [4] was used in Bragg transmission mode to convert the linearly polarized x-rays from the undulator into a circularly polarized beam with fraction of circular polarization ~ 0.99. The samples were positioned at the center of an electromagnet and the sample and magnetic field were oriented at 15° with respect to the incident beam. The magnetic field inversion method was used for acquiring the spectra in a fluorescence mode. Fluorescence data were obtained using an argon-filled ionization chamber [5] and helium-filled transmission chambers were used for normalization and acquiring reference spectra.

Films of Gd_xCo_{1-x} (x=0.227 and 0.217) amorphous alloys were grown by Ar sputtering onto a GaAs (001) single crystal substrate. The films were 250Å thick and were capped with a passivating film of Al_2O_3. The compensation temperature of the alloy with x= 0.217 was measured to be 260 K and, was estimated to be 320 K when x = 0.227.

Results and Discussion

The results of XMCD measurements at room temperature are shown in Fig.1. The dichroic signal, plotted as a percentage, is defined by:

$$I_c = \frac{I_{\uparrow\uparrow} - I_{\uparrow\downarrow}}{I_{\uparrow\uparrow} + I_{\uparrow\downarrow}} \qquad (1)$$

where $I_{\uparrow\uparrow}(I_{\uparrow\downarrow})$ corresponds to the parallel (antiparallel) projection of the helicity of the incident photon on the net magnetic moment of the absorbing element. In $Gd_{0.227}Co_{0.773}$ the percentage of Gd is such that at room temperature the net magnetization is determined by the Gd sublattice and T_{comp} is greater than room temperature.

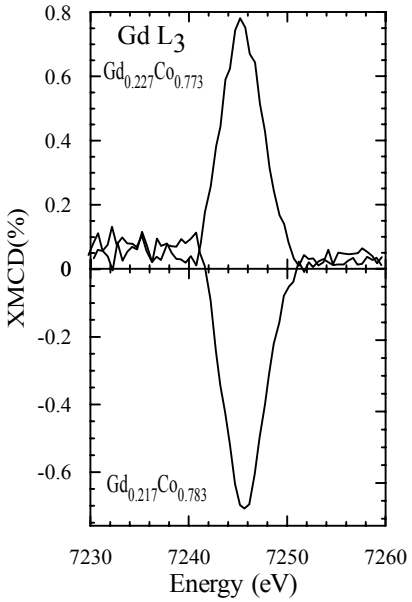

Fig.1: XMCD signal at the Gd L_3-edge in $Gd_{0.227}Co_{0.773}$ and $Gd_{0.217}Co_{0.783}$ alloys at 300 K.

The dichroic signal is positive at the Gd L_3 edge (Fig. 1, upper panel) and reversed at the Co K-edge (Fig.2). In $Gd_{0.217}Co_{0.783}$ the percentage of Gd is smaller, the net magnetization is determined by the Co at room temperature and the sign of the dichroic signal at the Gd L_3 edge is negative, Fig. 1 (lower panel).

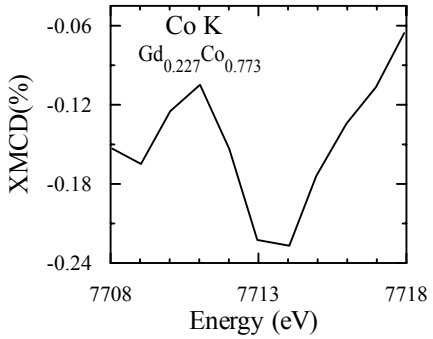

Fig.2: XMCD signal at the Co K-edge in $Gd_{0.227}Co_{0.773}$ alloy at 300 K.

In acquiring ESMH data, the x-ray energies were chosen to give a dichroic signal close to the maximum magnitudes measured at the Gd L_3- and Co K-edges. The intensity of the fluorescence as a function of the applied magnetic field is shown in Fig. 3. The intensity I has been plotted relative to its mean value and scaled to span the range -1 to +1, i.e. $[2I - (I_{\uparrow\uparrow} - I_{\uparrow\downarrow})]/(I_{\uparrow\uparrow} - I_{\uparrow\downarrow})$. For a given sample, the sense of the hysteresis loops for Gd and Co is reversed. This reversal is due to the antiferromagnetic coupling in the ferrimagnetic Gd_1Co_{1-x} alloys. Also because Gd and Co are exchange locked antiferromagnetically, the Gd and Co loops have the same coercivity (Fig. 3).

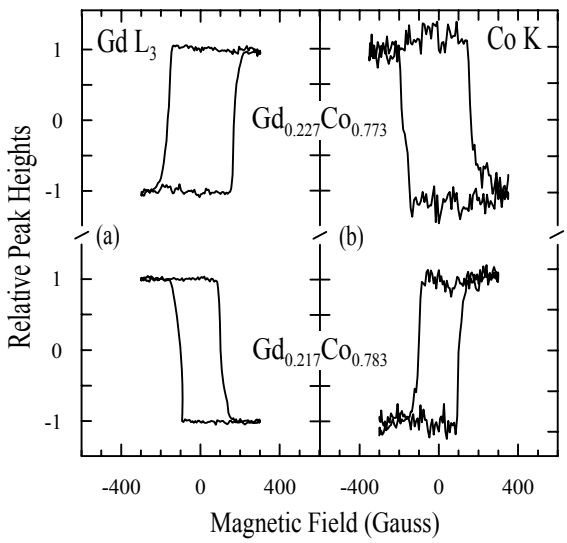

Fig.3: Element specific magnetic hysteresis at a) Gd L_3-edge b)Co K-edge in $Gd_{0.227}Co_{0.773}$ and $Gd_{0.217}Co_{0.783}$ alloys at 300 K.

Figure 4 shows the results of SMOKE measurements performed on Gd_xCo_{1-x} alloys with the same two compositions, x=0.227 and 0.217. The similarity to the Co K-edge ESMH is evident. The Kerr signal is optical, hence all the scattering is within about an eV of the Fermi energy, E_f. The spin-split bands in Gd are deep 4f states and have a very small density of states near E_f. Hence in the Kerr experiment we see only the Co even though the entire Co and Gd system responds to the applied magnetic field.

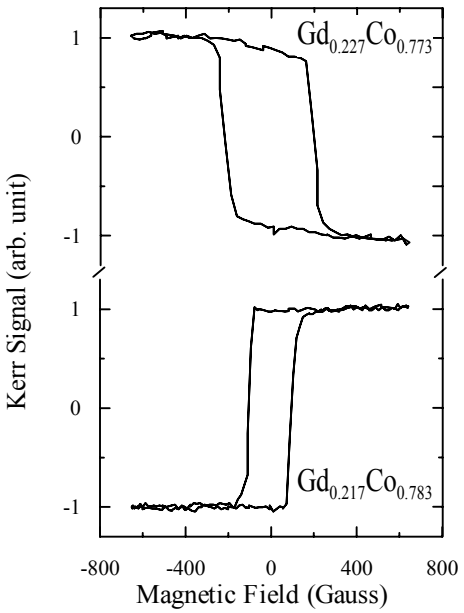

Fig.4: SMOKE measurement in $Gd_{0.227}Co_{0.773}$ and $Gd_{0.217}Co_{0.783}$alloys at 300 K.

Acknowledgements

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