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Magneto-optical measurement of anisotropy energy constants on amorphous rare-earth transition-metal alloys

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Measurements of the magneto-optic polar Kerr effect are performed on samples with perpendicular magnetization using in-plane magnetic fields. The magnetic anistropy constants are then determined from these measurements. The applied in-plane magnetic field varies from -20 to 20 kOe. Samples are mounted in a temperature-controlled chamber whose temperature is varied in the range of 80–475 K. In the theoretical model the anisotropy energy is expressed as the sum of terms containing $\sin^2\phi$ and $\sin^4\phi$ with two anisotropy constants, K_1 and K_2, to be determined. By matching the theoretical curves with the experimental data, we obtain two functions $\alpha(T)$ and $\beta(T)$, which are the normalized values of $K_1(T)$ and $K_2(T)$ with respect to the saturation magnetization $M_s(T)$.

I. INTRODUCTION

Understanding the temperature dependence of magnetic anisotropy in the media of magneto-optical data storage is important for their applications. Magnetic anisotropy in rare earth–transition metal (RE-TM) amorphous alloys has been the subject of many investigations in recent years.[1–6] There are very few published results concerning the temperature dependence of the anisotropy constants and we believe that the reason is the relative difficulty of measuring the temperature dependence by traditional torque magnetometry techniques. Measurements of the magneto-optic polar Kerr effect using in-plane external magnetic fields have been reported in the past and some preliminary results at room temperature were presented.[7] There was also an attempt to apply this technique at elevated temperatures, although the temperature dependence of the anisotropy constants were not found.[8] In this paper we present results of measurement of the magneto-optic polar Kerr effect on samples with perpendicular anisotropy using in-plane magnetic fields. The magnetic anisotropy constants at various temperatures are then determined from these measurements. In Sec. II we describe the measurement system. Normalized anisotropy constants are determined in Sec. III where we match the experimental results with those obtained from the theoretical model. Conclusions and general remarks are subjects of Sec. IV.

II. EXPERIMENTAL PROCEDURE

Figure 1 shows the experimental setup. The polarizer is used to get a stable polarized beam from the HeNe laser. The magnetic field from the electromagnet varies from -20 to 20 kOe and the electromagnet sits on a turntable allowing the field to be either perpendicular to or in the plane of the sample. Samples are mounted in a temperature-controlled chamber whose temperature is varied in the range of 80–475 K. The differential detection technique is used to measure the magneto-optic Kerr effect. The measurement procedure for anisotropy enegy constants is as follows. The sample is first saturated in a perpendicular magnetic field and the height of the hysteresis loop (θ_0) is obtained, as shown in Fig. 2(a). Then the magnet is rotated by 90° so that the field becomes parallel to the plane of the sample, as shown in Fig. 2(b). The Kerr rotation of the sample as a function of the in-plane field is measured for various temperatures. The samples reported in this paper were prepared by rf-diode sputtering from an FeCo alloy target decorated with terbium pellets.

III. CALCULATION OF ANISOTROPY CONSTANTS

In the theoretical model[7] the anisotropy energy is expressed as the sum of terms containing $\sin^2\phi$ and $\sin^4\phi$ with two anisotropy constants, K_1 and K_2. ϕ is the angle of deviation of the magnetization vector from the normal to the plane of the film. When the external field H is applied in the plane of the sample, the magnetization will assume a new orientation away from the normal axis. The new orientation angle ϕ_0 is determined by minimization of total energy. Energy is usually the sum of external field enegy, demagnetizing energy, and the anisotropy energy, all of which are functions of ϕ. The minimization gives a third-order polynomial equation in $\cos^2\phi_0$ and can be solved to yield $\cos\phi_0$ vs H curves, with two parameters α and β which are defined as follows:

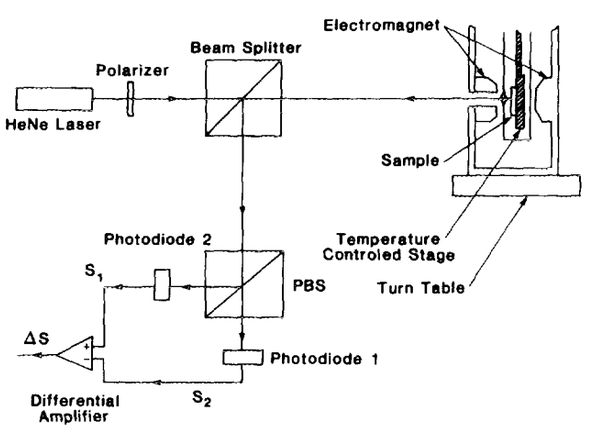

FIG. 1. Diagram of the measurement system.

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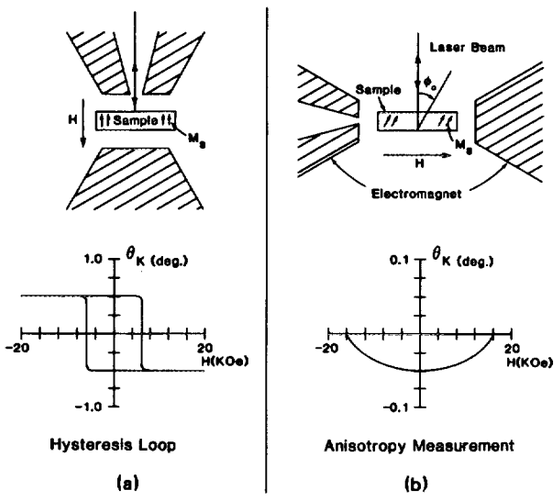

FIG. 2. Perpendicular (a) and in-plane (b) polar Kerr effect measurement.

$$\alpha = (K_1/M_s) - 2\pi M_s, \tag{1}$$

$$\beta = K_2/M_s. \tag{2}$$

Since the Kerr angle is proportional to the perpendicular component of magnetization, the normalized Kerr angle θ_k/θ_0 is equal to $\cos\phi_0$. By matching the measured curves of θ_k/θ_0 vs H with the theory, we determine the two parameters α and β. Figure 3 shows a typical measured curve of θ_k vs H (inset) and the result of matching to the theory with $\alpha = 3550$ and $\beta = 3250$, for a $Tb_{18.2}(Fe_{80}Co_{20})_{69.7}Ar_{12}$ sample at $T = 375$ K. In the matching process, β is first set to zero and the value of α is adjusted to match that part of the curve which corresponds to small values of H. Then β is adjusted to match the tails of the curve. Higher-order terms (i.e., $\sin^6\phi$,...) were not needed to match the experimental data. If measurements performed with larger magnetic field prove that higher-order terms are needed, then these terms would not affect the values for α and β found above since the influence of the higher-order terms on the curve is mainly on the tails.

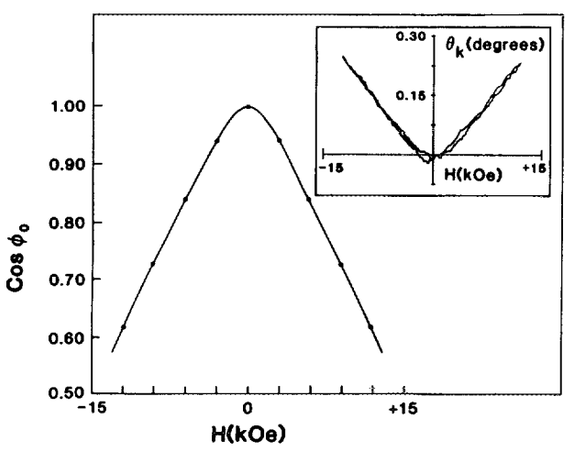

FIG. 3. Inset: Kerr rotation vs external in-plane field H for a $Tb_{18.2}(Fe_{80}Co_{20})_{69.7}Ar_{12}$ sample. The main figure is the matching of the theoretical curve with the normalized (θ_k/θ_0) experimental data with $\alpha = 3550$ and $\beta = 3250$.

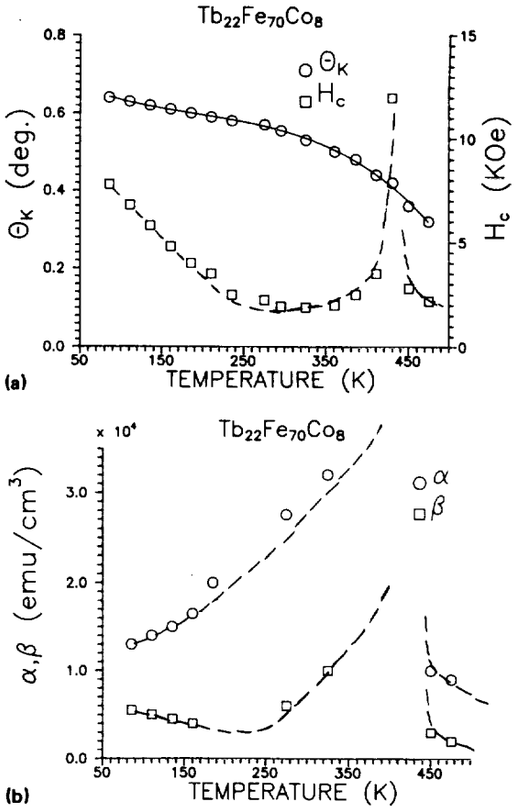

FIG. 4. (a) Kerr rotation (θ_k) and coercivity (H_c) vs temperature. (b) α and β vs temperature.

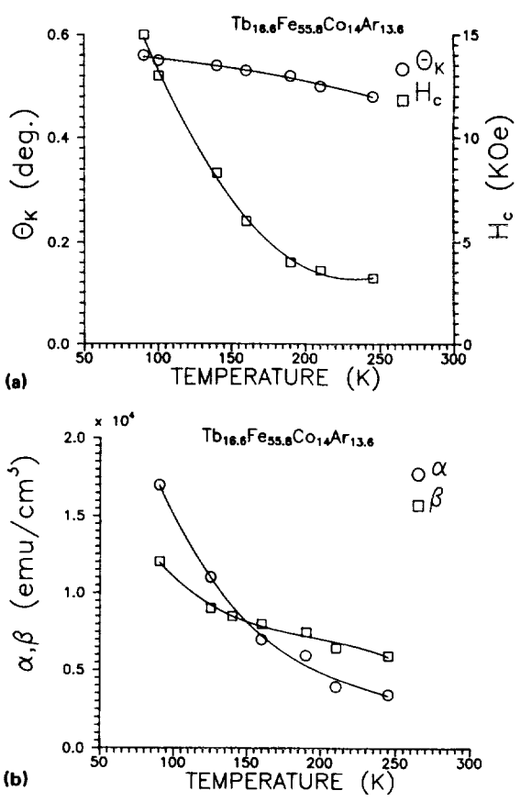

FIG. 5. (a) Kerr rotation (θ_k) and coercivity (H_c) vs temperature. (b) α and β vs temperature.

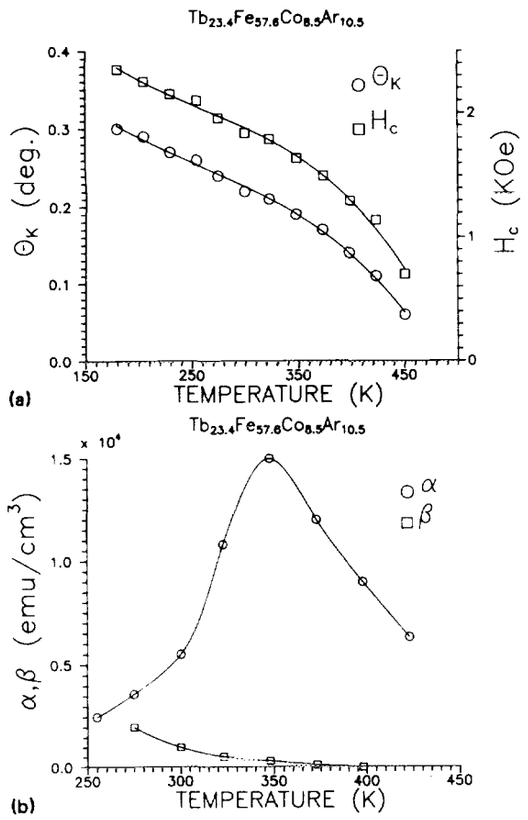

FIG. 6. (a) Kerr rotation (θ_k) and coercivity (H_c) vs temperature. (b) α and β vs temperature.

Figure 4(a) shows the Kerr rotation (θ_k) and the coercivity (H_c) versus temperature for a 100-nm TbFeCo sample with 100 nm of SiO_2 overcoat. The sample has a coercivity of 2.25 kOe at room temperature, a compensation temperature (T_{comp}) of 415 K, and a Curie temperature (T_C) of about 540 K. The values of α and β versus temperature are plotted in Fig. 4(b). Note the divergence of both α and β T_{comp} where M_s goes to zero. The values of $\alpha(T)$ for this sample were about a factor of 3 larger than those of $\beta(T)$. An approximate value of $M_s(T=300\ \text{K}) \simeq 125$ emu/cm^3 can be found from the mean-field theory,[9] which gives $K_1 \simeq 3.6 10^6$ erg/cm^3 and $K_2 \simeq 1.1\times 10^6$ erg/cm^3 at room temperature. The precise values of K_1 and K_2, however, must await the measurement of M_s with a vibrating sample magnetometer. A set of low-temperature measurements was carried out on a $Tb_{16.6}Fe_{55.8}Co_{14}Ar_{13.6}$ sample sandwichedf between two 40-nm AlN dielectric layers. From Fig. 5a, T_{comp} is estimated to be 85 K and T_C to be 530 K. Both α β diverge at the T_{comp} as shown in Fig. 5(b),

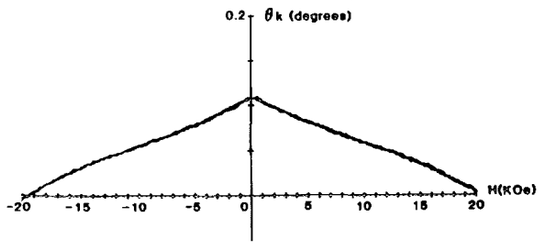

FIG. 7. In-plane measurement for a $Tb_{21}Fe_{70}Co_9$ that cannot be fitted with the model.

which, as explained before, is expected. At room temperature, β is about a factor of 2 larger than α; this, however, does not necessarily imply that K_2 is larger than K_1. From the mean field, $M_s(T=300\ \text{K}) \simeq 250$ emu/cm^3, which yields equal values for K_1 and K_2 both about 1.25×10^6 erg/cm^3. In Figs. 6(a) and 6(b), θ_k, H_c, α, and β are plotted versus temperature for a 90-nm-thick $Tb_{23.4}Fe_{57.6}Co_{8.5}Ar_{10.5}$ sample with a 400-nm protective coating of Al_2O_3. This sample has a coercivity of 1.9 kOe at room temperature and an estimated T_C of 500 K. The values of $\beta(T)$ decrease much faster than $\alpha(T)$; the latter peaks around 350 K. In the absence of the saturation magnetization data versus temperature, little can be said about the K_1 and K_2 dependencies on temperature. For this sample, K_1 was an order of magnitude larger than K_2 ($\simeq 1\times 10^6$ erg/cm^3) at room temperature given the mean-field estimate of $M_s \simeq 150$ emu/cm^3.

It is worthwhile mentioning that in certain cases the model could not be made to fit the experimental data as was the case, for example, for a $Tb_{21}Fe_{70}Co_9$ sample measured at room temperature, as shown in Fig. 7. This might be due to the occurence of random axis anisotropy caused by the rare-earth constituent. This occurence indicates the need for reliable models of anisotropy that can account for the local deviations of magnetization from the average direction due to a random local easy axis.

IV. CONCLUSIONS

Using the magneto-optical Kerr rotation effect, magnetic anisotropy constants were measured as a function of composition and temperature for rare-earth transition-metal alloy thin films. Given the magnetization from the mean field, room-temperature values of K_1 varied between 1 and 3.6 (10^6 erg/cm^3) while the values of K_2 varied within 0.15–1.25 (10^6 erg/cm^3) for the samples measured. Both α and β diverged at the T_{comp} and tend to decrease as a function of temperature. From the good matching of the theoretical curves with the experimental data, it was found that higher-order terms of anisotropy were not needed for the range of magnetic fields used in our experiment. However, a model including the random axis ansitropy (which is believed to be a characteristic of these alloys) might have to be considered if certain experimental results are to be explained.

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[1] P. Chaudhari and D. C. Cronemeyer, AIP Conf. Proc. **29**, 113 (1976).
[2] T. Mizoguchi and G. S. Cargill III, J. Appl. Phys. **50**, 3570 (1979).
[3] Tu Chen and G. B. Charlan, J. Appl. Phys. **54**, 5103 (1983).
[4] R. B. van Dover, M. Hong, E. M. Gyorgy, J. F. Dillon, Jr., and S. D. Albiston, J. Appl. Phys. **57**, 3897 (1985).
[5] P. Hansen and M. Hartmann, J. Appl. Phys. **59**, 859 (1986).
[6] Y. Suzuki, S. Takayama, F. Kirino, and N. Ohta, IEEE Trans. Magn. **MAG-23**, 2275 (1987).
[7] P. Wolniansky, S. Chase, R. Rosenvold, M. Ruane, and M. Mansuripur, J. Appl. Phys. **60**, 346 (1986).
[8] R. Uber and M. Mansuripur, IEEE Trans. Magn. **24**, 2461 (1988).