Measurement of the magnetic anisotropy energy constants for magneto-optical recording media

R.A. Hajjar, T.H. Wu, H. Fu and M. Mansuripur
Optical Sciences Center, University of Arizona, Tucson, AZ 85721

ABSTRACT

Measurement of the magneto-optical polar Kerr effect is performed on rare earth-transition metal (RE-TM) amorphous films using in-plane fields. From this measurement and the measurement of the saturation magnetization using a vibrating sample magnetometer (VSM), the magnetic anisotropy constants are determined. In this paper, we present the temperature dependence of the magnetic anisotropy in the range of -175°C to 175°C. The results show a dip in the anisotropy near magnetic compensation. This anomaly is explained based on the finite exchange coupling between the rare earth and transition metal subnetworks.

1. INTRODUCTION

Understanding the temperature dependence of magnetic anisotropy in the media of magneto-optical (MO) data storage is important for their applications. Measurements of the magneto-optical polar Kerr effect using in-plane external magnetic fields have been reported in several publications1-3. We have also reported recently, that the extraordinary Hall effect can be used to determine the magnetic anisotropy4. Due to the spin-orbit coupling, the perpendicular component of the magnetization of the transition metal subnetwork is proportional to the polar Kerr and Hall signals. Therefore, by proper normalization, the direction of magnetization θ with respect to the film normal can be obtained as function of the magnitude and direction α of the applied field H. Knowing θ, α, H and the saturation magnetization of the film $M_s$, which is determined separately using a VSM, the uniaxial anisotropy energy $E_{anis}(\theta)$ can be calculated. We determine the anisotropy energy constants by matching $E_{anis}(\theta)$ with an expression of the form $K_1 \sin^2(\theta) + K_2 \sin^4(\theta) + \ldots$. In this paper, we will present the temperature dependent anisotropy of TbFeCo films using the polar Kerr effect with perpendicular and in-plane applied magnetic fields. The films are of different terbium content ranging from 22.5% to 28%. The films were sputtered onto quartz substrates and consist of a quadrilayer structure of AlCr with MO layer sandwiched between two dielectric SiN layers. The magnetic anisotropy shows a dip near the magnetic compensation. We will discuss this anomaly based on the finite exchange coupling between rare earth (RE) and transition metal (TM) subnetworks.

2. TEMPERATURE DEPENDENT MAGNETIC PROPERTIES

Figure 1(a) displays the temperature dependence of $M_s$ for the six films studied. Figure 1(b) displays the compensation temperature ($T_{comp}$) and the room temperature $M_s$ versus terbium atomic percent ($T_{comp} = 25^\circ C$ when the terbium content is near 25%). Figure 2(a) displays the coercivity $H_c$ as a function of temperature for these samples. $H_c$ is obtained from the hysteresis loops measured using the polar Kerr effect. As expected, the coercivity diverges at $T_{comp}$ which is a characteristic of ferrimagnetic materials. The room temperature $H_c$ is shown in Fig. 2(b) as a function of the terbium content.

Figure 3(a) shows the magnetic anisotropy constant $K_1$ for these films as a function of temperature. The experimental set-up which uses the polar Kerr effect to determine $K_1$ and $K_2$ has been described in reference [2]. Since the maximum θ in the measurement was usually less than 15°, there was a large spread of about 50% in the fitted $K_2$ values. Figure 3(a) shows a dip in $K_1$ near the $T_{comp}$ for the samples measured. This dip is clearly shown in the plot of Fig. 3(b) for $K_1$ and $K_1 + K_2$ at room temperature versus terbium atomic percent. The sample with 25% terbium could not be measured at room temperature since it requires infinite fields to tilt the magnetization. This point is represented by a question mark in Fig. 3(b). It is important to note that direct measurements of the anisotropy constants using a torque magnetometer show a similar rapid drop.
Fig. 1(a) Saturation magnetization $M_s$ versus temperature for six TbFeCo samples.

Fig. 1(b) Saturation magnetization $M_s$ and compensation temperature $T_{comp}$ at room temperature plotted as a function of terbium atomic percent.
Fig. 2(a) Coercivity $H_c$ versus temperature for six TbFeCo samples.

Fig. 2(b) Coercivity $H_c$ at room temperature plotted as a function of terbium atomic percent.
Fig. 3(a) Magnetic anisotropy constant $K_1$ versus temperature for six TbFeCo samples.

Fig. 3(b) Magnetic anisotropy constants $K_1$ and $K_1 + K_2$ at room temperature plotted as a function of terbium atomic percent.
near $T_{\text{comp}}$ as well. This anomaly is independent of the preparation or measurement technique and has been previously observed in similar samples\textsuperscript{6-9}. The drop of anisotropy constant near compensation is quite unexpected, because compensation is simply a cancellation of the two subnetwork magnetizations and should have no effect on the anisotropy. Next, we discuss a mechanism that may explain this anomaly.

2.3 The Canting Model for the Anomaly

Sarkis and Calle\textsuperscript{10} pointed out that the exchange coupling between RE and TM subnetworks in RE-TM ferrimagnets is not so large as to hold the RE and TM moments rigidly antiparallel. The external field used in measuring anisotropy can cause canting between the two sublattices. The amount of the canting is usually very small. For example, it is on the order of 1° when a 20kOe field is applied to a typical TbFe thin film. However, neglecting this small canting by assuming infinite exchange between the two subnetworks in the total magnetic energy of the system and using this model to match the measured data, the $K_i$ found could be much smaller than the physical anisotropy constant near compensation and would be zero at the exact compensation. Only in regimes far away from the compensation, the fitted anisotropy approaches the physical anisotropy constant of the measured material. This problem has also been studied recently by Hellman\textsuperscript{11}.

In torque measurement, the reason why a small canting can cause a large discrepancy in the anisotropy constant can be easily understood in the following example. Consider the direction of the net magnetization $M_N$ of the two sublattices of a RE-TM thin film under the influence of an in-plane applied field (Fig. 4). Usually, the tilted angle $\theta_N$ of the net magnetization from the normal direction is directly related to the anisotropy constant: small $\theta_N$ implies large $K_1$ and large $\theta_N$ indicates small $K_1$. However, when there is a canting between the sublattice magnetizations near compensation, $\theta_N$ can be very large even if the two sublattice magnetization are slightly tilted from the normal direction, see Fig. 4(a). Obviously, this large $\theta_N$ is not a result of small $K_1$ (and $K_2$), but a result of canting near the compensation. Far away from the compensation, the net magnetization will not tilt too much away from the major sublattice magnetization if the canting is small, see Fig. 4(b).

However, in the case of Kerr effect measurement, we only monitor the TM subnetwork magnetization direction $\theta_{TM}$. The effect of the canting on the measured anisotropy constant becomes complicated. In fact, the fitted anisotropy based on infinite exchange can be smaller or larger than the physical anisotropy constant of the material, depending on the applied field direction $\alpha$, which is 90° in our case. Without going into a detailed theoretical treatment\textsuperscript{12}, it can be shown that if we assume a physical anisotropy constant of $5 \times 10^6$ erg/cc which is independent of $M$, and take into account a finite exchange interaction between the RE and TM subnetworks\textsuperscript{11}, we can reproduce the measured $\theta_{TM}$. Now, if we use the $\theta_{TM}$ found by the canting model and calculate $K_1$ with the assumption that the RE and TM moments are infinitely coupled to each other, we obtain the plot of Fig. 5 showing a dip in $K_1$ (for the case of $M_{TM} > M_{RE}$). This finding suggests that the dip in the fitted anisotropy constants might be caused by an incomplete model that neglects the finite exchange between the sublattices. We will present in [12] a series of different measurements of $K_1$ and $K_2$ performed on a set of TbFeCo samples and discuss their differences based on the canting model.

3. ACKNOWLEDGMENTS

We wish to thank Dr. T. Suzuki of IBM Almaden Research Center for interesting discussions on this subject. We are also greatful to Dr. F. Sequeda and H. Notaris of IBM Almaden Research Center for providing the samples for this study. This work has been supported by the Optical Data Storage Center at the University of Arizona. One of us (R.A.H.) would like to acknowledge the support of a Komag Inc. fellowship.
Fig. 4 The sublattice magnetization directions $\theta_{TM}$ and $\theta_{RE}$ and the net magnetization direction $\theta_{N}$ near (a) and far (b) from compensation. $\delta$ is the canting between the two sublattice magnetizations. In the case of (a) and when the canting is not zero, $\theta_{N}$ can be very large even when $\theta_{TM}$ and $\theta_{RE}$ are small. In the case of (b), the canting does not make $\theta_{N}$ and $\theta_{TM}$ too much different.

Fig. 5 Calculation of $K_{1}$ versus saturation magnetization $M_s$ for a sample with a physical anisotropy constant of $5 \times 10^6$ erg/cc. The dip observed near magnetic compensation is a consequence of neglecting the finite exchange interaction between the two subnetworks.
4. REFERENCES
