Subnetwork Exchange Coupling Coefficient of (Dy,Tb)FeCo Magneto-Optical Recording Films

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Anisotropy dispersion of rare earth constituents, and canting between rare earth and transition metal subnetworks were used to explain the recording characteristics of (Dy,Tb)FeCo magneto-optical recording films. Through the quantitative measurements and mean field calculations of the exchange coupling coefficient $\lambda$, we have found that the higher $\lambda$ is, the higher required bias field will be during recording. Therefore, the recording characteristics of ferrimagnetic and sperimagnetic films can be determined and further improved through careful characterization of $\lambda$ of magneto-optical media.

INTRODUCTION

Amorphous TbFeCo alloys are being used as magneto-optical (MO) recording media, since they possess the high coercivity ($H_c$) and perpendicular anisotropy ($K_u$) required for high density recording [1]. However, a bias field ($H_b$) of typically more than 300 Oe for single layered TbFeCo media limits their applications in magnetic field modulation direct overwrite which is essential to achieve high data rate. Therefore, reducing the bias field [2] or developing alternative MO recording media recordable at a reasonably low bias field [3-5] is essential in magnetic field modulation direct overwrite.

Amorphous DyFeCo films have been found to possess higher sensitivity in switching field and write power than that of TbFeCo films for MO recording [3-5]. Recording characteristics of (Dy,Tb)FeCo films were analyzed by mean field modeling and have been found to be dependent on domain wall mobility ($\mu_D$) which correlates with the anisotropy dispersion of rare earth (RE) constituents [5]. Canting between RE and transition metal (TM) subnetworks was used to explain the ferrimagnetic and sperimagnetic characteristics, owing to the finite value of exchange coupling coefficient ($\lambda$) [6-8]. The quantitative measurements and mean field calculations of $\lambda$ obtained in this work suggest that the anisotropy dispersion of RE constituents and exchange coupling between RE and TM subnetworks affect recording characteristics of ferrimagnetic and sperimagnetic MO films. Therefore, the MO recording performances can be determined and further improved through careful characterization of $\lambda$ of MO media.

EXPERIMENTAL

All the disks and samples of (Dy,Tb)$_x$(Fe$_{0.8}$Co$_{0.2}$)$_{100-x}$ films, with $18 \leq x \leq 28$ and $70 \leq y \leq 90$, and a thickness of 100 nm, were deposited on 5.25" polycarbonate substrates and 1" glass coupons, respectively, to study their recording and magnetic characteristics. The MO active layer was DC magnetron co-sputtered, and its composition was determined by inductively coupled plasma — atomic emission spectrometry (ICP-AES). Two silicon nitride layers were deposited to protect the MO active layer by RF magnetron reactive sputtering from a Si target in Ar and N$_2$ gases. The saturation magnetization $M_s(T)$ of the samples were measured by a vibrating sample magnetometer. Temperature dependence of $H_c$, anisotropy field ($H_{ak}$), and Kerr angle ($\theta_K$), used to derive compensation temperature ($T_{comp}$) and Curie temperature ($T_C$), were measured by a Kerr loop tracer. CNR and jitter were measured by a tester which is light intensity modulation with $\lambda = 785$ nm and an objective lens of NA = 0.55, at a linear velocity of 10 m/s, a write frequency of 3.7 MHz, write and erase powers of 10 mW, an erase field of 300 Oe, and a mark length of 1.35 $\mu$m.

The exchange coupling coefficient $\lambda$ of (Dy,Tb)FeCo films can be derived experimentally from the plot of the in-plane magnetization ($M_I$) vs magnetic field ($H$) applied in the film plane, i.e., $\lambda = H/M_I$, for samples at their $T_{comp}$ [7]. For the sake of simplicity, a series of (Dy,Tb)FeCo samples at compensation composition were chosen to derive $\lambda$ at room temperature ($R.T.$). The samples were saturated, in advance, in the film normal direction at a temperature different from $T_{comp}$. $M(I/H)$ of MO active layer was obtained after subtracting the substrate's component when the magnetic field was varied from 0 to 13 K Oe in the film plane. Then, the measured $\lambda$ is the 1/slope of $M(I/H)$ of MO active layer.

RESULTS AND DISCUSSION

The magnetic properties of ferrimagnetic and sperimagnetic films are governed by the exchange interaction of coupled subnetworks. To determine the
Hwang, W-K. et al. SUBNETWORK EXCHANGE COUPLING COEFFICIENT OF (Dy,Tb)FeCo MAGNETO-OPTICAL RECORDING FILMS

Fig. 1. Definition of exchange coupling coefficient $\lambda$ of sperimagnetic materials.

finite exchange coupling between RE and TM subnetworks as shown in Fig. 1, the total energy of a thin film sample under an applied field $H$ is given

$$E_{\text{total}} = -H \cdot M_{\text{RE}} - H \cdot M_{\text{TM}} + \lambda M_{\text{RE}} \cdot M_{\text{TM}} + K_{\text{RE}} \sin^2 \theta_{\text{RE}} + K_{\text{TM}} \sin^2 \theta_{\text{TM}} + 2\pi (M_{\text{RE}} \cos \theta_{\text{RE}} - M_{\text{TM}} \cos \theta_{\text{TM}})^2,$$

where $M_{\text{RE}}$ and $M_{\text{TM}}$, $K_{\text{RE}}$ and $K_{\text{TM}}$, and $\theta_{\text{RE}}$ and $\theta_{\text{TM}}$ are the respective magnetization, anisotropy energy constant, and magnetization orientation from the film normal of RE and TM subnetworks, respectively; and $\lambda M_{\text{RE}} \cdot M_{\text{TM}}$ is the exchange coupling energy. To characterize the magnetic properties of (Dy,Tb)FeCo films, $\lambda$ can be derived from the calculation of the exchange coupling energy between RE and TM subnetwork magnetization, and is given by $\lambda = 2Z |\theta_{\text{RE-TM}}| \cos \langle \phi_{\text{RE}} \rangle / N g_{\text{RE}} g_{\text{TM}} \mu_B^2$ [5-6].

All the parameters listed in TABLE I, whose definitions are the same as those in [5,9], could be obtained through the fitting of our magnetic data by the generalized mean field analysis. The respective slopes $(m)$ of compositional dependence of $T_{\text{comp}}$ and $T_c$ vs RE content for Dy$_x$(Fe$_{77}$Co$_{13}$)$_{100-x}$ and Tb$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$ are $(m_{T_{\text{comp}}})_{\text{Dy}} = 33 \text{ K/at.} \%$, $(m_{T_{\text{comp}}})_{\text{Tb}} = 46 \text{ K/at.} \%$, and $(m_{T_c})_{\text{Tb}} = 4 \text{ K/at.} \%$, respectively. Therefore, the calculated $\lambda$ is 571 and 1115 for Dy$_24$(Fe$_{77}$Co$_{13}$)$_{76}$ and Tb$_{23}$(Fe$_{90}$Co$_{10}$)$_{77}$ films, respectively. It is obvious that $\lambda$ is mainly determined by the RE-TM exchange integral $\theta_{\text{RE-TM}}$ and anisotropy dispersion $\cos \langle \phi_{\text{RE}} \rangle$ which are constituent dependent.

Magnetic and MO properties of RE-TM films such as $M_s(T)$, $H_c(T)$, and $\theta_{\text{c}}(T)$ in the recording temperature range are dependent on $T_c$ and $T_{\text{comp}}$ [1]. Thus, Tb$_{23}$(Fe$_{90}$Co$_{10}$)$_{77}$ and Dy$_{24}$(Fe$_{77}$Co$_{13}$)$_{76}$ films of $T_c \approx 220$ °C and $T_{\text{comp}} = R.T.$ were used to determine the constituent dependence of $\lambda$. As shown in Fig. 2, the measured $\lambda$ is 557 and 1110 for DyFeCo and TbFeCo, respectively; and they are very close to those derived by mean field modeling. It denotes that, through mean field analysis, anisotropy dispersion of RE constituents by canting model can be used to explain the sperimagnetic characteristics of (Dy,Tb)FeCo films, quantitatively. Therefore, from the measured $\lambda$ and mean-field model derived $\theta_{\text{RE-TM}}$, we found $\theta_{\text{DY-TM}} < \theta_{\text{Tb-TM}}$, implying that the interaction of Dy-TM moments is less than that of Tb-TM moments; and $\langle \phi_{\text{RE}} \rangle_{\text{Dy}} > \langle \phi_{\text{RE}} \rangle_{\text{Tb}}$, indicating that DyFeCo films are more anisotropically dispersive than that of TbFeCo films. It has been reported that $\mu_B \theta_{\text{c}}(T)$, governed by the exchange interaction between RE and TM moments and anisotropy dispersion of RE constituents, also affects the recording characteristics of (Dy,Tb)FeCo films [5]. Thus, through the quantitative measurements and mean field calculations of $\lambda$, exchange coupling coefficient could be correlated with the recording characteristics of ferrimagnetic and sperimagnetic films.

From the viewpoint of MO recording, switching $H_b$ at several MHz is still an issue in magnetic field modulation direct overwrite to achieve high density recording and data rate, simultaneously. However, to

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**TABLE I. PARAMETERS USED TO DERIVE EXCHANGE COUPLING COEFFICIENT $\lambda$ OF SPERIMAGNETIC FILMS [5-6].**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dy</th>
<th>TM</th>
<th>Tb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$</td>
<td>1.33</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>$\langle \phi_{\text{RE}} \rangle$</td>
<td>50°</td>
<td>0°</td>
<td>35°</td>
</tr>
<tr>
<td>$\theta_{\text{RE-TM}}$ (erg)</td>
<td>0.55 x 10^{-15}</td>
<td>0.95 x 10^{-15}</td>
<td></td>
</tr>
<tr>
<td>$Z$</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N$ (atoms/cm$^3$)</td>
<td>6.5 x 10^{22}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu_B$ (emu)</td>
<td>9.27 x 10^{-21}</td>
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reduce \(H_b\) of MO media is feasible by carefully tailoring their magnetic properties. Constituent dependence of \(\lambda\) and \(H_b\) of \((\text{Dy,Tb})\text{FeCo}\) films with \(T_c \approx 220^\circ C\) and \(T_{\text{comp}} = R.T.\) are shown in Fig. 3. We found that the \(\lambda\) of TbFeCo films is twice of that of DyFeCo films, and \(H_b\) of 160 Oe for TbFeCo films is higher than that of 70 Oe for DyFeCo films. Moreover, \(\lambda\) and \(H_b\) increase inversely with Dy at \% in \((\text{Dy,Tb})\text{FeCo}\) films. It implies that \(\lambda\) is mainly determined by the RE constituents; and the higher \(\lambda\) is, the higher \(H_b\) is required during recording. Therefore, DyFeCo films seem to be superior to TbFeCo films for used as MO media in magnetic field modulation direct overwrite, when both films have about the same \(T_c\) and \(T_{\text{comp}}\).

Recording characteristics of MO films depend on \(T_c\) and \(T_{\text{comp}}\) because \(Hc(T)\) and \(M_s(T)\) are dependent on \(T_c\) and \(T_{\text{comp}}\). Compositional dependence of \(\lambda\) of DyFeCo films with \(T_{\text{comp}} = R.T.\), but different \(T_c\) is shown in Fig. 4. We found that \(\lambda\) increases slightly with increased \(T_c\) which is proportional to Co at \% of the sample, implying that the strong Co-Co exchange interaction would only promote the RE-TM interaction slightly. Also, \(H_b\) is mainly determined by \(\lambda\). Nevertheless, \(H_b\) increases slightly with \(T_c\) when Co\% in TM content is over of 20 \%

It has been reported that compositional dependence of \(H_b\) is also governed by the maximum demagnetizing field during thermal-magnetic recording \([4,10]\). The demagnetizing field \(H_d(T)\) is proportional to \(M_s(T)\) which increases with \(T_c\), when \(T_{\text{comp}} = R.T.\). Then, the higher \(T_c\) is, the higher \(H_d(T)\) will be during recording; and \(H_b\) increases slightly with \(T_c\). Thus, from the above discussions, we have found \(H_b\) is mainly determined by \(\lambda\), and secondarily by the \(H_d(T)\) during recording. Through the quantitative measurements and mean field calculations of \(\lambda\) and \(M_s(T)\), the differences in MO recording characteristics of ferrimagnetic and sperimagnetic films can be determined.

**CONCLUSION**

Amorphous \((\text{Dy,Tb})_x(\text{Fe}_{1-x})\text{Co}_{100-x}\) films, with \(18 \leq x \leq 28\) and \(70 \leq y \leq 90\), were fabricated to study their magnetic and recording characteristics which were also analyzed by mean field modeling. Anisotropy dispersion of RE constituents by canting model was used to explain the exchange coupling between RE and TM subnetworks. Through the quantitative measurements and mean field calculations of \(\lambda\), it is found that the anisotropy dispersion of RE constituents and exchange coupling between RE and TM subnetworks strongly affect the recording characteristics of ferrimagnetic and sperimagnetic MO films. It is also found that \(\lambda\) is mainly determined by the RE constituents; and the higher \(\lambda\) is, the higher \(H_b\) will be required during the recording of \((\text{Dy,Tb})\text{FeCo}\) films. Therefore, the recording characteristics of ferrimagnetic and sperimagnetic films can be determined and further improved through careful characterization of \(\lambda\) of MO media.

**REFERENCES**