Magneto-Optical Recording Characteristics of (Dy,Tb)FeCo Films

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Abstract — **Recording characteristics of (Dy,Tb)FeCo disks were studied. *'Anisotropy dispersion'* of rare earth constituents such as Gd, Tb, and Dy qualitatively accounts for domain wall mobility and domain size. Results, obtained in this study, indicated that both coercivity and domain wall mobility play critical role in the magneto-optical recording.**

INTRODUCTION

Amorphous TbFeCo alloys are being used as magneto-optical (MO) materials, since they possess the high coercivity (*Hc*) and perpendicular anisotropy (K_u) required for high density recording [1]. However, a bias field (*Hb*) of, typically, more than 300 Oe for TbFeCo recording media limits their capability in field modulation direct overwrite. Therefore, reducing the bias field or developing alternative MO recording media recordable at a reasonably low bias field is essential in field modulation direct overwrite.

Amorphous DyFeCo films have been found to possess a high perpendicular anisotropy. They require a low bias field and write power for successful recording. Therefore DyFeCo films are promising as MO recording media [2]. In this work, we study thermomagnetic recording on DyFeCo films at low bias magnetic field. Domain size, critical to the recording characteristics, is strongly governed by coercivity, domain wall mobility (μ_{eff}), and velocity. Recording characteristics of (Dy,Tb)FeCo films obtained in this work suggest that *'anisotropy dispersion'* [3] of the rare earth (RE) constituents is responsible for domain wall mobility and domain size.

EXPERIMENTAL

All the disks and samples of amorphous $Dy_x(Fe_{87}Co_{13})_{1-x}$ and $Tb_x(Fe_{90}Co_{10})_{1-x}$ films in quadrilayer disk structure, with a range of $0.18 \le x \le 0.28$, were deposited on 5.25″ polycarbonate substrates and on 1″ glass coupons, respectively. Two silicon nitride layers were deposited by RF magnetron reactive sputtering from Si target in Ar and N_2 gases. Both MO and AlCr-reflector layers were DC magnetron co-sputtered. The MO layer composition was determined by ICP-AES. The saturation magnetization (M_s) was measured by a vibrating sample magnetometer. The temperature dependence of *Hc*, which was used to determine the compensation temperature (T_{comp}) and Curie temperature (*Tc*), were measured by a Kerr loop tracer. Recording characteristics such as CNR, jitter, and byte error rate (BER) were measured by a dynamic tester.

RESULTS

Recording characteristics depend on T_{comp} and *Tc* because *Hc*(*T*) and $M_s(T)$ in the recording temperature range are dependent on *Tc* and T_{comp}. Therefore, we studied the recording characteristics of DyFeCo and TbFeCo recording media having about the same T_{comp} and *Tc*. All disks were tested at a linear velocity of 10 m/s, a write frequency of 3.7 MHz, write and erase laser powers of 10 mW, an erase field of 300 Oe, and a mark length of 1.35 μm. CNR vs *Ha* for $Dy_{.235}(Fe_{87}Co_{13})_{.765}$ and $Tb_{.225}(Fe_{90}Co_{10})_{.775}$ is shown in Fig. 1. *Tc* of both films is 500 K. *Hb* of 80 Oe for the DyFeCo disk is markedly lower than that of 160 Oe for the TbFeCo disk. Next, two sets of DyFeCo and TbFeCo film disks, with RE content varying from 18 to 28 at.%, were fabricated. Compositional dependence of *Hb* for the (Dy,Tb)FeCo films is shown in Fig. 2. Both films, possessed the lowest

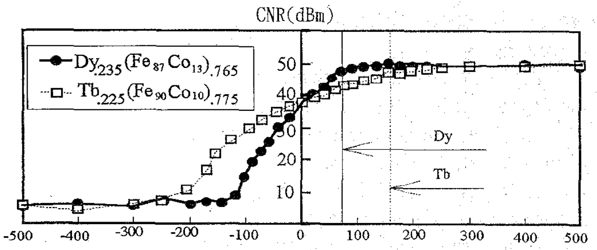

Fig. 1. Dependence of CNR on bias field for (Dy,Tb)FeCo films at compensation composition.

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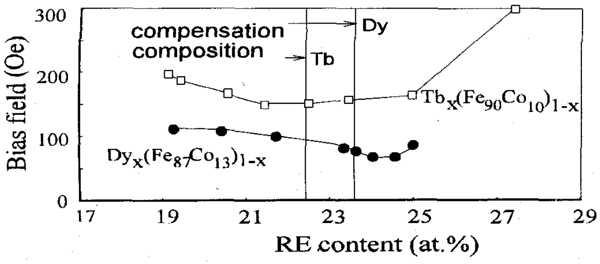

Fig.2. Compositional dependence of bias field for (Dy,Tb)FeCo films.

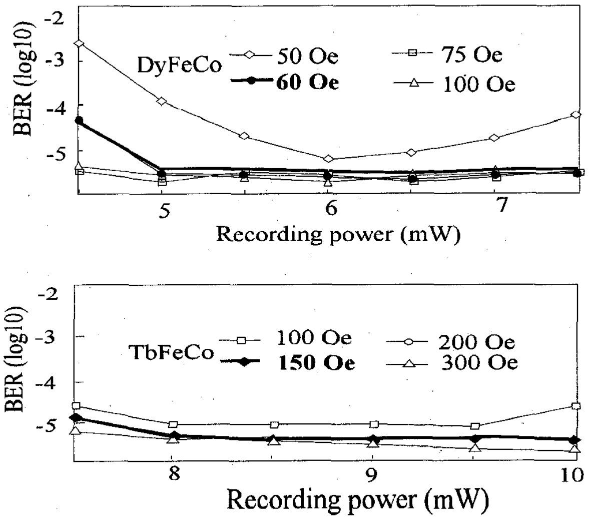

Fig. 3. BER of (Dy,Tb)FeCo films as functions of bias field and recording power.

Hb for MO recording, are near compensation composition. However, *Hb* for the DyFeCo films is approximately 1/3 ~ 1/2 that of the TbFeCo films.

BER for both (Dy,Tb)FeCo films at compensation composition are shown in Fig. 3 as functions of *Hb* and recording power (*Pw*) with the erase field equal to *Hb*. BER of less than 10^{-5} was reached at $Hb \geq 60$ Oe and $Pw \geq 5$ mW for the DyFeCo disks, and at $Hb \geq 150$ Oe and $Pw \geq 8$ mW for the TbFeCo disks. Therefore, the recording characteristics of the DyFeCo disks seem to be superior to those of the TbFeCo disks.

DISCUSSION

The recording characteristics of MO materials are governed by $\mu_{eff}(T)$, $Hc(T)$, and others. '*Anisotropy dispersion*' [3] of RE(Gd,Tb,Dy) constituents, shown in Fig. 4, is related to μ_{eff}. Domain size is used here to account for qualitatively the differences in the recording characteristics of the (Dy,Tb)FeCo films.

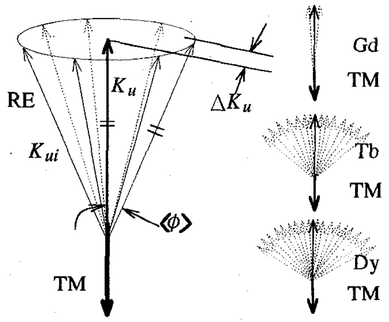

Fig. 4. *Anisotropy dispersion* of (Gd,Tb,Dy)-TM alloys.

TABLE I. PARAMETERS USED IN THE MEAN FIELD ANALYSIS. ONLY THE VALUES OF PARAMETERS DIFFERENT FROM THOSE VALUES IN [4] ARE LISTED.

	$\vartheta_{TM\text{-}TM}$(erg)	$\vartheta_{RE\text{-}TM}$(erg)	$\vartheta_{RE\text{-}RE}$(erg)	J_{TM}	α
Dy-TM	$\pm 10\times10^{-15}$	-0.60×10^{-15}	0.15×10^{-15}	1.02	0.15
Tb-TM	$\pm 9.5\times10^{-15}$	-0.95×10^{-15}	0.20×10^{-15}	1.02	0.15

When local anisotropy (K_{ui}) is negligible for S-state RE elements, *e.g.*, Gd, the magnetic structure is ferrimagnetic. With regards to the non S-state RE constituents, *e.g.*, Tb or Dy, K_{ui} is no longer negligible and sperimagnetic order could occur as a result of random anisotropy [3]. The RE moments orient at random within a cone of half-angle, defined as dispersion angle(ϕ_{Ku}) and whose axis is antiparallel to that of the TM moments. Therefore, an anisotropy drop (ΔK_u), defined as $\Delta K_u = K_{ui} - K_u$, occurs, where K_u is the macroscopic perpendicular anisotropy. The average angle ($\langle\phi\rangle$) of the distributed RE moments, to the easy axis, is defined as

$$\langle\phi\rangle = tan^{-1}(\Delta K_u/K_u) \qquad (1)$$

Therefore,

$$\cos\langle\phi\rangle = K_u/\sqrt{K_u{}^2 + \Delta K_u{}^2} \cong K_u/K_{ui} \qquad (2)$$

The generalized mean field model [4] is adopted here to calculate dispersion angles of RE-TM alloys. Except for material dependent parameters, this model can sufficiently account for magnetic characteristics with fixed parameters because it allows an antiferromagnetic subnetwork to exclude the compositional variation of exchange constants. Fe and Co subnetworks were treated as a TM cluster in our calculation for simplicity. All material dependent parameters, as listed in TABLE I, could be used to fit our magnetic data reasonably: the respective slopes (*m*) of compositional dependence of T_{comp} and *Tc* vs RE content for DyFeCo and TbFeCo are $(m_{Tcomp})_{Dy} \cong 35$ K/at.%, $(m_{Tc})_{Dy} \cong 7$ K/at.%, $(m_{Tcomp})_{Tb} \cong 46$ K/at.%, and $(m_{Tc})_{Tb} \cong 4$ K/at.%, respectively. In the

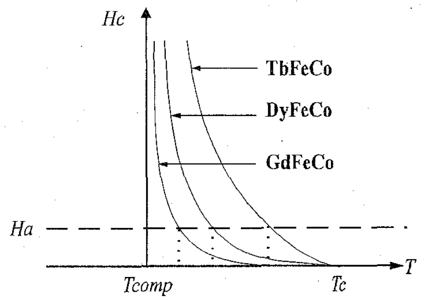

Fig. 5. Temperature dependence of *Hc* for (Gd,Tb,Dy)-FeCo films having about the same *Tc* and T_{comp}.

composition range considered here, about 8 μ_B and 8.2 μ_B effective moments, as derived from the mean field model, were given by per Dy and Tb atoms at 4 K, respectively. Consequently, ϕ_{Ku} can be derived from [3]:

$$\frac{effective\ \ moment/atom}{free\ \ ion\ \ moment/atom} = \frac{1}{2}\left[1 + cos\left(\phi_{K_u}\right)\right] \tag{3}$$

where $(\phi_{Ku})_{Dy} \cong 60°$ and $(\phi_{Ku})_{Tb} \cong 42°$. $(\phi_{Ku})_{Dy}$ is consistent with literature [3,5]. In contrast, $(\phi_{Ku})_{Gd} \cong 0°$ as Gd is an S-state element [3]. Therefore, $cos[\langle\phi_{Gd}\rangle] > cos[\langle\phi_{Tb}\rangle] > cos[\langle\phi_{Dy}\rangle]$. Microscopic exchange stiffness is reduced with $cos(\phi)_{Ku}$. The macroscopic exchange stiffness (A), which is related to exchange forces, is proportional to $cos\langle\phi\rangle$ [4]. For two sub-lattice ferrimagnetic RE-FeCo films, the damping parameter (α) of magnetic energy loss is related to spin-orbit interaction. Non S-state rare earths, such as Tb and Dy are expected to exhibit large damping. The mobility of domain wall is [6]

$$\mu_{eff} \propto \frac{1}{\alpha}\sqrt{A/K_u} \propto \frac{1}{\alpha}\sqrt{cos\langle\phi\rangle/K_u} \propto \frac{1}{\alpha}\sqrt{1/K_{ui}} \tag{4}$$

$$\text{As } (K_{ui})_{Gd} < (K_{ui})_{Dy} < (K_{ui})_{Tb} \text{ and } \alpha_{Gd} < \alpha_{Dy} \leq \alpha_{Tb}, \tag{5}$$

$$\text{consequently, } (\mu_{eff})_{Gd} > (\mu_{eff})_{Dy} > (\mu_{eff})_{Tb}. \tag{6}$$

Tc and T_{comp}, relative to the ambient temperature, influence the recording behavior prominently. *Hc*(*T*) of (Gd,Tb,Dy)FeCo films, having about the same *Tc* and T_{comp}, is shown in Fig. 5 in order to compare their respective recording characteristics. This comparison reveals that *Hc* of TbFeCo films is the largest among the three at any given temperature between *Tc* and T_{comp}. Neither a pure domain wall motion model nor a pure nucleation model can accurately describe the detailed domain formation. Nevertheless, magnetization reversal process was dominated by domain wall motion at high temperatures [7]. When the total force acting on the domain wall is larger than the coercive force during thermomagnetic writing, the domain may be formed with diameter (d) which is equal to

$$d = d_{initial} + 2\int \mu_{eff}(T)[Ha - Hc(T)]dt. \tag{7}$$

where $d_{initial}$ is the initial size of a domain. In other words, domain wall with high μ_{eff} and low *Hc* moves relatively easily. Thus, under the same writing conditions, $d_{Gd} >> d_{Dy} > d_{Tb}$. CNR is proportional to domain size when the duty cycle of mark length is no more than 50 % detected by a fixed aperture. Under the recording conditions mentioned previously, 1.35 μm mark was reached when CNR saturated. Therefore, DyFeCo films require a lower bias field to produce the same CNR value, as compared with those of TbFeCo films. Despite the fact that the domains in GdFeCo films can be recorded more easily than in DyFeCo films, the insufficient K_u of GdFeCo films limits their applications in high density recording.

CONCLUSION

Both amorphous $Dy_x(Fe_{87}Co_{13})_{1-x}$ and $Tb_x(Fe_{90}Co_{10})_{1-x}$ films, with a range of $0.18 \leq x \leq 0.28$, possess the lowest *Hb* near compensation composition. However, *Hb* for DyFeCo films is about 1/3 ~ 1/2 that of TbFeCo films for MO recording. At compensation composition, BER of less than 10^{-5} was reached at $Hb \geq 60$ Oe and $Pw \geq 5$ mW for DyFeCo disks, and at $Hb \geq 150$ Oe and $Pw \geq 8$ mW for TbFeCo disks. Therefore, the recording characteristics of DyFeCo disks seem to be superior to those of TbFeCo disks in field modulation direct overwrite.

Domain size is strongly governed by coercivity, domain wall mobility, and velocity. '*Anisotropy dispersion*' of the RE(Gd,Tb,Dy) constituents has been suggested to qualitatively account for domain wall mobility and domain size. Both coercivity and domain wall mobility play critical role in the recording characteristics of MO materials.

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