TEMPERATURE DEPENDENCE OF THE AMORPHOUS SmTbFeCo MAGNETO-OPTICAL FILMS

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Abstract - A mean-field theory is developed to research the temperature dependence of the amorphous SmTbFeCo thin films. It is shown that with available Sm substitution of Tb, the composition temperature T_{comp} decreases, Curie temperature T_c remains unchanged, Kerr angle becomes larger, the saturation magnetization M_s at room temperature increases. Therefore, LRE-HRE-TM amorphous films can be used as the high density magneto-optical media in a wide range of temperature. However, the Sm substitution of TM does not improve the magneto-optical performance.
KEYWORDS TEMPERATURE DEPENDENCE, MAGNETO-OPTICAL FILMS, MEAN-FIELD THEORY.

The heavy rare earth - transition metal (HRE-TM) amorphous alloys are now commercially used as magneto-optical (MO) media^[1-2]. Their MO Kerr angles are about 0.3° at wavelength region of 780 ~ 830nm, but decrease with decreasing wavelength. For high density MO recording, it is essential to develop materials which have a high MO performance at short wavelengths. The light rare earth (LRE) can exhibit a large MO Kerr angle in amorphous alloys with TM^[3-5]. However, the recording properties of these alloys are not suitable as MO media. To make a MO storage medium which takes advantage of these improved properties, it is necessary to incorporate the light rare earth into HRE-TM alloys. Until now it has not clear if the addition of LRE into HRE-TM alloys enhances MO performance^[8-9]. The present study is motivated by the desire to understand the magnetic and magneto-optical properties in pseudo-ternary alloy films of SmTbFeCo and the behavior of magnetization versus temperature.

MEAN-FIELD THEORY

The mean-field theory becomes cumbersome when ternary and quaternary samples are treated since the parameters are numerous and adjustment is rather arbitrary. As an alternative, we consider modeling quaternary alloys of RE-TM with three sub-networks. The first sub-network consists of HRE atoms $x_1=x_{\text{HRE}}$. The second sub-network consists of LRE atoms $x_2=x_{\text{LRE}}$. The third sub-network consists of TM atoms $x_3=x_{\text{TM}}$.

The localized mean-field theory is based on the Heisenberg Hamiltonian. The energy of interaction between atoms i and j with average angular momenta s_i and s_j is given by^[5-6]:

$$e_{ij} = -2J_{ij}s_i s_j \quad (1)$$

where s_i and s_j are the projections of angular momenta along the axis of the anisotropy and J_{ij} is the exchange interaction energy. The total exchange energy of i arising from interactions with its nearest neighbors in our triple-magnetic-subnetwork model is thus given by

$$E_i = -Z_i s_i \sum_{j=1}^3 x_j J_{ij} \langle s_j \rangle \quad (2)$$

where Z_i is coordination number, x_j is atomic percentage of the j th species in the compound, then

$$\langle s_i \rangle = \left(S_i + \frac{1}{2} \right) \coth \left[\frac{Z_i (2S_i + 1) \sum_{j=1}^3 x_j J_{ij} \langle s_j \rangle}{2kT} \right] - \frac{1}{2} \coth \left[\frac{Z_i \sum_{j=1}^3 x_j J_{ij} \langle s_j \rangle}{2kT} \right] \quad (3)$$

The subnetwork magnetization are then obtained from the relation

$$M_i = N x_i \mu_B g_i \langle s_i \rangle \quad (4)$$

μ_B is the Bohr magneton, g_i is gyromagnetic factor, and N is the total number of atoms(ions) in unit volume. Since amorphous materials are usually less dense than their crystalline counterparts, we assume that only 95% percent of the space is filled in the amorphous state. the total number of atoms per unit volume N is thus given by

$$N = \frac{0.95}{\sum_{i=1}^n \frac{4}{3} \pi r_i^3 x_i} \quad (5)$$

r_i is the atomic radius.

EXPERIMENTS

SmTbFeCo films with perpendicular magnetic anisotropy have been deposited by r.f. magnetron

sputtering from a mosaic target onto glass substrate. The sputtering conditions are as follows: background pressure 1.07×10^{-4} Pa; Ar pressure 0.4 ~ 1.0 Pa; the sputtering power 300 W; substrate temperature

Fig. 1 The temperature dependence of the coercivity of amorphous SmTbFeCo films

Fig. 2 Temperature dependence of the saturation magnetization of amorphous SmTbFeCo films

Fig. 3 Temperature dependence of the Kerr rotation angle of amorphous SmTbFeCo films

80 ~ 100 °C. We have also deposited AlN film using r.f. reactive sputtering for RE metal selective oxidation protection. The layer configuration is AlN/SmTbFeCo^[9]. The coercivity H_c and Kerr angle θ_k are measured from Kerr hysteresis, and the saturation magnetization M_s by using a vibrating sample magnetometer.

The temperature dependencies of coercivity H_c , saturation magnetization M_s and Kerr angle θ_k are shown in Fig. 1, Fig. 2 and Fig. 3 respectively. As shown in Fig. 1, H_c exhibits a rise with film fabricated under high pressure. Microvoids and columnar structure may act as pinning points in magnetic domain walls, increasing H_c . It is also shown that at the same sputtering conditions, the coercivity of SmTbFeCo film with available Sm substitution of Tb is larger than that of TbFeCo film, the coercivity versus temperature becomes more slowly, and its Kerr angle can be 0.33° , which is larger than that of TbFeCo.

Table 1 The parameters of SmTbFeCo amorphous films used in calculation of Ms-T curve

		Tb	Sm	FeCo
atomic radius	r (nm)	22.4	22.4	16.5
gyromagnetic factor	g	1.5	2/7	2.2
angular quantum number	S	6	adjustable	
coordination number	Z		12	

Table 2 The fitting parameters of the spins and exchange integrals of SmTbFeCo films

S_{Sm}	S_{TM}	J_{TbTb}	J_{TbSm}	J_{TbTM}	J_{SmSm}	J_{SmTM}	$J_{TM TM}$
2.51	0.67	3.67	-3.10	-2.63	2.91	5.18	90.38

RESULTS AND DISCUSSION

We use the above mean-field theory to verify the experimentally observed behavior of saturation magnetization versus temperature in SmTbFeCo alloys. the parameters are listed in table 1. The value of the parameters S_{Sm} , S_{TM} , J_{SmSm} , J_{TbSm} , J_{SmTM} and J_{TMTM} are determined to fit the experimental data on the temperature dependencies of M_s shown in Fig. 2. The obtained value of the parameters are listed in table 2. Using the parameter values obtained above, the calculated values fitted well with the experimental values.

The temperature dependencies of M_s of SmTbFeCo at a constant TM content are shown in Fig. 4. The more Tb are replaced by Sm, the lower the compensation temperature, the larger the saturation magnetization M_s at the room temperature, and the Curie temperature remains nearly unchanged. It is also found that with available Sm substitution of Tb, the saturation magnetization M_s versus temperature changes more slowly. Thus, SmTbFeCo amorphous films can be used as the high density magneto-optical recording media in a wide range of temperature.

The temperature dependencies of M_s of SmTbFeCo at a constant Tb content are shown in Fig. 5. With TM replaced by Sm, the compensation temperature T_{comp} becomes higher, the Curie temperature T_C tends to lower, and the saturation magnetization M_s at the room temperature decreases.

Fig. 4 Temperature dependence of the saturation magnetization M_s for SmTbFeCo films at a constant TM content

Fig. 5 Temperature dependence of the saturation magnetization M_s for SmTbFeCo films at a constant Tb content

In the HRE-LRE-TM films, the Kerr effect is attributed to the sublattice magnetic moments. The Kerr rotation angle θ_k of HRE-LRE-TM films will be represented by

$$\theta_k = K(TM)M_{sTM} + K(LRE)M_{sLRE} - K(HRE)M_{sHRE} \quad (7)$$

where value of the coefficients $K(TM)$, $K(LRE)$ and $K(HRE)$ are determined such that eq (7) fitted the experimental data. the samples are shown in Fig. 3 . the obtained values of the coefficients $K(TM)$, $K(Sm)$ and $K(Tb)$ are 9.45×10^{-7} , 4.05×10^{-7} and 1.03×10^{-7} deg · m/A respectively.

Fig. 6 Temperature dependence of the Kerr rotation angle θ_k of amorphous SmTbFeCo films at a constant TM content

Fig. 7 Temperature dependence of the Kerr rotation angle θ_k of amorphous SmTbFeCo films at a constant Tb content

The temperature dependencies of the Kerr rotation angles θ_k of SmTbFeCo films at constant TM content are shown in Fig. 6. With Sm substitution of Tb, the Kerr rotation angle θ_k increases. Therefore, the available Sm substitution of Tb can enhance the magneto-optical effect. The temperature dependencies of the Kerr rotation angles θ_k of SmTbFeCo films at constant Tb content are shown in Fig. 7. With Sm substitution of TM, the Kerr rotation angle θ_k decreases. Thus, Sm substitution of TM does not enhance the magneto-optical effect. Therefore, we can explain why the addition of LRE into TbFeCo films enhances MO performance at same time or not at other time.

CONCLUSION

A mean-field model is applied to SmTbFeCo films and to explain the behaviors of the saturation magnetization and Kerr rotation angle versus temperature. It is shown that the available Sm substitution of Tb can cause the composition

temperature T_{comp} to decrease, the Curie temperature T_C remains unchanged, the Kerr rotation angle becomes larger, and the saturation magnetization M_s at room temperature increases. Therefore, LRE-HRE-TM amorphous films can be used as the high density magneto-optical media in a wide range of temperature. On the contrary, with Sm substitution of TM, the composition temperature T_{comp} increases, Curie temperature T_C decreases, the Kerr rotation angle becomes small, and the saturation magnetization M_s at room temperature decreases. Therefore, it does not improve the magneto-optical performance. Thus, we can explain whether the addition of LRE into HRE-TM alloys enhances MO performance.

REFERENCES

- [1] Z. Y. Lee, X. S. Miao, P. Zhu, et al. J Magn Mater, 115 (1): 44-54 (1992)
- [2] R. Carey, D. M. Newman, B. W. J. Thomas. J Phys D: Appl Phys, 28: 2207-2227 (1995)
- [3] Z. Y. Lee, X. S. Miao, P. Zhu, et al. J Magn Soc Jpn, 15 (8): 421-424 (1991)
- [4] Z. Q. Lu, Z. Y. Lee, Y. K. Zheng, et al. SPIE, 2890: 20-25 (1996)
- [5] M. Mansuripur, and M. F. Ruane. IEEE Trans Magn, 22(1): 33 (1986)
- [6] S. Honda, and M. Yoshiyama. Jpn J Appl Phys, 27(9): 1687-1692 (1988)
- [7] Z. Q. Lu, Z. Y. Lee, Y. K. Zheng, et al. Chin Phys Lett, 14(2): 131-133 (1997)
- [8] M. Nakada, H. Yokota, S. Yumoto. IEEE Trans Magn, 25(5): 3767-3769 (1989)
- [9] C. B. Peng, W. M. Kim, B. K. Cheong, et al. J Appl Phys, 80(8): 4498-4502 (1996)