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Amorphous Tb/Co compositionally modulated films were deposited on Si substrates with different modulation layer thicknesses ranging from about 2.5 to 15 Å. The nominal Tb to Co layer thickness ratios were systematically varied and the complex refractive index (n and k) and polar magneto-optical Kerr effects (rotation and ellipticity) were measured in the 3000–8000-Å spectral range as well. The samples were divided into two groups. In one group, the thickness of the Co layers was fixed, the Tb layer thickness varied. In the second group, the thickness of the Tb layer was fixed, and that of the Co layer thickness varied. The Kerr rotation and the coercivities of the samples showed very consistent and interesting changes. X-ray diffraction and x-ray fluorescence were also performed on the samples, which revealed layered structures, or compositional modulation, and provided information on the Tb to Co atomic ratios in the samples.

I. INTRODUCTION

Amorphous rare-earth–transition-metal (RE-TM) magnetic alloys are being considered for erasable magneto-optical (MO) recording, although, recently, metal multilayers such as Co/Pt are studied as new candidates.[1] MO properties of RE-TM alloys are strongly dependent on the composition, thus the RE content can be adjusted to tune the recording performance. Although many studies have been made in the last decade,[2-6] the role of the localized RE moments played in the RE-TM(Fe, Co) alloys still remains controversial. Intrinsically, the magneto-optical Kerr effect (MOKE) is primarily from the "magnetic" electrons, i.e., d and f electrons for the RE-TM alloys since the MOKE is proportional to the spin-orbit coupling strength. Therefore, a spectroscopic MOKE is useful to probe the role of the RE elements in the alloys. In this paper, we present optical and polar Kerr experimental results for compositionally modulated magnetic Tb/Co films with varied Tb to Co concentration ratios, and discuss some interesting new results.

II. EXPERIMENTAL METHODS

A rotating analyzer magneto-optical spectrometer was used to measure the polar Kerr effect (both the Kerr rotation θ_k and Kerr ellipticity ϵ_k), in the 3000–8000-Å spectral range. This technique has been discussed in detail in Ref. 7. Ellipsometric measurements were also made on a variable angle spectroscopic ellipsometer[8] in the same spectrum (3000–8000 Å) and at incident angles of 60°–70° to obtain the optical constants n and k. The samples used for this experiment consisted of Si substrates onto which compositionally modulated Tb/Co magnetic films were magnetron sputtered. During sputtering, the substrate was kept at 19 °C to obtain amorphous layers, as verified by x-ray diffraction. The nominal Co and Tb layer thicknesses varied systematically from 2.5 to 15 Å as shown in Table I. For all samples, the total thicknesses of magnetic films were made optically thick (1000 Å) to avoid optical interference effects, and both the MOKE and ellipsometric measurements were made at room temperature.

TABLE I. Sample bilayer structures.

Sample group I[a]	Sample group II
Tb(2.5)/Co(10)	Tb(10)/Co(2.5)
Tb(5)/Co(10)	Tb(10)/Co(5)
Tb(7.5)/Co(10)	Tb(10)/Co(7.5)
Tb(10)/Co(10)	Tb(10)/Co(10)
Tb(12.5)/Co(10)	Tb(10)/Co(12.5)
Tb(15)/Co(10)	Tb(10)/Co(15)
Extra sample Tb(8.75)/Co(10)	

[a]Angstrom units.

III. RESULTS AND DISCUSSION

The complex index of refraction $\tilde{n} = n + ik$ and magneto-optical Kerr rotation θ_k and ellipticity ϵ_k for

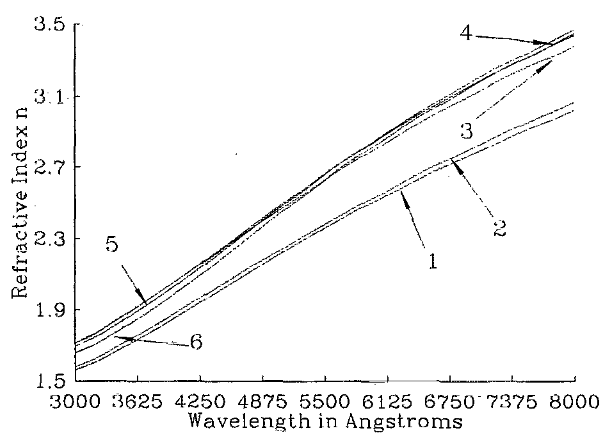

FIG. 1. Index of refraction n of the Tb/Co multilayer system. 1: Tb(10)/Co(2.5); 2: Tb(10)/Co(5); 3: Tb(10)/Co(7.5); 4: Tb(10)/Co(10); 5: Tb(10)/Co(12.5); 6: Tb(10)/Co(15).

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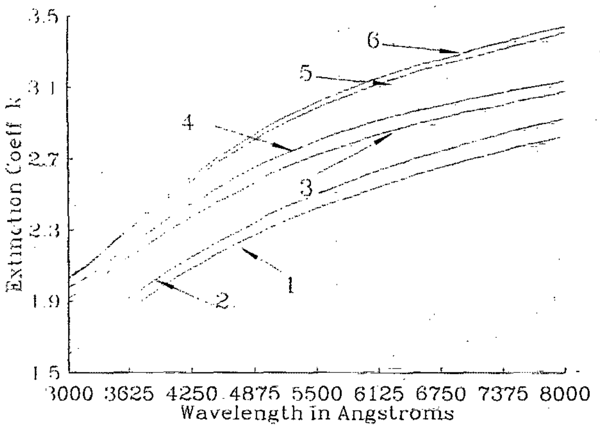

FIG. 2. Extinction coefficient k of the Tb/Co multilayer system. 1: Tb(10)/Co(2.5); 2: Tb(10)/Co(5); 3: Tb(10)/Co(7.5); 4: Tb(10)/Co(10); 5: Tb(10)/Co(12.5); 6: Tb(10)/Co(15).

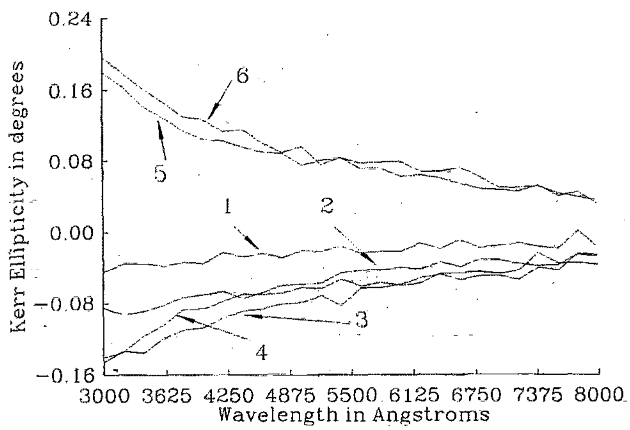

FIG. 4. Magneto-optical Kerr ellipticity of the Tb/Co multilayer system. 1: Tb(10)/Co(2.5); 2: Tb(10)/Co(5); 3: Tb(10)/Co(7.5); 4: Tb(10)/Co(10); 5: Tb(10)/Co(12.5); 6: Tb(10)/Co(15).

group-II samples with the indicated nominal Tb and Co layer thicknesses are shown in Figs. 1–4. In addition, the complex magneto-optical parameter $\tilde{Q} = Q_1 + iQ_2$ was also calculated from experimental data based on classical electrodynamic theory, but is not shown. The results of group-I samples which are not shown in this paper are similar to those of group-II samples.

The optical constants n and k in Figs. 1 and 2 show the effect of the Tb to Co composition changes in the samples. There is a sudden increase in refractive index n when the Co layers reach 7.5 Å. This is likely due to the change from alloy behavior to compositionally modulated behavior. That is, distinguishable layers are formed at this thickness. This point has been confirmed using by x-ray diffraction which showed a "superlattice" peak for samples with Co thicknesses greater than 7.5 Å, but no peak at all for thicknesses less than this. The extinction coefficient k increases with Co composition increase, approaching the value of bulk Co. Thus there is a systematic change of optical constants with Co concentration.

Figures 3–5 show the Kerr rotation θ_k, Kerr ellipticity ϵ_k, and Kerr rotation loops. Several interesting effects are observed. First of all, additional Co added to the system causes systematic changes of θ_k and ϵ_k over the entire spectral range, particularly for ϵ_k in the short-wavelength range. Sign changes in θ_k and ϵ_k can be seen clearly. Also, Figs. 5(b), 5(c), and 5(d) show the Kerr rotation loops exhibiting perpendicular anisotropy when the Tb to Co thickness ratio is about 8:10. An extra sample, Tb(8.75)/Co(10), was made to check the magnetic properties of samples near the "critical point" where the magnetization of the films changed sign. The Kerr rotation loop of the extra sample with 8 kOe coercivity is shown in Fig. 5(c). The increase of coercivity from both the positive and negative sides of the magnetization near the Tb-Co layer thickness ratio of 8:10 implies that there exists a magnetic compensation point, although magnetization measurements

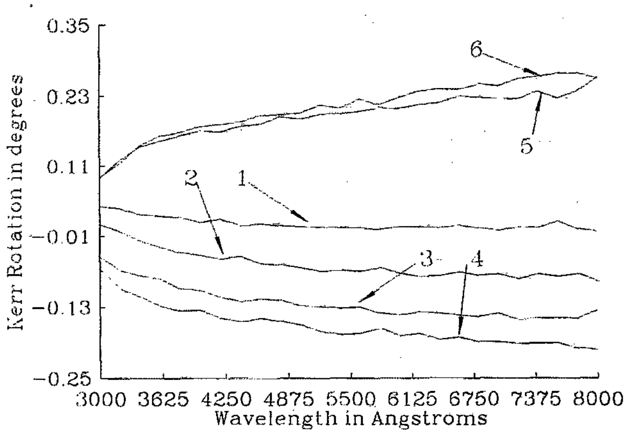

FIG. 3. Magneto-optical Kerr rotation of the Tb/Co multilayer system. 1: Tb(10)/Co(2.5); 2: Tb(10)/Co(5); 3: Tb(10)/Co(7.5); 4: Tb(10)/Co(10); 5: Tb(10)/Co(12.5); 6: Tb(10)/Co(15).

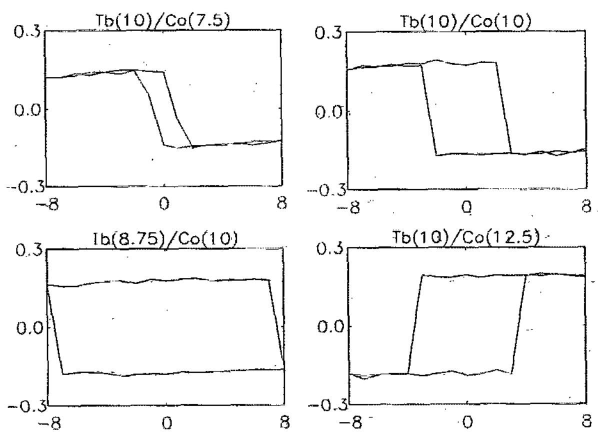

FIG. 5. Magneto-optical Kerr rotation loops of the Tb/Co multilayer system. The x axes are the magnetic field in kG, and the y axes are Kerr rotations (at $\lambda = 5000$ Å) in degrees.

need to be made to confirm this point. On the other hand, for the Tb-rich sample, Tb(10)/Co(2.5), the Kerr effects were very small, and a perpendicular anisotropy was not present (the Kerr rotation loop for this sample is not shown). This result agrees with Buschow's report[4] that amorphous Tb_xCo_{1-x} alloys with $x > 0.4$ have a Curie temperature below room temperature. For Co-rich samples, such as Tb(2.5)/Co(10), the Kerr effects were not small, but the samples have no perpendicular magnetic anisotropy. There are still many questions about the roles played by Tb and Co in either compositionally modulated films or alloys. More experimental work, such as photoemission to explore in detail the electronic states near the Fermi level, as well as theoretical studies in this system, is needed.

ACKNOWLEDGMENT

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[1] W. B. Zeper, F. J. A. M. Greidanus, P. F. Carcia, and C. R. Fincher, J. Appl. Phys. **65**, 4971 (1989).
[2] P. Chaudhari, J. J. Cuomo, and R. J. Gambino, Appl. Phys. Lett. **22**, 337 (1973).
[3] M. Hartmann, J. Braat, and B. Jacobs, IEEE Trans. Magn. **MAG-20**, 1013 (1984).
[4] T. R. McGuire and M. Hartmann, IEEE Trans Magn. **MAG-22**, 1224 (1986).
[5] K. H. J. Buschow, J. Appl. Phys. **51**, 2795 (1980).
[6] G. A. N. Connell, J. Magn. Magn. Mater. **54–57**, 1561 (1986).
[7] L. Y. Chen and J. A. Woollam, SPIE **1166**, 267 (1989).
[8] J. A. Woollam, P. G. Snyder, and M. C. Rost, Thin Solid Films **166**, 317 (1988).