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Temperature and layer-thickness dependencies of Kerr rotation in Dy/Co multilayers

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Amorphous Dy/Co multilayers with the individual layer thickness between 4 and 10 Å in steps of 0.5 to 1 Å were studied systematically over the temperature range 100–300 K. The Kerr rotation increases as temperature decreases, or as Co content increases and the coercivity increases both in the low temperature region and in the vicinity of the compensation point. These characteristics were analyzed in terms of simple models of the magnetic structure and magnetization reversal.

I. INTRODUCTION

Amorphous RE/TM multilayers (RE = rare earth; TM = transition metal) are potentially interesting materials for magneto-optic recording.[1] They possess a variety of properties desirable for magneto-optic data storage media such as large Kerr rotation for readout, large perpendicular anisotropy, and proper coercivity for thermomagnetic writing. The challenge is to understand these characteristics well enough to enable the design of desirable media. In this paper, we focus on a systematic study of the layer thickness and temperature dependence of magneto-optic properties in Dy/Co multilayers.

II. EXPERIMENTS

The samples with the form of Y-Å Dy/X-Å Co (X and Y denote the Dy and Co layer thickness, respectively) were prepared using a dc dual-gun sputtering onto glass substrates. The sputtering rate was about 1 Å/s for both Dy and Co targets and the other preparation conditions were the same as those mentioned in Ref. 2. The total thickness of the film is about 1000 Å. The structural properties were studied with x-ray diffraction. Kerr rotation measurements were measured using light of wavelength $\lambda = 632.8$ nm over a temperature range from 100 to 300 K.

III. RESULTS AND DISCUSSION

A. Structural properties

The large-angle x-ray diffraction measurement for 8-Å Dy/8-Å Co shows only broad peaks [see Fig. 1(a)], indicating an amorphous or noncrystalline structure. The small-angle x-ray diffraction shows a weak first-order peak for the same sample [see Fig. 1(b)] and the bilayer thickness determined from this peak is 17 Å which is close to the nominal bilayer thickness of 16 Å. This indicates that the Dy and Co atoms are not completely intermixed, so that a compositionally-modulated structure (or layered structure) exists.

Two series of samples (5-Å Dy/X-Å Co, and Y-Å Dy/5-Å Co) with the layer thickness from 4 to 10 Å in steps of 0.5 to 1 Å were measured systematically over the temperature range from 100 to 300 K. The layer-thickness and temperature dependence of magneto-optic properties are discussed in the following sections.

B. Layer-thickness dependence of magneto-optic properties

Room temperature Kerr rotation hysteresis loops for 5-Å Dy/X-Å Co ($X = 4, 5, 5.5, 6, 7, 8, 9, 10$) are shown in Fig. 2. Two points should be noticed: (1) The Kerr loops are quite square with the exception of 5-Å Dy/4-Å Co which has the thinnest Co layer. The coercivity H_c of sample 5-Å Dy/7-Å Co is larger than 15 kOe, and so the Kerr loop cannot be measured in our apparatus. (2) There is a change in sign of Kerr rotation θ_k between $X = 6$ and 8, which indicates that the sample with $X = 7$ is in the vicinity of the compensation point and the Co sublattice magnetizations (referred as Co magnetization hereafter) of these samples change their directions respect with the applied field. This is because for $X < 6$, the Dy sublattice magnetizations dominate, so that the Co magnetizations are aligned antiparallel with the applied field; for as $X \geqslant 8$, the Co magnetizations dominate, so that they are aligned parallel with the applied field.

An example of the θ_k and H_c as a function of Co (or Dy) layer thickness is given in Fig. 3(a) and Fig. 3(b), respectively.

Figure 3(a) shows that θ_k increases with increasing the Co layer thickness for 5-Å Dy/X-Å Co, and approaches ~0.4°, which is the Kerr rotation of pure Co. For the Y-Å Dy/5-Å Co series, θ_k decreases as the Dy layer thickness increases because of the decreasing Co content and decreasing Co magnetization.

This θ_k behavior may be interpreted in terms of the mean-field model for RE/TM multilayers in which the Co magnetization can be calculated.[3–5] An example of the calculated Co magnetization for 6-Å Dy/X-Å Co multilayers, which is close to the 5-Å Dy/X-Å Co studied in this paper, is given in Fig. 9 of Ref. 5. The similarity between the Co magnetization σ_{Co} curve there and the θ_k curve of 5-Å Dy/X-Å Co is an evidence that the mean-field model can be used to analyze the Kerr rotation behavior of RE/TM multilayers.

Figure 3(b) shows the coercivity H_c as a function of Co (or Dy) layer thickness for 5-Å Dy/X-Å Co (or Y-

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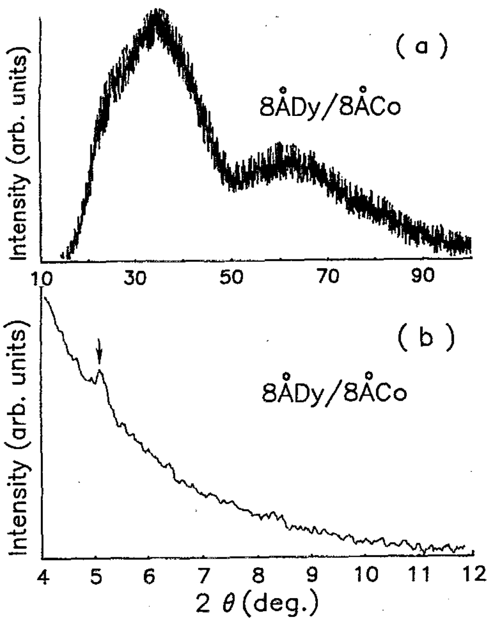

FIG. 1. X-ray diffraction intensity as a function of 2θ for 8-Å Dy/8-Å Co multilayer. (a) Large-angle pattern and (b) small-angle pattern.

Å Dy/5 Å Co) series. The coercivity is enhanced rapidly in the vicinity of the compensation composition, and this phenomenon will be discussed in the next section.

C. Temperature dependence of magneto-optic properties

An example of Kerr loops as a function of temperature for 5-Å Dy/10-Å Co is given in Fig. 4. As the temperature decreases, θ_k almost remains constant for this sample and H_c increases rather rapidly. A summary of the Kerr rotation and coercivity as the function of temperature is given in Fig. 5(a) and Fig. 5(b), respectively.

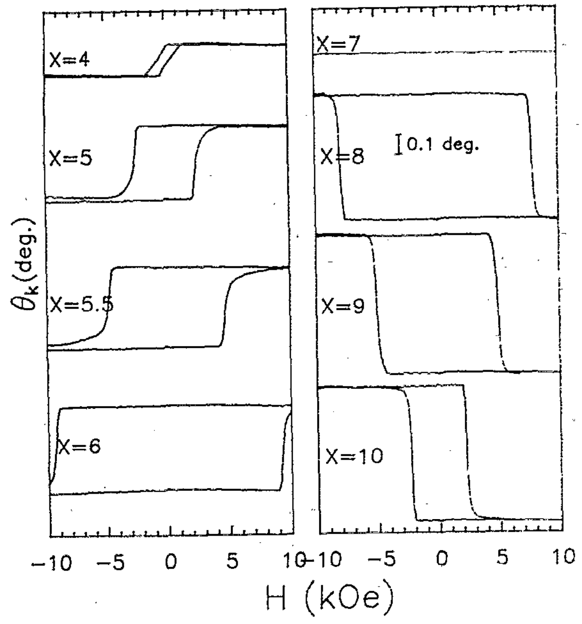

FIG. 2. Layer-thickness dependence of Kerr rotation hysteresis loops for 5-Å Dy/X-Å Co ($X=4$, 5, 5.5, 6, 7, 8, 9, and 10) at $T=300$ K. The scale of 0.1° for θ_k is shown in the loop with $X=8$.

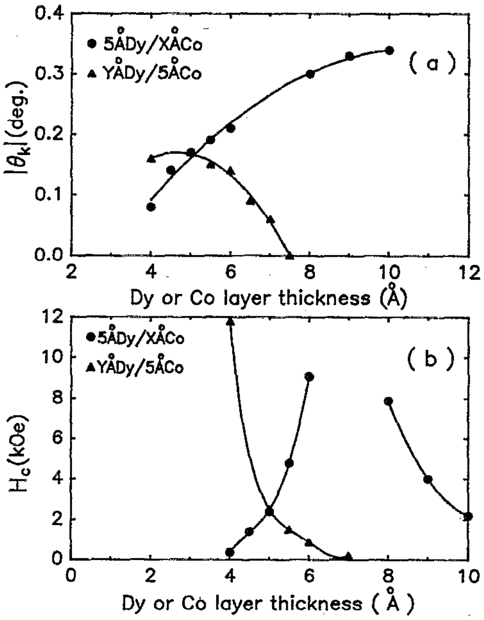

FIG. 3. (a) Kerr rotation as a function of Co (or Dy) layer thickness and (b) coercivity as a function of Co (or Dy) layer thickness. Lines are a guide for the eye.

In Fig. 5(a), these features should be noticed: (1) For Dy/Co multilayers, θ_k increases smoothly as temperature decreases and this tendency becomes weaker as the Co layer gets thicker. (2) For a given temperature, θ_k increases with increasing Co layer thickness.

Figure 5(b) demonstrates the temperature dependence of coercivity. The sample 5-Å Dy/6-Å Co shows the representative character of the temperature dependence of co-

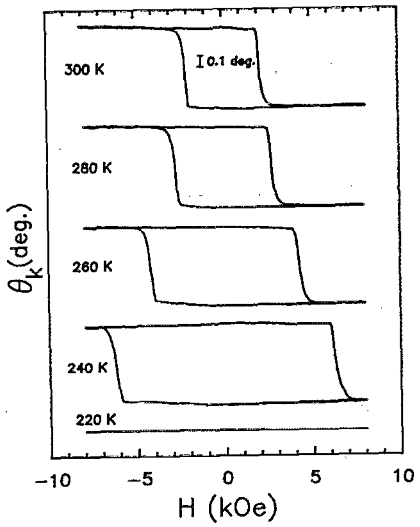

FIG. 4. Temperature dependence of Kerr rotation hysteresis loops for 5-Å Dy/10-Å Co multilayer. The scale of 0.1° for θ_k is shown in the loop with $T=300$ K.

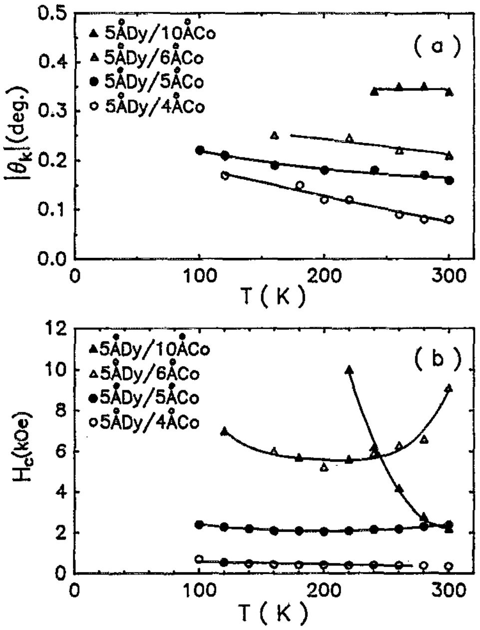

FIG. 5. (a) Kerr rotation as a function of temperature and (b) coercivity as a function of temperature. Lines are a guide for the eye.

ercivity: H_c increases both at $T \sim 300$ K which is near the compensation temperature T_{comp} and at $T \sim 100$ K. This behavior may be interpreted qualitatively in terms of the following expression suggested by Kronmüller, Durst, and Sagawa[6]

$$H_c = \alpha(2K/M) - N_1 M, \tag{1}$$

where α is a parameter of order unity describing the effects of nucleation or domain wall pinning, N_1 is the local demagnetization factor and M is the magnetization. The first term in the right side of Eq. (1) is greater than the second term for our samples. As the sample is in a state close to T_{comp}, M approaches zero and thus H_c is enhanced rapidly because the anisotropy K changes its value smoothly through T_{comp}.[5] When the temperature is well below T_{comp}, the Dy sublattice magnetization dominates, so that

$$M = |\langle M_{\text{Dy}} - M_{\text{Co}} \rangle| \simeq \langle M_{\text{Dy}} \rangle \quad (\text{since } M_{\text{Dy}} \gg M_{\text{Co}}), \tag{2}$$

where M_{Dy} and M_{Co} are the magnetizations of Co sublattice and Dy sublattice, respectively. K is dominated by the Dy anisotropy, K_{Dy}, which is proportional to the Dy-sublattice magnetization squared[4,5]

$$K \simeq K_{\text{Dy}} \propto \langle M_{\text{Dy}}^2 \rangle, \tag{3}$$

therefore

$$(K/M) \simeq \langle M_{\text{Dy}} \rangle. \tag{4}$$

Thus H_c increases as temperature approaches 100 K since the Dy-sublattice magnetization $\langle M_{\text{Dy}} \rangle$ increases noticeably for this sample. Samples with thinner Co layer (i.e., 5-Å Dy/5-Å Co and 5-Å Dy/4-Å Co) show flatter H_c curves because their T_{comp} is much higher than 300 K and their $\langle M_{\text{Dy}} \rangle$ values just start to increase at 100 K. Sample 5-Å Dy/10-Å Co has $T_{\text{comp}} \simeq 200$ K and thus its H_c grows near this temperature.

In summary, a systematic study of the magneto-optic properties of nanostructured Dy/Co multilayers has been conducted. Their character can be understood in terms of the behavior of magnetic ordering and coupling of the Dy and Co atoms through the mean-field model together with Kronmüller's model. Additional measurements in our laboratory of time decay of the Kerr rotation show that nucleation is the major origin of magnetization reversal for these multiyears and further studies are underway.[7]

ACKNOWLEDGMENTS

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