Optical- and magnets-optical measurements using a variable angle of incidence spectroscopic ellipsometer: Application to DyCo multilayer

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Optical- and magneto-optical measurements using a variable angle of incidence spectroscopic ellipsometer: Application to DyCo multilayers

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We have extended the technique of variable angle spectroscopic ellipsometry to measurement of the magneto-optical effects as a function of wavelength and angle of incidence and field strength. Results on DyCo multilayers are reported.

I. INTRODUCTION

Thin films on the rare earth–transition metal alloys are leading candidates for magneto-optic recording[1] because they have perpendicular anisotropy, significant Kerr rotation, and desirable ranges of compensation and Curie temperatures.

In this paper we describe adaptation of a variable angle spectroscopic ellipsometer[2] (VASE) to magneto-optic measurements in fields to ± 8 kOe. Thus with one instrument one can measure both the real and imaginary parts of the diagonal and off-diagonal elements of the dielectric function $\tilde{\epsilon}$. These measurements can be made over the spectral range from 3000 to 8400 Å.

Another representation of $\tilde{\epsilon}$ is in the terms of the index of refraction, extinction coefficient, Kerr rotation, and Kerr ellipticity. All four quantities are measured in our modified VASE. It should be pointed out that the Kerr rotation is a function of both the diagonal *and* off-diagonal element of the $\tilde{\epsilon}$ tensor. Thus the ellipsometric measurements are an important part of a complete investigation of these materials.

We have investigated the $\tilde{\epsilon}$ tensor in a series of Dy/Co multilayers (typically 3000-Å total thickness), where the Dy-to-Co atom ratio was kept constant, and layer thicknesses were 5.25/3.75, 7.0/5.0, 10.5/7.5, and 14/10 in angstroms. All samples in these thicknesses ranges had dominant perpendicular magnetic anisotropy as determined by magnetization measurements in both the perpendicular and parallel orientations.[3] These samples were prepared by magnetron sputtering using a room-temperature rotating substrate. This paper reports mainly on results of magneto-optic VASE measurements on Dy 10.5/Co 7.5, as these results are representative of the entire system.

II. MEASUREMENTS OF THE KERR ROTATION

The measured experimental quantity is the ellipsometric parameter ρ', where

$$\rho' = R'_p/R'_s \qquad (1)$$

and R_p and R_S are the pseudo-Fresnel coefficients for the sample. For ferromagnets under the influence of a strong polar magnetic field we measure $\rho^{\pm}$, where the $\pm$ refers to positive or negative saturation magnetization in the sample. Assuming the zero magnetization point to be given by $\rho_0 = \frac{1}{2}(\rho^+ + \rho^-)$, i.e., absence of significant overlayers, we can equate the two reflection equations for the system:

$$\begin{bmatrix} E_p \\ E_S \end{bmatrix}^R = \begin{bmatrix} R'_p & 0 \\ 0 & R'_S \end{bmatrix} \begin{bmatrix} E_p \\ E_S \end{bmatrix}^i$$

(experimental measurement), (2)

$$\begin{bmatrix} E_p \\ E_S \end{bmatrix}^r = \begin{bmatrix} R_p & K_S \\ K_p & R_S \end{bmatrix} \begin{bmatrix} E_p \\ E_S \end{bmatrix}^i$$

(physical system)

to get Kerr Rotation in terms of measured or known quantities.

$$\theta_{K_p} = R_e\left(\frac{K_S}{R_p}\right) = R_e\left[\frac{\tan\theta_p(1-\rho'/\rho_0)}{\rho' - \tan^2\theta_p}\right], \qquad (3)$$

$$\theta_{K_S} = -R_e\left(\frac{K_p}{R_S}\right) = -R_e\left[\frac{\tan\theta_p(\rho'-\rho_0)}{\tan^2\theta_p - \rho'}\right], \qquad (4)$$

where $\theta_p = \tan^{-1} E_S/E_p$ is the polarizer azimuth.

III. RESULTS AND DISCUSSION

Optical characterization of the DyCo multilayers was achieved by extracting the complex index of refraction from experimental ellipsometrically determined reflectance versus angle of incidence data. These data were analytically derived from raw ellipsometric data, and a regression analysis

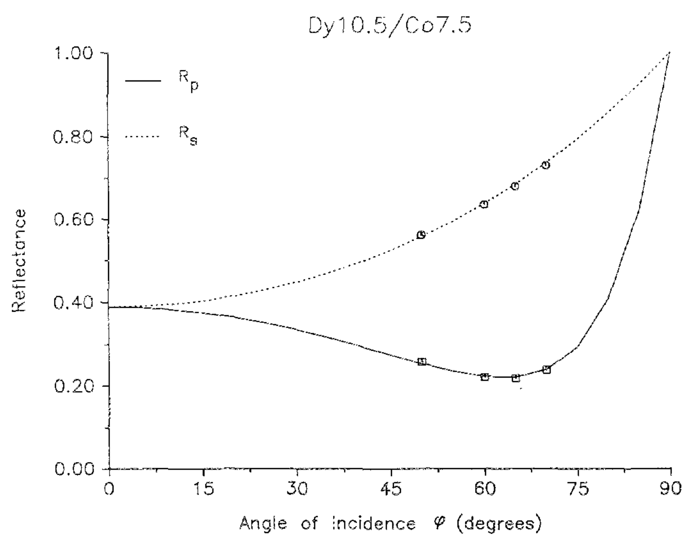

FIG. 1. Reflections vs angle of incidence for Dy 10.5/Co 7.5. Symbols represent measured values and lines represent best-fit calculated values with $\tilde{n} = 1.28 - j1.78$. The measurements were taken at a wavelength of 4000 Å.

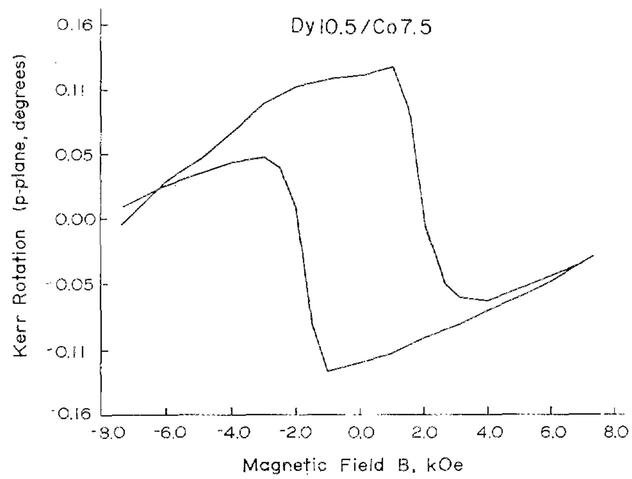

FIG. 2. Hysteresis loop for Dy 10.5/Co 7.5 showing p-plane Kerr rotation vs applied magnetic field strength. Measurements were taken at a 60° angle of incidence and wavelength at 6328 Å.

was employed to find the best-fit value of the index of refraction over a series of wavelengths. Figure 1 shows p- and s-plane reflectance, derived from experimental ellipsometric measurements for Dy 10.5/Co 7.5. The best-fit value of n_o was found to be $1.78 - j1.28$. The curves shown are for a photon wavelength of 4000 Å and are considered representative of the multispectral data.

Figure 2 shows a typical hysteresis loop for the p-plane Kerr rotation in the Dy 10.5/Co 7.5 sample at an angle of incidence of 60° and wavelength of 6328 Å. Coercive forces measured magnetically and optically were within error limits of being the same.

Figure 3 shows the angle of incidence dependence of the s-plane component of the Kerr rotation for Dy 10.5/Co 7.5 at five different wavelength values. The angle of incidence effects are predictable from theory,[4] and the s- and p-polarization components of the Kerr rotation merge together at normal incidence for any given wavelength.[5]

The magnitudes of the Kerr rotation are on the order of

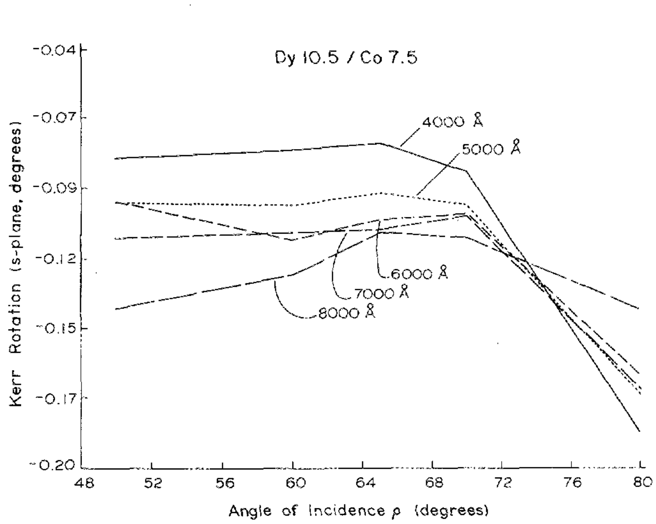

FIG. 3. S-plane Kerr rotation vs angle of incidence at five wavelengths for Dy 10.5/Co 7.5.

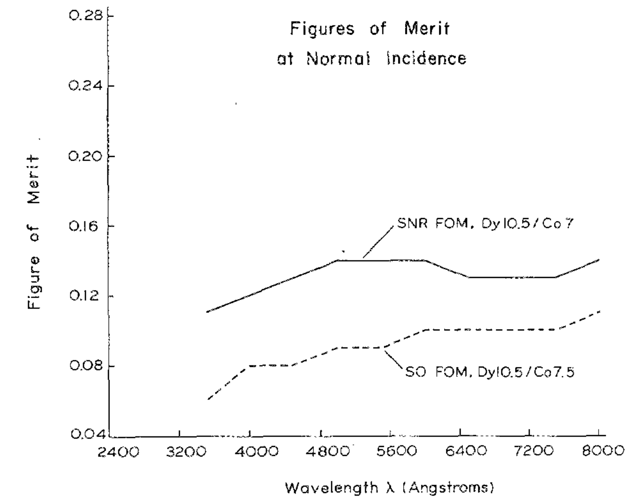

FIG. 4. SNR FOM and SO FOM vs wavelength for Dy 10.5/Co 7.5. Curves are calculated from measured Kerr rotation and reflectance data extrapolated to normal incidence.

0.1°. These results are similar to those found on nonmultilayered transition metal–rare earth alloy films reported in the literature.[6]

The reflectance *and* the Kerr rotation are important for magneto-optic recording, therefore we include Fig. 4, which shows the spectral dependence of two common figures of merit (FOM) for Dy 10.5/Co 7.5. These quantities are defined as

$$\text{Signal-to-noise (SNR) FOM} \equiv 100\sqrt{R}\ \sin 2\theta_k, \quad (5)$$

$$\text{Signal output (SO) FOM} \equiv R \sin 2\theta_k, \quad (6)$$

where R is the reflectance and θ_k is the Kerr rotation, both at normal incidence.[7]

Typical (SNR) FOM and (SO) FOM for TbFeCo are ~1.8 and 1.1, respectively. These numbers are considerably larger than those for DyCo.[7] However, the rare earth/transition metal materials system is far from optimized with respect to choice of elements, layer thickness, and corrosion resistant surfaces.

In summary, we have successfully extended the VASE technology to magneto-optic measurements, and have applied it to the DyCo multilayer materials system.

ACKNOWLEDGMENT

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