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William A. McGahan
University of Nebraska-Lincoln

Liang-Yao Chen
University of Nebraska-Lincoln

Z. S. Shan
University of Nebraska-Lincoln

David J. Sellmyer
University of Nebraska-Lincoln, dsellmyer@unl.edu

John A. Woollam
University of Nebraska-Lincoln, jwoollam1@unl.edu

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William A. McGahan, Liang-Yao Chen, Z. S. Shan, D. J. Sellmyer, and John A. Woollam

Departments of Electrical Engineering and Physics, University of Nebraska, Lincoln, Nebraska 68588-0511

Abstract
Enhanced Kerr rotation spectra are measured in thin magnetic layers on silver. Also, variable angle of incidence spectroscopic ellipsometry is employed to measure the optical dielectric function of both the thin magnetic layer and the underlying thick silver layer. These results are explained quantitatively using the electromagnetic theory for reflection of light from multiple layers of isotropic and gyrotropic materials.

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William A. McGahan, Liang-Yao Chen, Z. S. Shan, D. J. Seilmyer, and John A. Woollam
Departments of Electrical Engineering and Physics, University of Nebraska, Lincoln, Nebraska 68588-0511

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Enhanced Kerr rotation spectra are measured in thin magnetic layers on silver. Also, variable angle of incidence spectroscopic ellipsometry is employed to measure the optical dielectric function of both the thin magnetic layer and the underlying thick silver layer. These results are explained quantitatively using the electromagnetic theory for reflection of light from multiple layers of isotropic and gyrotropic materials.

In 1987, Feil and Haas found that spectrally sharp magneto-optic Kerr effects (MOKEs) exhibited by certain materials could be explained as a consequence of classical plasma resonance of charge carriers.[1] A number of subsequent attempts to enhance the MOKE by alloying or layering magnetic materials with nonmagnetic metals possessing sharp plasma edges have enjoyed various degrees of success. Katayama *et al.*, for example, have presented MOKE data on Fe/Cu multilayers showing enhanced rotations at photon energies corresponding to the plasma edge of copper.[2]

Schoenes and Reim[3] and Feil and Haas[4] further discussed the interpretation of MOKE data in similar systems. Recently, Reim and Weller presented MOKE data on thin TbFeCo deposited on copper and silver in which they demonstrate enhancement of the Kerr rotation of up to factors of 2 (copper underlayer) to 5 (silver underlayer) over the bulk values. These enhancements occur at photon energies which are significantly removed from the plasma edge of the underlayer, but at which the optical constants n and k of the substrate are small.[5] Thus, there exists growing evidence that enhanced MOKEs can occur in layered structures exhibiting unusual optical dielectric functions.

The purpose of this letter is twofold. First, we present experimental data showing large resonant MOKE in magnetic multilayers deposited on silver, with enhancements over bulk values of up to a factor of 4. Second, we use the experimental data in conjunction with the electromagnetic model to demonstrate the fundamental dependence of the MOKE in these structures on n and k and, most important, the reflectance of the structure. In this way we can completely understand the spectral MOKE behavior in these structures, and can engineer the MOKE spectra as desired through adjustments in layer thickness and choice of substrate material.

The samples used for these experiments consisted of glass substrates on which 500-Å-thick silver films were evaporated, followed by magnetron-sputtered, compositionally modulated Dy(7*a*)/Co(5*A*) magnetic layers. The various samples had amorphous magnetic layers of total nominal thicknesses of 72, 108, 204, 372, and 2000 Å. From both the MOKE hysteresis loops and independently measured magnetization measurements,[6] we know that these films exhibit perpendicular magnetic anisotropy.

The samples were characterized by normal incidence Kerr spectroscopy (NIKS), which provides the Kerr rotation at normal incidence, and variable angle spectroscopic ellipsometry (VASE), which yields the pseudodielectric function for the structure. Subsequent analysis of the VASE data using a multilayer optical modeling program[7,8] provided the optical constants for both the silver layer and the magnetic overlayers. Bulk values for both the optical and magneto-optical constants were obtained from the 2000-Å-thick sample using a VASE system adapted to make MOKE measurements.[9]

Figure 1 shows the measured MOKE spectra over the photon energy range 1.5–3.7 eV. Note that the position and magnitude of the rotation peak is extremely sensitive to the overlayer thickness, and that the peak broadens and shifts to lower energies as the overlayer becomes thicker.

Figure 2 shows the reflectivity spectra for the same set of samples. These spectra are derived from the VASE measurements previously described. Note the change in the character of the spectra from silver-like to the smooth bulk Dy/Co curve as the overlayer thickness is increased. Also note that, as would be expected, the energies at which the MOKE peaks occur in Fig. 1 coincide with the energies at which the reflectance is minimal in Fig. 2. This is due to the cancellation of the isotropic component of the reflected beam associated with the reflectance minima in Fig. 2.

Figure 3 shows the real ($E1$) and imaginary ($E2$) parts of the complex optical dielectric function ϵ_{xx} for the Dy/Co layers for all samples, obtained from analysis of VASE data. Notice that there is a distinct dependence on the overlayer thickness. The off-diagonal elements of the dielectric tensor

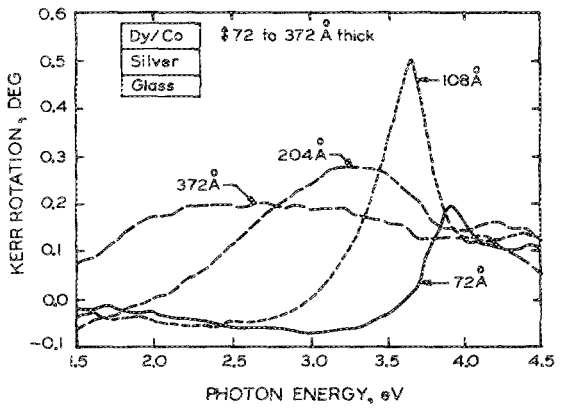

FIG. 1. Measured magneto-optic Kerr rotations in a series of Dy(7*A*)/Co(5*A*)/Ag/glass samples, with the Dy/Co multilayer total thicknesses indicated.

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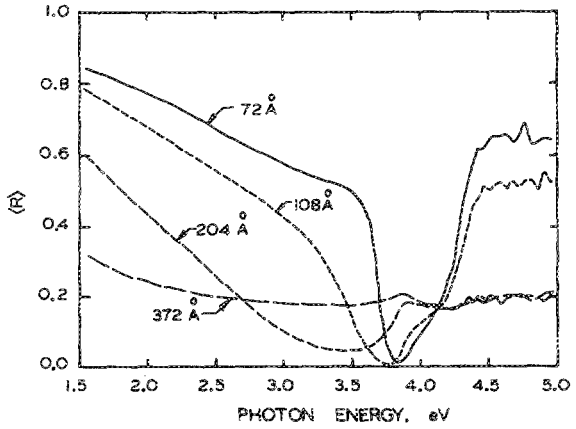

FIG. 2. Reflectivity spectra for samples described in Fig. 1.

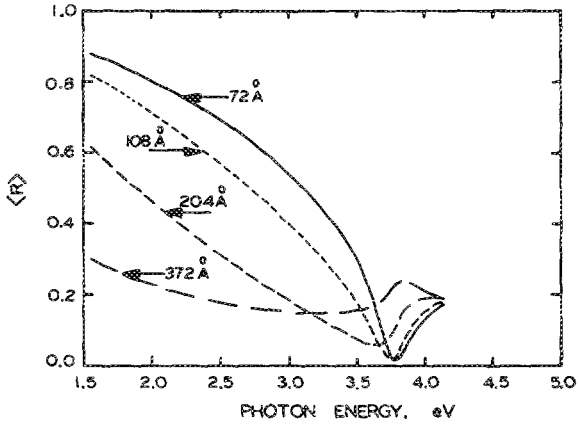

FIG. 4. Calculated reflectance for the Dy(7Å)/Co(5Å) layers.

(ϵ_{xy}) were obtained for the thick (2000 Å) sample from variable angle spectroscopic magneto-optic ellipsometry.[9]

Using the values for the complete dielectric tensor for each layer in the system, we calculate the expected Kerr rotation spectra for the samples. For this calculation we use the bulk optical and magneto-optical constants for the layers, i.e., we assume that the optical and magneto-optical constants remain relatively constant over the range of layer thicknesses in the study. This calculation is performed using the characteristic matrix method, where a transfer matrix is calculated to express the relationship between the tangential field components at the front and back sides of a given film.[10] After the characteristic matrix has been calculated for each layer, elementary matrix manipulations yield both the optical and magneto-optical spectra for the system of interest. Results of these calculations for the samples previously described are shown in Figs. 4 and 5. Note in Fig. 5 that the peak rotation value is very narrow and highly sensitive to the thickness of the overlayer. For this reason, we expect qualitative agreement between measured and calculated spectra, as slight errors in overlayer thickness will greatly effect the calculated spectra. We plan to alleviate this problem by implementing model fitting algorithms to perform a best-fit analysis of the experimental data.

The resonant behavior of both the observed and calculated spectra is quite easily understood in terms of the optical constants of the system. As the overlayer thickness goes from very thin to very thick, the optical character of the system changes smoothly from that of the substrate (silver in this case) to that of the overlayer. This effect is most easily observed in the reflectance spectra (Fig. 2). Note that the spectrum for the thinnest overlayer (72 Å) exhibits the sharp plasma edge and reflectance minimum characteristic of the silver underlayer, while the thickest sample shows the structureless behavior of the amorphous overlayer. This smooth mixing of the optical character of the system is the sole cause of the resonant behavior of the Kerr spectra. For the thin overlayers, the isotropic component of the reflected beam is suppressed at the plasma edge of the silver under-

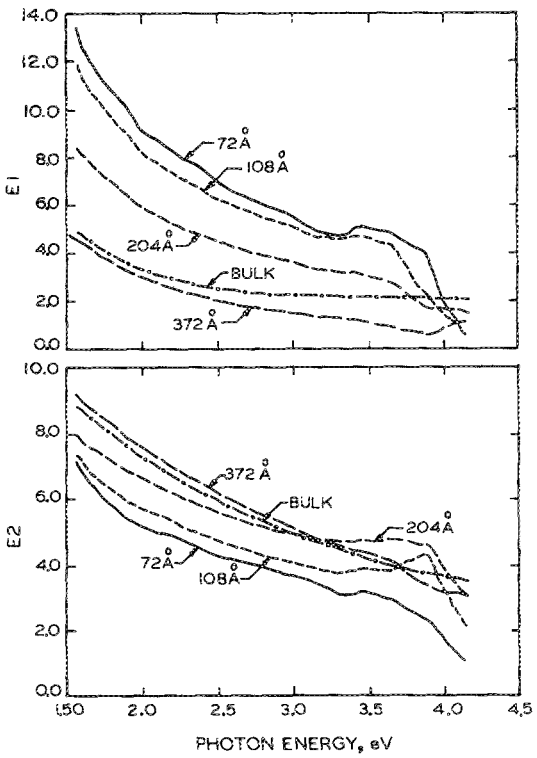

FIG. 3. Measured real (E_1) and imaginary (E_2) parts of the optical dielectric response function for the Dy(7Å)/Co(5Å) layers with the total thicknesses indicated.

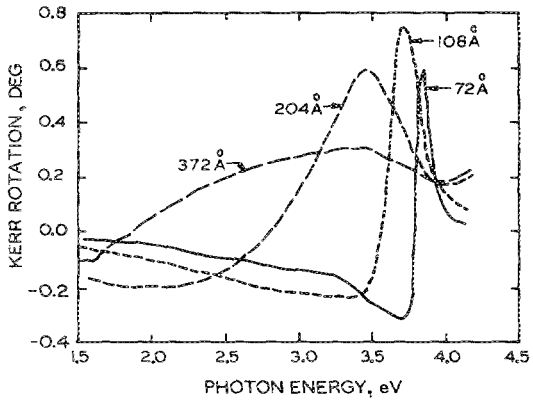

FIG. 5. Calculated Kerr rotation as a function of Dy/Co layer thickness and photon energy for the structure shown in the inset of Fig. 1.

layer. As a basic tool for understanding, we recall the basic equation for the Kerr effect in a system described by a single Jones matrix:

$$E_r = \begin{pmatrix} R_p & K_p \\ K_s & R_s \end{pmatrix} E_i.$$

At normal incidence, the complex Kerr effect is given by $\Psi_K = \theta_k - i\zeta_k = K_p/R_s$. Now, K_p represents the anisotropic component of the scattered light, while R_s will represent the isotropic component. We see that, in this approximation, minimization of the isotropic reflected signal will provide enhancement of the derived parameter which is the Kerr effect. Hence, a system of layers designed to suppress the isotropic component of the reflected light will display an enhanced Kerr effect, provided there exists some anisotropically scattered component of the beam.

In conclusion, we have offered a simple explanation for the resonant enhancement of the polar Kerr effect in layered systems such as the magnetic layer/silver layer system investigated in this work. We have shown that this enhancement is controllable due to the smooth dependence on the overlayer thickness, and that it is entirely a consequence of the optical character of the system.

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