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Thickness dependence of interfacial magneto-optic effects in Pt/Co multilayers

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Spectroscopic ellipsometry and magneto-optic Kerr effects are measured on Pt/Co multilayers with a series of Co layer thicknesses from 0.08 to 1 nm. An electromagnetic theory of multilayered structures allows regression analysis fits between acquired data and parameter dependent model analysis. Recently, we determined the single layer Co magneto-optic Voigt parameter and found that it depends on Co layer thickness. In the present work, we report an in-depth study of interfacial magneto-optic effects for a large number of Pt/Co multilayer samples. Kerr rotation and ellipticity were measured over the spectral range from 200 to 1700 nm. Voigt parameters of the magnetic layers for these Pt/Co multilayer samples with different thicknesses were compared, and the Pt–Co interface thicknesses were determined in terms of the material dielectric tensor. [S0021-8979(98)46711-2]

I. INTRODUCTION

Metallic multilayers of Pt/Co are very promising magneto-optic (MO) media, especially for the short wavelength range.[1] Our recent studies have shown that the Pt–Co interface regions and the Co rich regions contribute differently to the magneto-optic response, with the Pt–Co interface making the greater contribution.[2] That is, off-diagonal components of the complex dielectric tensor for the Pt–Co interface are greater in magnitude than those of the Co rich regions. In the study reported in Ref. 2, the thicknesses of the interfaces were assumed to be equal to one atomic layer of Pt, since the growth was at room temperature, resulting in minor atom mixing. Also in our previous work, magneto-optic response studies were limited to the spectral range from 300 to 700 nm.

Due to the larger contribution of the Pt–Co interface to the total MO response, the actual thickness of this interface is very important for the optimum design of Pt/Co multilayer structures. In this article, MO data from a much wider spectral range for two sets of ten Pt/Co multilayer samples are presented. Each set has the same Pt layer thickness and a series of ten magnetic layer thicknesses from very thin to reasonably thick. The magnetic layer (denoted as ''mag-opt'' layer) includes the Co rich regions as well as the Pt–Co interface regions. The off-diagonal components of the mag-opt layer's dielectric tensor are determined from experiments using electromagnetic magneto-optic theory,[3,4] in an effort to decide the beginning of the Co rich region and the thickness of Pt–Co interface.

II. THEORY AND EXPERIMENT

An electromagnetic theory (originally proposed by Lissberger and others)[5] was developed and simplified by McGahan and He for the case of normal incidence polar Kerr effects.[3,4] A Jones matrix was used to describe the optical properties of the multilayer structure, as given by

$$\mathbf{J}=\begin{pmatrix} R_x & K_y \\ K_x & R_y \end{pmatrix}. \tag{1}$$

The reflected light beam is related through this Jones matrix to the incident beam by $\mathbf{E}^r=\mathbf{J}\cdot\mathbf{E}^i$, where r and i denote ''reflected'' and ''incident.'' Kerr rotation and ellipticity θ_k and η_k are defined by $\theta_k=\mathrm{Re}\{K_x/R_x\}$ and $\eta_k=\mathrm{Im}\{K_x/R_x\}$.

For multilayer systems, each of the four elements in the Jones matrix is a function of the thickness and dielectric tensors of the individual layers. The uniaxially symmetric dielectric tensor is given by

$$\tilde{\epsilon}=\begin{pmatrix} \tilde{\epsilon}_{xx} & -\tilde{\epsilon}_{xy} & 0 \\ \tilde{\epsilon}_{xy} & \tilde{\epsilon}_{xx} & 0 \\ 0 & 0 & \tilde{\epsilon}_{zz} \end{pmatrix} \tag{2}$$

and the Voigt parameters are defined as $\tilde{Q}=Q_1+jQ_2=-i\tilde{\varepsilon}_{xy}/\tilde{\epsilon}_{xx}$. The Q value is a direct indication of the magnitude of the MO response, which increases with increasing Voigt parameter.[3,4]

To determine the MO responses of the multilayer structures, *in situ* spectroscopic ellipsometry (*in situ* SE) analysis was used to determine the layer thicknesses and diagonal components of the dielectric tensor for each individual layer. In this article these are Pt and mag-opt layers. MO Kerr rotation and ellipticity data were then taken on the samples. The Voigt parameters were determined by regression fitting the MO data to models using Voigt parameters as variables.[1] The layer thicknesses and diagonal dielectric components were obtained from *in situ* SE.

III. EXPERIMENTAL RESULTS AND ANALYSIS

Two series of Pt/Co multilayer structures were deposited using dc magnetron sputtering. *In situ* SE data were taken during the depositions. The thicknesses for the Pt and mag-opt layers in the multilayer structures were determined using

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TABLE I. Thicknesses of samples 1 through 10 (a), and samples 11 through 20 (b) for two series of 50 period multilayers.

(a) Sample No. (50 periods)	1	2	3	4	5	6	7	8	9	10
Pt layer thickness (nm)	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Mag-opt layer thickness (nm)	0.08	0.16	0.24	0.32	0.40	0.47	0.55	0.71	0.87	1.03

(b) Sample No. (50 periods)	11	12	13	14	15	16	17	18	19	20
Pt layer thickness (nm)	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2 04	2.04	2 04
Mag-opt layer thickness (nm)	0.08	0.16	0.24	0.32	0.40	0.47	0.55	0.71	0.87	1.03

in situ ellipsometric analysis. Meanwhile, the optical constants (diagonal components of the dielectric tensor) of the Pt and mag-opt layer were determined. The thicknesses of the Pt and mag-opt layers of all samples are listed in Table I.

Magneto-optic Kerr rotation and ellipticity data were taken using a modified *ex situ* ellipsometer system.[6] The spectral ranges of the measurements were from 200 to 1700 nm (0.73 to 6.2 eV). The MO data taken from all samples listed in Table I are shown in Fig. 1. As one can see from Figs. 1(a) and 1(b), the magnitudes of the MO Kerr rotation and ellipticity data increase as the mag-opt layer thickness increases from 0.08 to 0.87 nm, when the Pt layer thickness is fixed at 1.02 nm. There is almost no rotation or ellipticity change between samples 9 and 10. Likewise, for the data in Figs. 1(c) and 1(d), the responses increase as the mag-opt layer thickness increases from 0.08 to 0.71 nm when the Pt layer thickness is fixed at 2.04 nm. The effect saturates for mag-opt layers thicker than 0.71 nm, since the thicker Pt layer prevents the incident light from reaching the bottom mag-opt layers. (Note that there are 50 periods of the multilayers.)

Using the MO analysis described above, the Voigt parameters for the mag-opt layers of each sample were determined by regression fits.[6] Fits were not unique for the samples with mag-opt layer thicknesses smaller than 0.32 nm, likely because it is too thin to form an actual layer. Fits were excellent and unique for samples with mag-opt layer thicknesses equal to or thicker than 0.32 nm. The spectral range for Voigt parameter fits were limited to 280 to 760 nm, the same as the *in situ* SE spectral range. During the regression fits, equal values of Voigt parameters were assumed for samples with the same mag-opt layer thicknesses but different Pt layer thicknesses.[2]

In Fig. 2, the Voigt parameters at a wavelength of 350 nm for samples with mag-opt layer thicknesses equal to or larger than 0.32 nm are plotted. We see that, starting from the sample with a 0.40 nm mag-opt layer thickness, the magnitudes of Voigt parameters decrease as the mag-opt layer thicknesses increase. However, the results are almost identical for the sample with 0.32-nm-thick mag-opt layer and 0.40-nm-thick mag-opt layer. As described in the Intro-

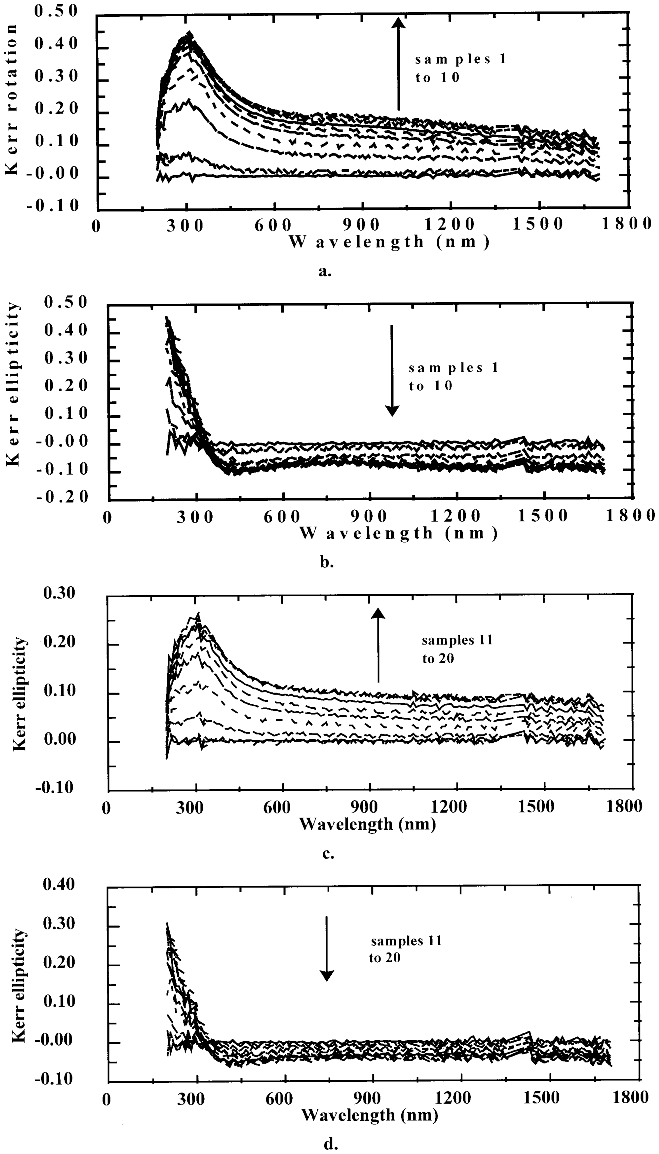

FIG. 1. (a) Kerr rotation data for samples 1 to 10 listed in Table I. (b) Kerr ellipticity data for samples 1 to 10 listed in Table I. (c) Kerr rotation data for samples 11 to 20 listed in Table I. (d) Kerr ellipticity data for samples 11 to 20 listed in Table I.

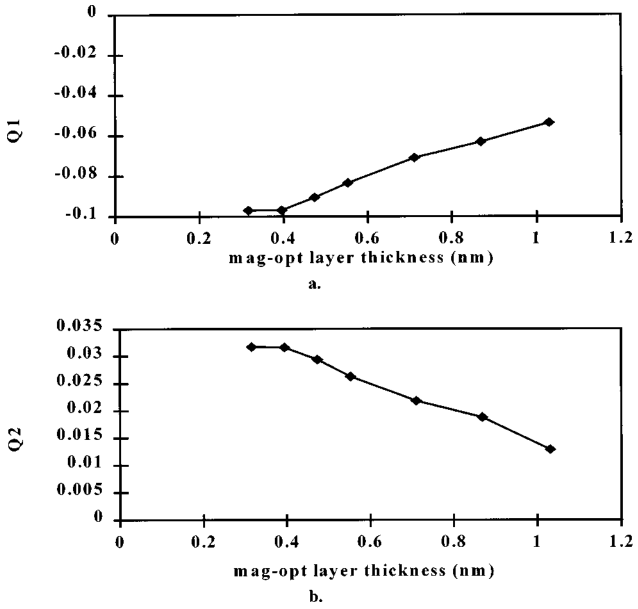

FIG. 2. Voigt parameters Q1 (a), and Q2 (b) determined from regression fits for the MO responses in Fig. 1 on samples 4 to 10 and samples 14 to 20.

duction, there are actually two regions, the Co rich region and the Pt–Co interface, in the Pt/Co multilayer structure, and the Voigt parameters for the Pt–Co interface region are larger. Therefore, the pseudo-Voigt parameters (the Voigt parameter determined if there were only one homogeneous region) for both the Co rich region, and the Pt–Co interface should decrease with increase in mag-opt layer thickness. The equal Q values for the sample with 0.32-nm-thick mag-opt layers and 0.40 nm mag-opt layers indicate that the Co rich regions have disappeared. On the other hand, the decrease of the Voigt parameters for samples with mag-opt layer thicknesses larger than 0.4 nm indicates that the formation of Co rich regions begins at a thickness of around 0.4 nm (smaller than 0.47 nm). This is very close to the value we *assumed* in earlier research.[2]

IV. SUMMARY

Wide spectral range magneto-optic Kerr rotation and ellipticity responses from two series of Pt/Co multilayer structures were measured. An optimal choice between Co layer thicknesses and number of multilayer periods can be made, thus maximizing the magneto-optic Kerr response for practical applications. Finally, by comparing the Voigt parameters of the magnetic layer for samples with mag-opt layer thickness greater than 0.32 nm, a Pt–Co interface thickness of around 0.40 nm was determined.

ACKNOWLEDGMENTS

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