Spectroscopic Kerr investigations of CoNi/Pt multilayers

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Co$_x$Ni$_{1-x}$/Pt multilayers with $x=0.4$ and 0.5 were sputtered onto Si substrates. Magnetic and spectroscopic magneto-optic measurements (1.4--5.2 eV) reveal a Kerr rotation up to $-0.48^\circ$ at about 4.5 eV for a sample with rectangular hysteresis loop, about 170 kA/m coercivity, and a Curie temperature of about 300°C. Pt layers could be made extremely thin (2.9 Å) without loss of perpendicular anisotropy and rectangular hysteresis loop. Simulations show that the Kerr rotation peak shifts back from 4.5 to 3.9 eV with increasing number of bilayers. © 1996 American Institute of Physics. [S0021-8979(96)13208-6]

I. INTRODUCTION

The interest in Co/Pt based multilayers as magneto-optical recording material is due to several merits: the high magneto-optical (MO) output at short wavelengths, due to the polarized Pt$^2$ or alloy layers at the interfaces, the high corrosion resistance, and the high perpendicular anisotropy $K_{\text{eff}}$ in very thin layers. A disadvantage is the relatively high Curie temperature $T_C$, which reduces writability. By alloying Co with another element, $T_C$ can be lowered, but the favorable properties of Co/Pt should be preserved in the new material. We tried to alloy Co with Ni, as the magnetic phase diagram indicated that $T_C$ decreases significantly with Ni content. Recently, this was confirmed by a study of CoX/Pt multilayers.

II. EXPERIMENT

CoNi/Pt multilayers (ML) were prepared by magnetron sputtering from 2 in. sputter guns in argon pressures $8 \leq P_{\text{ar}} \leq 48$ μbar. The guns were equipped with shutters and the time between deposition of subsequent layers was about 2 s. The target-substrate distance was fixed at 100 mm, which keeps the substrate relatively plasma free. The samples were prepared on 2 in. Si (111) wafers, which were cleaned in a standard way before insertion. The ML always consisted of a Pt base layer (typically 400 Å) and a stack of 17 or 18 bilayers. Sputter rates were between 1 and 2.5 Å/s. The background pressure before deposition was $<10^{-8}$ mbar. Layer thicknesses were measured by x-ray diffraction (XRD) (low and high angle) and Dektak surface profiler, both on thick layers (of CoNi resp. Pt) and on ML. The bilayer peak was visible up to $P_{\text{ar}} = 40$ μbar. Above that the structure is too distorted to observe.

Kerr rotation $\theta_K$ and ellipticity $e_K$ of uncoated samples were measured in the range 1.4--5.2 eV by a homemade, automated setup applying the photoelastic modulator principle. The accuracy was about 0.001°, and an automatic calibration for both $\theta_K$ and $e_K$ is performed before each measurement. Details of this calibration will be published elsewhere. A sample heater in the Kerr setup served as the $T_C$ measurement stage.

Magnetic measurements were carried out with a vibrating-sample magnetometer (VSM) ($H_{\text{max}} = 3$ T, resolution $5 \times 10^{-9}$ A m$^2$) and a homemade torque meter ($H_{\text{max}} = 1.8$ T, resolution $3 \times 10^{-9}$ Nm).

III. RESULTS AND DISCUSSION

Perpendicular (⊥) anisotropy was found for both Co$_{40}$Ni$_{60}$/Pt and Co$_{50}$Ni$_{50}$/Pt ML in the range $4 \leq t_{\text{CoNi}} \leq 20$ Å, where $t_{\text{Pt}} = 15$ Å. The ⊥ anisotropy was found for very thin Pt layers: a $17 \times (5.5$ Å Co$_{40}$Ni$_{60}/2.8$ Å Pt) ML still had $K_{\text{eff}} > 0$. $K_{\text{eff}}$ can be decomposed in a surface and a volume anisotropy ($K_S$ resp. $K_V$) by

$$t_{\text{magn}}K_{\text{eff}} = 2K_S + t_{\text{magn}}K_V,$$

where $t_{\text{magn}}$ is the thickness of the magnetic layer.

For the 50% (40%) Co multilayers $K_S = 0.26 (0.21)$ mJ/m$^2$ and $K_V = -257 (-185)$ kJ/m$^2$ were found. These values are in good agreement with others. The maximum ⊥ anisotropy was found for $5 \leq t_{\text{CoNi}} \leq 8$ Å in both cases.

Figure 1 displays spectroscopic Kerr measurements of a series of 230 Å Pt + 17 × (X Å Co$_{50}$Ni$_{50}$/14.7 Å Pt). The thinnest magnetic layer (3.8 Å CoNi) gives the lowest $\theta_K$. In this case $M_{\text{S,CoNi}}$ is also very low, which suggests that the magnetic layers are not continuous. $\theta_K$ increases gradually with increasing $t_{\text{CoNi}}$ to a maximum of about $-0.30^\circ$ at $t_{\text{CoNi}} = 25$ Å. Thicker CoNi layers did lower $\theta_K$ (not drawn). Enhancement due to more CoNi in the skin-depth layer is counteracted by the reduction of the amount of polarized Pt in this region, which is dependent on the number of interfaces.

It is clear that $\theta_K$ at lower photon energies increases with increasing $t_{\text{CoNi}}$ and the features of the Co and Ni spectra (e.g., the peak in $\theta_K$ around 1.5 eV) become more pronounced. The same can be seen for $e_K$, where the spectrum for the sample with 25 Å CoNi layers resembles a mix of the bulk Co and Ni curves. The MO contribution of polarized Pt at high photon energies is found for thin magnetic layers.

The samples with $t_{\text{Co$_{50}$Ni$_{50}$}} = 5$, 6.3, and 8.8 Å have ⊥ anisotropy and unity squareness. Of these, only the first sample has a rectangular hysteresis loop, and therefore $t_{\text{Co$_{50}$Ni$_{50}$}} = 5$ Å was chosen as the starting point for a Pt thickness variation. Figure 2 displays the spectroscopic Kerr measurements for $t_{\text{Co$_{50}$Ni$_{50}$}} = 5$ Å, and $t_{\text{Pt}} = 14.7$, 8.4, and 5.9 Å.

Even the 5.9 Å sample is perpendicular, in contrast to Co/Pt ML's with similar layer thicknesses. At high photon energies
\( \theta_K \) increases considerably with decreasing \( t_{\text{Pt}} \). The maximum value is \( \theta_K = -0.48^\circ \) for \( t_{\text{Pt}} = 5.9 \, \text{Å} \), and this is the highest value observed by us for any CoNi/Pt ML. With decreasing \( t_{\text{Pt}} \), the energy at which the peak occurs shifts up from 4.0 to 4.6 eV. This shift is due to the decreasing total layer thickness, as will be shown by simulations in the next paragraph. Spectroscopic studies of Co/Pt multilayers,\(^{13,14}\) CoPt alloys,\(^{15,16}\) and CoNi/Pt multilayers\(^{11}\) did not reveal such peak shifts, as those results are all taken of ML’s that are optically thick.

Figure 3 shows the Kerr hysteresis loop of the sample with a stack of 5 Å CoNi/5 Å Pt, taken at 4.13 eV. The loop features unity squareness and high rectangularity. This sample was sputtered at 40 μbar, which results in a high \( H_C \approx 170 \, \text{kA/m} \). Although high \( P_s \) is a poor way to introduce a morphology that supports a high \( H_C \) (due to the increase in media noise), Fig. 3 demonstrates that it is possible to make a CoNi/Pt multilayer with high rectangularity, high \( H_C \), and high \( \theta_K \) at short wavelengths.

**IV. SIMULATION OF KERR EFFECTS**

Because the thickness of these ML’s is of the order of the skin depth\(^{16}\) (which is between 10.5 and 13.5 nm for CoNi and Pt between 1.5 and 4.0 eV), it is of interest to estimate the Kerr effects for an optical thick ML. Using a simulation based on the mathematical approach of Visnovsky\(^{17}\) the Kerr effects for arbitrary \( N \) were calculated using the measurement results for the thin ML as a starting point. In this way it is possible to estimate the Kerr effect of a thick ML from the measurement of a thin one. The approach was as follows: (1) Calculate the MO Voigt constants \( Q(\lambda) \) of either polarized Pt or CoNiPt alloy layers at the interface by fitting these constants in such a way that the calculation gives the same \( \theta_K \) and \( \epsilon_K \) as the measurement. (2) These \( Q(\lambda) \) are used to calculate the \( \theta_K \) and \( \epsilon_K \) for a hypothetical \( N \) bilayer medium, with arbitrary \( N \).

The layer structure of our “best sample,” including the Pt seedlayer and 100 nm of the Si substrate, was used as input for the simulation. Now one can either assume that alloyed layers occur at the interface, or that no alloying occurs, and Pt polarizes at the interfaces. For the alloyed layer, a weighted mix of the optical constants of its constituents was taken. Both schemes were applied with several thicknesses of the polarized resp. the alloyed layer, and negligible

![Fig. 1: Spectroscopic Kerr measurements for 230 Å Pt+17 Å(X Co<sub>90</sub>Ni<sub>10</sub>/14.7 Å Pt). The series ranges from X = 3.8 to 25 Å.](image1)

![Fig. 2: Spectroscopic Kerr measurements for three samples with decreasing Pt thickness. The samples are 100 Å Pt+17×(5 Å Co<sub>90</sub>Ni<sub>10</sub>/X Pt) with X = 5.9, 8.4, and 14.7 Å.](image2)

![Fig. 3: Kerr hysteresis loop at \( E_{\text{photon}} = 4.13 \, \text{eV} \) for 100 Å Pt+17×(5 Å Co<sub>90</sub>Ni<sub>10</sub>/5.9 Å Pt). The loop has good rectangularity, which is imperative for MO recording.](image3)
The simulated $\epsilon_K$ decreases faster with increasing photon energy and the overall output is larger (both positive and negative) than in the measurement.

V. CONCLUSIONS

Co$_x$Ni$_{1-x}$/Pt ML's with $x=0.4$ and 0.5 were prepared by magnetron sputtering. Perpendicular anisotropy was achieved up to $t_{\text{CoNi}}=20$ Å for both compositions. A sample of $17 \times (5$ Å Co$_{40}$Ni$_{60}$/2.8 Å Pt) was still perpendicular. We attribute this to the lower magnetic moment of CoNi compared to pure Co, which on its turn reduces the demagnetizing field. $\theta_K=-0.48^\circ$ was found for $17 \times (5$ Å Co$_{50}$Ni$_{50}$/5.9 Å Pt). A large $H_C$ (170 kA/m) and high squareness were other features of this sample.