Spectroscopic Kerr investigations of CoNi/Pt multilayers

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Co_xNi_{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° 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,¹ due to the polarized Pt² or alloy layers³ at the interfaces, the high corrosion resistance, and the high perpendicular anisotropy K_{eff} in very thin layers. A disadvantage is the relatively high Curie temperature T_C , which reduces rewritability. 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,⁴ as the magnetic phase diagram⁵ indicated that T_C decreases significantly with Ni content. Recently, this was confirmed by a study of CoX/Pt multilayers.⁶

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 θ_K and ellipticity ϵ_K of uncoated samples were measured in the range 1.4–5.2 eV by a homemade, automated setup applying the photoelastic modulator principle.^{7–9} The accuracy was about 0.001° , and an automatic calibration for both θ_K and ϵ_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, resolu-

tion 5×10^{-9} A m²) and a homemade torque meter ($H_{\text{max}}=1.8$ T, resolution 3×10^{-9} Nm).

III. RESULTS AND DISCUSSION

Perpendicular ($\perp$) anisotropy was found for both Co₄₀Ni₆₀/Pt and Co₅₀Ni₅₀/Pt ML in the range $4 \leq t_{\text{CoNi}} \leq 20$ Å, where $t_{\text{Pt}} \approx 15$ Å. The $\perp$ anisotropy was found for very thin Pt layers: a $17 \times (5.5$ Å Co₄₀Ni₆₀/2.8 Å Pt) ML still had $K_{\text{eff}} > 0$. K_{eff} can be decomposed in a surface and a volume anisotropy (K_S resp. K_V) by¹⁰

$$t_{\text{magn}} K_{\text{eff}} = 2K_S + t_{\text{magn}} K_V, \quad (1)$$

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

For the 50% (40%) Co multilayers $K_S=0.26$ (0.21) mJ/m² and $K_V=-257$ (–185) kJ/m³ were found. These values are in good agreement with others.^{11,12} The maximum $\perp$ 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 Co₅₀Ni₅₀/14.7 Å Pt). The thinnest magnetic layer (3.8 Å CoNi) gives the lowest θ_K . In this case $M_{S,\text{CoNi}}$ is also very low, which suggests that the magnetic layers are not continuous. θ_K increases gradually with increasing t_{CoNi} to a maximum of about -0.30° at $t_{\text{CoNi}}=25$ Å. Thicker CoNi layers did lower θ_K (not drawn). Enhancement due to more CoNi in the skin-depth region 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 θ_K at lower photon energies increases with increasing t_{CoNi} and the features of the Co and Ni spectra (e.g., the peak in θ_K around 1.5 eV) become more pronounced. The same can be seen for ϵ_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 $t_{\text{CoNi}}=5.0, 6.3$, and 8.8 Å have $\perp$ anisotropy and unity squareness. Of these, only the first sample has a rectangular hysteresis loop, and therefore $t_{\text{CoNi}}=5$ Å was chosen as the starting point for a Pt thickness variation. Figure 2 displays the spectroscopic Kerr measurements for $t_{\text{CoNi}}=5$ 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

FIG. 1. Spectroscopic Kerr measurements for 230 Å Pt + 17x (X Co₅₀Ni₅₀/14.7 Å Pt). The series ranges from X = 3.8 to 25 Å.

θ_K increases considerably with decreasing t_{Pt} . The maximum value is $\theta_K = -0.48^\circ$ for $t_{Pt} = 5.9$ Å, and this is the highest value observed by us for any CoNi/Pt ML. With decreasing t_{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,^{14,15} and CoNi/Pt multilayers¹¹ 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/5.9 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 $H_C \approx 170$ kA/m. Although high P_{ar} 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 θ_K at short wavelengths.

IV. SIMULATION OF KERR EFFECTS

Because the thickness of these ML's is of the order of the skin depth¹⁶ (which is between 10.5 and 13.5 nm for Co, Ni 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 Visnovsky¹⁷ 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

FIG. 2. Spectroscopic Kerr measurements for three samples with decreasing Pt thickness. The samples are 100 Å Pt + 17x (5 Å Co₅₀Ni₅₀/X Pt) with X = 5.9, 8.4, and 14.7 Å.

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 θ_K and ϵ_K as the measurement.

(2) These $Q(\lambda)$ are used to calculate the θ_K and ϵ_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. 3. Kerr hysteresis loop at $E_{\text{photon}} = 4.13$ eV for 100 Å Pt + 17x (5 Å Co₅₀Ni₅₀/5.9 Å Pt). The loop has good rectangularity, which is imperative for MO recording.

FIG. 4. Simulated Kerr rotation and Kerr ellipticity for several numbers of bilayers N . Measurement of 100 Å Pt + 17 × (5 Å Co₅₀Ni₅₀/5.9 Å Pt) (points) was taken as a starting point for the simulations.

differences between these schemes were found. This corresponds to the expectation that such a thin stack behaves as a single optical layer. For the following a 3 Å alloy layer model was taken. In Fig. 4 measurement and simulations are shown for $N=10, 30$, and 100 .

According to the simulations the maximum $\theta_{K,\max}$ should be reached at about 30 bilayers. $\theta_{K,\max}$ calculated by simulations of $N=20, 25, 40$, and 50 (not drawn) was lower than in the $N=30$ case. $\theta_{K,\max}$ for $N=30$ occurs at about 4.1 eV, which is in good agreement with reported results for Co/Pt. θ_K decreases for $N<17$. In the range 1.5–4 eV the simulated optical thick layer has a higher θ_K than the thin one. The UV peak for $N=100$ occurs at a $E_{\text{photon}} \sim 3.9$ eV. This is slightly lower than the 4.2 eV that is expected for the contribution of Pt in Co/Pt ML's and it is certainly lower than the peak position in the measurement. The simulation for the optical thick layer ($N=100$) gives $\theta_{K,\max} = -0.46^\circ$. This is lower than the measurement for $N=17$ ($\theta_K = -0.48^\circ$), but for application purposes it occurs at a much more favorable photon energy.

The simulated ϵ_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 × (5 Å Co₄₀Ni₆₀/2.8 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 × (5 Å Co₅₀Ni₅₀/5.9 Å Pt). A large H_C (170 kA/m) and high squareness were other features of this sample.

- ¹W. B. Zeper, F. J. A. M. Greidanus, and P. F. Carcia, IEEE Trans. Magn. **MAG-25**, 3764 (1989).
- ²E. R. Moog, J. Zak, and S. D. Bader, J. Appl. Phys. **69**, 880 (1991).
- ³J. Nakajima, A. Takahashi, K. Ohta, and T. Ishikawa, J. Magn. Soc. Jpn. **15**, Suppl. S1, 41 (1991).
- ⁴M. Mes, J. C. Lodder, T. Takahata, I. Moritani, and N. Imamura, J. Magn. Soc. Jpn. **17**, Suppl. S1, 44 (1993).
- ⁵W. Bendick and W. Pepperhoff, J. Phys. F. **9**, 2185 (1979).
- ⁶S. Hashimoto, J. Appl. Phys. **75**, 438 (1994).
- ⁷S. N. Jaspersion, D. K. Burge, and R. C. O'Handley, Surf. Sci. **37**, 548 (1973).
- ⁸K. Sato, Jpn. J. Appl. Phys. **20**, 2403 (1981).
- ⁹P. Q. J. Nederpel and J. W. D. Martens, Rev. Sci. Instrum. **56**, 687 (1985).
- ¹⁰H. J. G. Draaisma, W. J. M. de Jonge, and F. J. A. den Broeder, J. Magn. Mater. **66**, 351 (1987).
- ¹¹R. Krishnan and H. Lassri, J. Magn. Mater. **133**, 453 (1994).
- ¹²R. Krishnan, H. Lassri, M. Seddat, M. Porte, and M. Tessier, Appl. Phys. Lett. **64**, 2312 (1994).
- ¹³H. Brändle, D. Weller, J. C. Scott, S. S. P. Parkin, and C.-J. Lin, IEEE Trans. Magn. **MAG-28**, 2967 (1992).
- ¹⁴D. Weller, W. Reim, K. Spörl, and H. Brändle, J. Magn. Mater. **93**, 183 (1991).
- ¹⁵K. Sato, H. Ikekame, Y. Tosaka, K. Tsuzuki, Y. Togami, and M. Fujisawa, J. Magn. Mater. **126**, 572 (1993).
- ¹⁶R. M. A. Azzam and N. M. Bashara, *Ellipsometry and Polarized Light* (North-Holland, Amsterdam, 1977), p. 75, ISBN 0-7204-0694-3.
- ¹⁷S. Visnovsky, J. Magn. Soc. Jpn. **15**, Suppl. S1, 67 (1991).