May 1994

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Y. B. Zhang
University of Nebraska - Lincoln

P. He
University of Nebraska - Lincoln

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

J. X. Shen
University of Nebraska - Lincoln

Roger D. Kirby
University of Nebraska-Lincoln, rkirby1@unl.edu

See next page for additional authors

Authors
Y. B. Zhang, P. He, John A. Woollam, J. X. Shen, Roger D. Kirby, and David J. Sellmyer

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Y. B. Zhang, P. He, and J. A. Woollam
Center for Microelectronic and Optic Materials Research, and Department of Electrical Engineering, University of Nebraska, Lincoln, Nebraska 68588

J. X. Shen, R. D. Kirby, and D. J. Sellmyer
Center for Materials Research and Analysis, and Department of Physics, University of Nebraska, Lincoln, Nebraska 68588

We have investigated the magnetic and magneto-optic properties of Co/Ni multilayers deposited on Ag and Au buffer layers. The samples with Au buffer layers show perpendicular magnetic anisotropy, but those with Ag buffer layers do not. The structure and degree of crystalline alignment of the buffer layer are evidently crucial to development of perpendicular magnetic anisotropy. We also present the results of polar Kerr rotation measurements as a function of wavelength and layer thickness of the multilayers.

INTRODUCTION

Magnetic multilayers have attracted much attention[1] due to the resulting novel properties that are suitable for a variety of applications. One interesting phenomenon is the so-called perpendicular magnetic anisotropy that has been found in Co/*X* (*X* being a nonmagnetic metal such as Pt, Pd, Au, or Ir) multilayers.[2–4] The large perpendicular magnetic anisotropy shown in these multilayers makes them potential candidates for MO recording media. Recently, Co/Ni multilayers were also predicted to have perpendicular magnetic anisotropy, and this was confirmed in *e*-beam evaporated multilayer samples.[5] Magneto-optic and thermomagnetic writing tests on this *e-beam evaporated* multilayer have yielded encouraging results.[6]

In this article, the magnetic and magneto-optic properties of *sputtered* Co/Ni multilayers are reported. The effects of Au and Ag buffer layers on the perpendicular magnetic anisotropy of the sputtered Co/Ni multilayers are discussed, then the dependencies of the magneto-optic properties on the wavelength and the multilayer structure parameters are presented.

EXPERIMENT

Samples were prepared using both dc and rf magnetron sputtering. The system was first evacuated to below 5×10^{-7} Torr before sputtering, and Ar gas (5×10^{-3} Torr) was used in the sputtering process. In most cases, 50-nm-thick Au or Ag buffer layers were first deposited onto glass substrates. The Co thickness was varied from 0.1 to 0.4 nm and the Ni thickness from 0.2 to 1.2 nm. Multilayered structures were realized by rotating the substrates above the separate guns. The total Co/Ni thickness was varied between 5 to 30 nm.

The magnetic properties were measured using an alternating gradient force magnetometer (AGFM). Crystalline texture studies were performed using x-ray diffractometry with a Cu $K\alpha$ target in the θ–2θ mode, and a scanning angle of 10°–90°. The Kerr rotation (θ_k) and the Kerr ellipticity (ϵ_k) were measured at normal incidence over the wavelength range from 300 to 800 nm using apparatus previously described.[7] All experiments are performed at room temperature.

RESULTS AND DISCUSSIONS

Figure 1(a) shows hysteresis loops obtained with the AGFM for Co(0.2 nm)/Ni(0.8 nm) on Ag for magnetic fields applied both in the plane and perpendicular to the film plane. Clearly, this sample has in-plane magnetic anisotropy, as did all other samples deposited on Ag buffer layers. In contrast, Fig. 1(b) shows perpendicular and parallel hysteresis loops for a similar multilayer deposited on a Au buffer layer. This sample clearly has perpendicular anisotropy, and the value of the uniaxial anisotropy constant (as determined by the loop-area method) is about 100 kJ/m^3. All of our Co/Ni multilayers deposited on Au showed perpendicular anisotropy, in agreement with the results of Daalderop *et al.*[5]

While the origins of perpendicular magnetic anisotropy (PMA) are often difficult to determine, PMA can be due to tensile internal stresses.[8] Thus the structural details of the buffer layer may be of considerable importance in determining the magnitude of the anisotropy. Figure 2 shows x-ray diffraction scans of the fcc Au and Ag buffer layers, each 50 nm thick. The dominant feature of both scans is the [111]

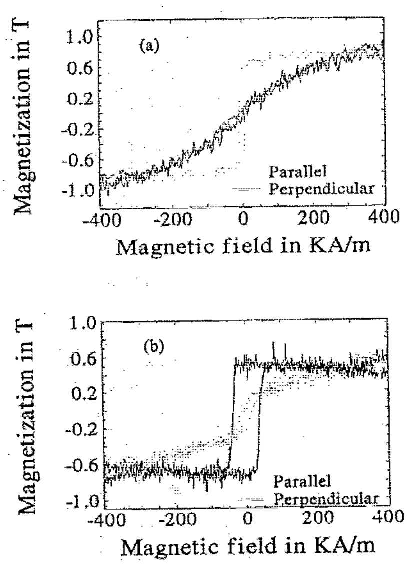

FIG. 1. Room temperature hysteresis loops for (a) Co(0.2)/Ni(0.8)×12 multilayers on Ag buffer layers and (b) Co(0.2)/Ni(0.8)×8 on Au buffer layers.

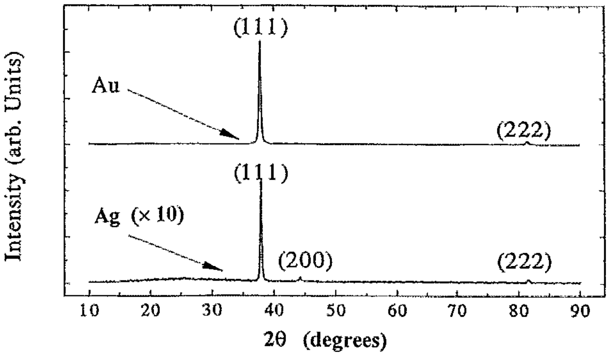

FIG. 2. 2θ x-ray diffraction patterns of Au and Ag buffer layers.

peak, indicating that the films are highly textured. The intensity of the Au peak is 10 times that of the Ag peak, whereas the ratio of the electron densities squared is only 2.8. This result suggests that the Au buffer layers exhibit either a higher degree of crystallinity or a higher degree of texture, either of which could lead to the differences in anisotropy. The presence of a weak [200] diffraction peak for the Ag buffer layer, but not for the Au buffer layer (see Fig. 2), is direct evidence that the Au buffer layer is more completely textured than the Ag buffer layer.

To further test these ideas, we carried out annealing experiments, where the buffer layer was annealed prior to deposition of the Co/Ni multilayer. Annealing the Ag buffer layer in vacuum at 400 °C for 1.5 h prior to depositing the Co/Ni multilayer resulting in significant changes in the shape of the perpendicular hysteresis loop. The remanence ratio M_r/M_s of the Co/Ni multilayers increased considerably, and the coercivity increased by a factor of nearly 5. However, the easy magnetization direction remained in the film plane. Similar annealing experiments on Au buffer layer resulted in only minor changes in the hysteresis loops. One can speculate that if the [111] texture of the Ag buffer layer could be improved, Co/Ni multilayers deposited on Ag might also show PMA.

The wavelength dependencies of θ_k and ϵ_k for Co/Ni multilayers on both Au and Ag buffer layers are shown in

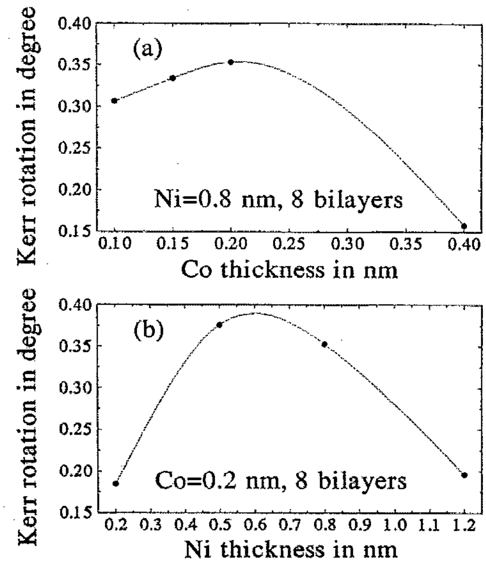

FIG. 4. Polar Kerr rotation at 350 nm as a function of (a) Co thickness and (b) Ni thickness for multilayers on Ag buffer layers.

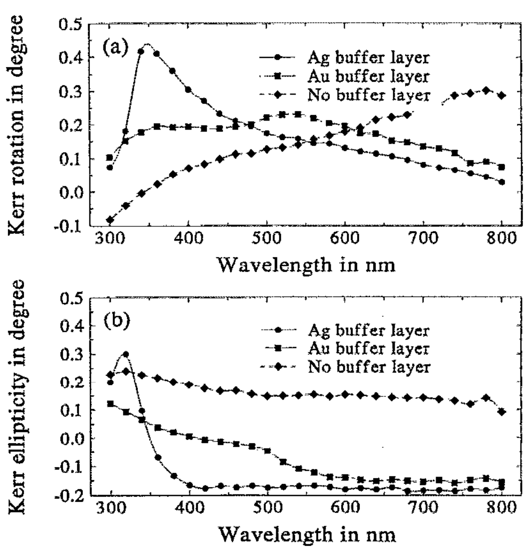

FIG. 3. Wavelength dependencies of Co(0.2)/Ni(0.8)×16 multilayers (a) polar Kerr rotation, (b) polar Kerr ellipticity.

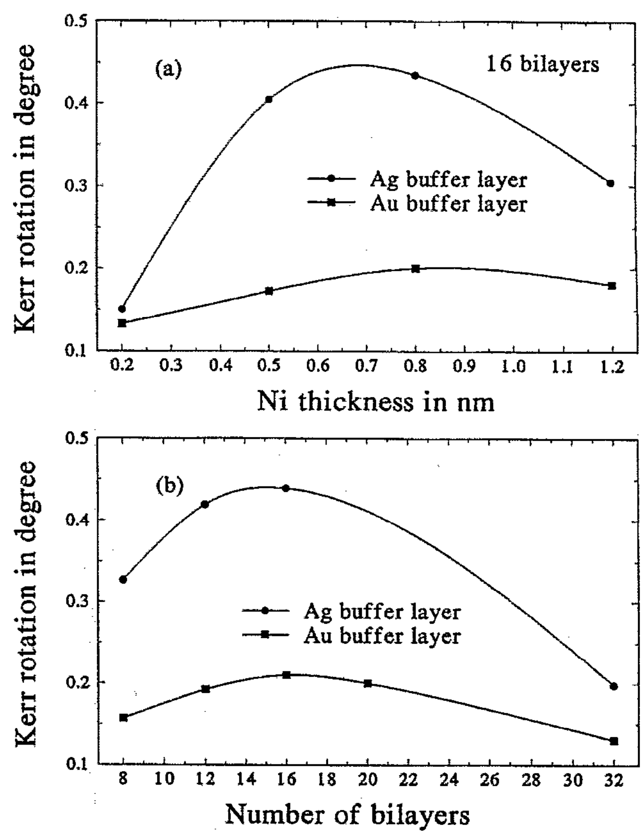

FIG. 5. Polar Kerr rotation at 350 nm as a function of (a) Ni thickness at Co=0.2 nm, (b) bilayer numbers for Co(0.2)/Ni(0.8) multilayers on Ag and Au buffer layers.

Fig. 3. For Co/Ni multilayer thickness near 10 nm, the optical effects of the buffer layer or the glass substrate is considerable,[9] since the magnitudes of θ_k and ϵ_k are due to a combination of the magneto-optical properties of the Co/Ni multilayer and the optical properties of the buffer layer. From Fig. 3, we note that the peak of θ_k for Co/Ni on Ag falls at 350 nm, or at about the same wavelength where ϵ_k drops rapidly. These two effects occur where the optical properties of Ag are changing rapidly due to d-band transitions.[10] Similar, but less dramatic, effects are noted for Co/Ni on Au. It should also be noted that the short-wavelength polar Kerr rotations of Co/Ni multilayers with Au buffer layers are considerably larger than those of rare-earth–transition-metal alloys.[11]

We varied the individual Co and Ni layer thicknesses, and also the number of bilayers, to optimize the polar Kerr rotation, and the results are shown in Figs. 4 and 5. The maximum polar Kerr rotation is obtained for Co$\approx$0.2 nm, Ni$\approx$0.6 nm, at about 16 bilayers. The Kerr rotation for Co/Ni on Ag is considerably larger than that of Co/Ni on Au (see Fig. 5), primarily because the measurements were performed at λ=350 nm, where the optical properties of Ag cause a considerable enhancement of the Kerr rotation.

SUMMARY AND CONCLUSIONS

Sputtered Co/Ni multilayers show perpendicular magnetic anisotropy when deposited on a Au buffer layer, but in-plane anisotropy when deposited on a Ag buffer layer. This difference most likely arises because the Au buffer layers are more completely oriented with the [111] direction perpendicular to the film plane. The optical properties of the buffer layer also strongly affect the magnitude of the Kerr rotation. The largest Kerr rotation measured was 0.44° for Co(0.2 nm)/Ni(0.6 nm)$\times$16 bilayers on a Ag buffer layer.

ACKNOWLEDGMENTS

The authors would like to thank Z. S. Shan, D. X. Wang, and S. Nafis for assistance and helpful discussion. We are grateful to the National Science Foundation for financial support under Grant No. DMR-9222976.

[1] See, for example, *Science and Technology of Nanostructured Magnetic Materials*, edited by G. C. Hadjipanayis and G. A. Prinz (Plenum, New York, 1991).

[2] F. J. A. den Broeder, W. Hoving, and P. J. H. Bloemen, J. Magn. Magn. Mater. **93**, 562 (1991).

[3] P. F. Carcia, A. D. Meinhaldt, and A. Suna, Appl Phys. Lett. **47**, 178 (1985).

[4] B. N. Engel, C. D. England, R. A. Vanleeuwen, M. H. Wiedmann, and C. M. Falco, Phys. Rev. Lett. **67**, 1910 (1991).

[5] G. H. O. Daalderop, P. J. Kelly, and F. J. A. den Broeder, Phys. Rev. Lett. **68**, 682 (1992).

[6] F. J. A. den Broeder, H. W. van Kesteren, W. Hoving, and W. B. Zeper, Appl. Phys. Lett. **61**, 1468 (1992).

[7] L. Y. Chen and J. A. Woollam, in *Proceedings of the SPIE 33rd Annual International Symposium on Optical and Opto-electronic Applied Science and Engineering*, **1166**, 267 (1989).

[8] F. J. A. den Broeder, E. Janssen, W. Hoving, and W. B. Zeper, IEEE Trans. Magn. **28**, 2760 (1992).

[9] P. He, William A. McGahan, and J. A. Woollam, J. Appl. Phys. **69**, 4021 (1991)

[10] Frederick Wooten, *Optical Properties of Solids* (Academic, New York, 1972).

[11] P. F. Carcia, W. B. Zeper, H. W. van Kesteren, B. A. J. Javobs, and J. H. M. Spurit, in *Proceedings of the Magneto-Optical Recording International Symposium*, 151 (1991).