**Journal of Magnetics** 1(2), 86-89 (1996)

# (Pt/Co/Pt/Ni) Multilayers for Novel Magneto-Optical Recording Media

**G. Srinivas and Sung-Chul Shin**
*Department of Physics, Korea Advanced Institute of Technology,*
*Taejon 305-701, Korea.*

(Received 23 December 1996)

**The dc magnetron sputter deposited (Pt/Co/Pt/Ni) multilayers which exhibited Curie temperatures in the range of 150-300 ℃ were studied as possible alternative multilayers for magneto-optical recording to the widely studied Co/Pt, whose Curie temperatures are in the range of 200~400 ℃. The Coercivities of these multilayers were between 450 Oe and 800 Oe. These multilayers exhibited comparable magnetic and magneto-optical properties to Co/Pt multilayers with enhancement of the Kerr rotation at lower wavelengths and negligible Kerr ellipticity over a wide range of the spectrum (4000~7000 Å).**

## 1. Introduction

The Curie temperatures, $T_C$, of the Co-based multilayers [1-5] for use as magneto-optical storage media are between 250 and 400 ℃, while the optimal disk writing temperatures are between 150 and 200 ℃ [6, 7]. Recent attempts to reduce the $T_C$ of Co/Pt multilayers involved increasing the thickness of platinum layer or adding Ni to the cobalt layer [2, 8-11], which invariably leads to changes in the saturation magnetization, Kerr rotation, interfacial structure, and anisotropy energy etc. Although Co and Ni have almost similar lattice parameters, it is reported that the magnetostriction constant $\lambda_{100}$ of fcc Co-Ni alloys at room temperature increases while the magnetostriction constant $\lambda_{111}$ marginally decreases with increasing Co content and the magnetocrystalline anisotropy decreases with increasing Co [12]. These changes in magnetostriction and magnetocrystalline anisotropy constants will affect the anisotropy of (Co, Ni)/Pt multilayers. In a novel approach we tried to combine the attractive features of Co/Pt and the low $T_C$ feature of Ni/Pt multilayers in (Pt/Co/Pt/Ni) multilayers. Since the surface anisotropy is major source of perpendicular magnetic anisotropy (PMA) in Co/Pt multilayers, addition of Ni/Pt multilayers to Co/Pt multilayers is expected to increase the number of interfaces and thereby improve PMA. In this paper we discuss the magnetic and magneto-optical properties of (Pt/Co/Pt/Ni) multilayers.

## 2. Experiment

(Pt/Co/Pt/Ni) multilayers with same number of repeats of 20 were deposited by dc magnetron sputtering on glass substrates under a base pressure of $1 \times 10^{-6}$ Torr and sputtering argon gas pressure of 7 mTorr. The substrate-to-target distance was 7.5 cm. Deposition rates of 1.5 Å/s for Co, 1 Å/s for Ni, and 3 Å/s for Pt, were achieved by applying the same power of 30 W to each of the targets (Co, Ni, and Pt). The thickness of platinum, $t_{Pt}$, was varied from one monolayer (2.3 Å) to three monolayers (6.9 Å). The thicknesses of Co and Ni were varied from 3 Å to 7 Å in step of 2 Å. The dwelling time of substrates above the targets was controlled using a microprocessor-based stepping motor. Low angle x-ray diffraction of these multilayers was studied to investigate the integrity of multilayer structure, thickness of the sublayers and total layer, and the details of the interfaces. The Kerr loops at 5320 Å and the spectral dependence of the Kerr rotation were measured using a Kerr spectrometer based on a photo-elastic modulator. The Curie temperature was determined by monitoring the Kerr rotation at a wavelength of 3000 Å (since Kerr rotation was observed to be maximum at this wavelength) in the temperature range of 290 K and 600 K. The magnetization was measured using a vibration sample magnetometer.

## 3. Results and Discussion

The low-angle XRD patterns of (Pt/Co/Pt/Ni) multilayers showed peaks characteristic of the superlattice structure with smooth interfaces. Figure 1 illustrates the typical low angle XRD pattern of (Pt/Co/Pt/Ni) multilayer corresponding to (2.3-Å Pt/5-Å Co/2.3-Å Pt/5-Å Ni). The peaks observed at angles smaller than $2\theta = 6°$, ascribed to the the total film thickness, confirm the smooth film surface. The diffraction peaks observed at $2\theta = 6.1°$ and $2\theta = 12.2°$ correspond to the first and second order maxima respectively, caused by a periodicity of 14.6 Å of the multilayer. The intensity of the maximum corresponding to the multilayer periodicity was observed to increase with increase in thickness of cobalt or nickel sublayers. The larger value of intensity and smaller value of FWHM were observed for multilayers with the sublayer thicknesses of about two monolayers than those with one or three monolayers. These observations indicate that the integrity of multilayers with sublayer thickness of two monolayers is better than the integrity of multilayers with sublayer thickness of one or three monolayers. Lower input power to platinum target is expected to improve the (111) orientation of multilayer and lower process pressure is expected to develop smooth surfaces. In sputter deposition the energetic bombardment of reflected Ar neutrals reduces (111) fcc texture and thereby anisotropy. Since one monolayer of a material hardly forms a continuous film, the surface of a material with two or more monolayers is expected to be smoother than that of one monolayer. In sputter deposition of (Pt/Co/Pt/Ni) multilayers, the backscattered Ar neutrals from Pt target are expected to cause more damage to the growing multilayer than those from Co or Ni target, because of higher atomic mass of Pt. Therefore, it is reasonable to expect that multilayers with three monolayers have relatively rough interfaces due to more exposure of backscattered Ar neutrals. Similar observations were predicted by Bertero et al. in the preparation (Pt/Co/Pt/X) multilayers with X = Pd, Ag, Cu [13].

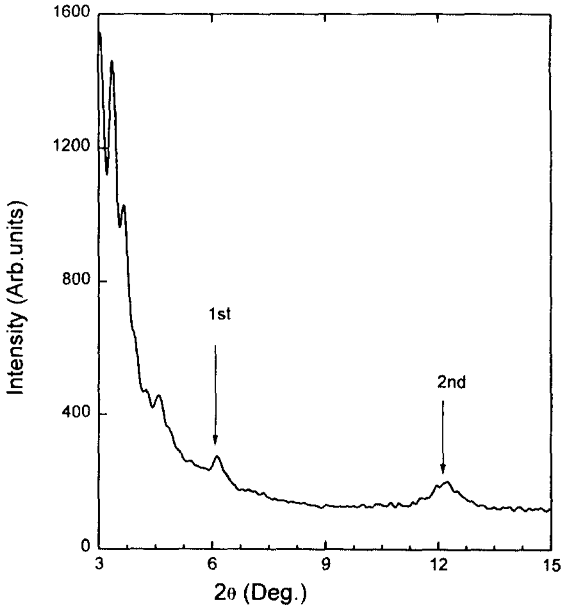

Fig. 1. Low angle x-ray diffraction pattern of (2.3-Å Pt/5-Å Co/2.3-Å Pt/5-Å Ni)$_{20}$ multilayer deposited on glass substrate.

Figure 2 illustrates typical polar Kerr loops of these multilayers corresponding to (4.6-Å Pt/5-Å Co/4.6-Å Pt/x-Å Ni)$_{20}$ where x = 3 Å and 5 Å, deposited on glass substrates with 100-Å thick Pt buffer layers and without buffer layers, measured at 5320 Å and varying applied fields ($-5$ kOe to 5 kOe). As can be observed from Fig. 2, underlayers were essential to obtain perfect rectangularity of the loop. The coercivity of (Pt/Co/Pt/Ni) multilayers deposited on glass substrates were between 350 Oe and 650 Oe. The lower coercivity values are a consequence of lower process pressure and the dense microstructure. However, these process conditions lead to sharper interfaces and better anisotropy. The loop squareness of these multilayers deposited on glass was between 0.55 and 0.85. The coercivities of the multilayers deposited on glass substrates with Pt buffer layers was in the range of 400-750 Oe, while the loop squareness ratio was in the range of 0.65-1. The process conditions for depositing these buffer layers were also kept similar to those of the multilayers to maintain the same microstructural features. We have observed an increase in the coercivity with increase in the nickel layer thickness from 3 Å to 5 Å and a slight decreasing trend when the nickel sublayer thickness was further increased to 7 Å (for the same cobalt and platinum sublayer thicknesses). Similar trends were noticed with increasing the cobalt sublayer thickness (for the same platinum and nickel sublayer thicknesses). When $t_{Co}$ was 3 Å, increase in $t_{Pt}$ was found to decrease the coercivity for the same thickness of nickel sublayer. When $t_{Co}$ was 5 Å, increase in $t_{Pt}$ from one monolayer to two monolayers increased the coercivity, but further increase to three monolayers showed a decreasing trend. The increase in coercivity with increasing platinum sublayer thickness is probably due to the improvement in PMA, due to the reduced interlayer coupling between cobalt layers. We also observed that increasing the nickel sublayer thickness improves loop-shape for fixed thickness of platinum and cobalt.

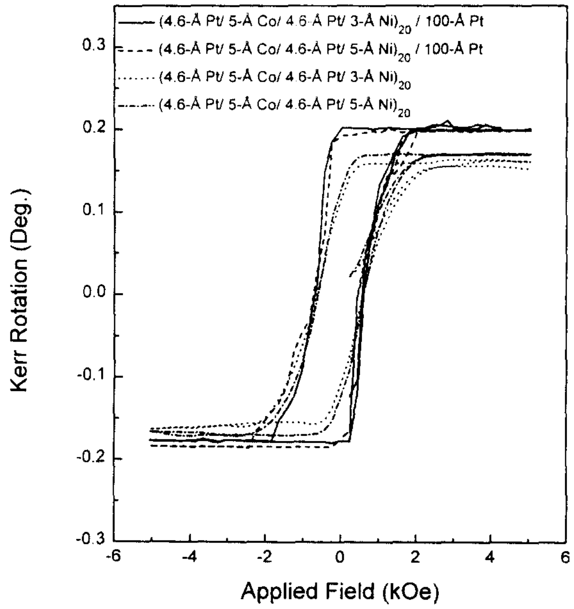

Fig. 2. Polar Kerr rotation hysterisis loops corresponding to (4.6-Å Pt/5-Å Co/4.6-Å Pt/x-Å Ni) multilayers, where x = 3 Å and 5 Å deposited on glass substrates with 100-Å thick Pt buffer layers and without buffer layers.

The coercivity, loop squareness, saturation magnetization, $M_S$, of (Pt/Co/Pt/Ni) multilayers are summarized in Table I. It can be observed from Table I that as expected, $M_S$ and $T_C$ increase with increasing $t_{Ni}$ or $t_{Co}$ and decrease with increasing $t_{Pt}$ and Curie temperatures of these multilayers are between 135 and 330 ℃. The Curie temperatures of Co/Pt multilayers with $t_{Co}$ = 4 Å and $t_{Pt}$ = 10-20 Å were reported to be in the range of 300-400 ℃ [15], while those with $t_{Co}$ = 4.5 Å and $t_{Pt}$ = 10-23 Å are reported to be in the range of 200-400 ℃ [10]. The saturation magnetization of the multilayer, (4.5-Å Co/23-Å Pt) which exhibited lowest $T_C$ of 200 ℃ was reported to be 190 emu/cc, while that of (4.5-Å Co/10-Å Pt) which exhibited $T_C$ of 400 ℃ was 480 emu/cc. Thus, it can be observed that although increasing $t_{Pt}$ decreases $T_C$, it also leads to a dramatic decrease of magnetization, which will thereby reduce Kerr rotation. Therefore, instead of reducing the Curie temperature by increasing $t_{Pt}$, alloying Co with Ni and then layering with Pt had been studied as an alternate approach to reduce $T_C$. Hashimoto [9, 10] reported that the Curie temperatures of such (Co, Ni)/Pt multilayers with $t_{(Co,\ Ni)}$ = 4 Å and $t_{Pt}$ = 7-11 Å were in the range of 230-350 ℃. Maarten *et al.* [11] have reported the saturation magnetization value of 353 emu/cc for (3.5-Å $Co_{60}Ni_{40}$/8-Å Pt) which exhibited $T_C$ of 290 ℃. It can be observed from Table I that the Curie temperatures of (Pt/Co/Pt/Ni) multilayers are lower than those of Co/Pt and (Co, Ni)/Pt multilayers and the saturation magnetization values are comparable to both of them. To appreciate the advantage of this approach of reducing the Curie temperature, it should be noted that magnetization of bulk cobalt is 1422 emu/cc and that of Ni is 484 emu/cc and therefore alloying Co with Ni not only reduces Curie temperature but also leads to a rapid decrease in magnetization. Therefore, in order to maintain sufficient magnetization of the multilayer, the cobalt content in the (Co, Ni) alloyed layer has to be kept relatively higher than that of Ni. Though Co and Ni have almost similar lattice parameters, it is reported that the magnetostriction constant $\lambda_{100}$ of fcc Co-Ni alloys at room temperature increases while the magnetostriction constant $\lambda_{111}$ marginally decreases with increasing Co content. It is also reported that magnetocrystalline anisotropy at room temperature decreases with increasing Co [12]. Therefore, these changes in magnetostriction and magnetocrystalline anisotropy constants will affect the anisotropy of (Co, Ni)/Pt multilayers. In contrast, since the surface anisotropy is the major source of PMA in Co/Pt multilayers, the addition of Ni/Pt multilayers to Co/Pt multilayers is expected to increase the number of interfaces and thereby improve PMA in (Pt/Co/Pt/Ni) multilayers.

The trends of the magnetic and magneto-optical properties of (Pt/Co/Pt/Ni) multilayers appear to be the combination of the properties of Pt/Co and Pt/Ni multilayers. The published data on Ni/Pt multilayers indicate that multilayers with $t_{Ni}/t_{Pt} < 1/3$ have very low Curie temperatures and are paramagnetic at room temperature, while multilayers with $t_{Ni}/t_{Pt} > 1$ are ferromagnetic and $T_C$ increases with increasing $t_{Ni}/t_{Pt}$ [15, 16]. Therefore, if one considers (Pt/Co/Pt/Ni) multilayers as coupled Co/Pt multilayers (with high $T_C$) and Ni/Pt multilayers (with low $T_C$), the results of the Kerr spectra, magnetization, coercivity, and $T_C$ measurements are easily understood.

Table I. Coercivity $H_C$, Saturation magnetization $M_S$, squareness r and Curie temperature $T_C$ of (Pt/Co/Pt/Ni) multilayers deposited on glass substrates with 100-Å thick Pt underlayers.

| Sample | $H_C$ (Oe) | Sqaureness r | $M_S$ (emu/cc) | $T_C$ (℃) |
|---|---|---|---|---|
| (2.3 Å Pt/3 Å Co/2.3 Å Pt/3 Å Ni)$_{20}$ | 383 | 0.65 | 270 | 135 |
| (2.3 Å Pt/3 Å Co/2.3 Å Pt/5 Å Ni)$_{20}$ | 426 | 0.78 | 303 | 180 |
| (2.3 Å Pt/3 Å Co/2.3 Å Pt/7 Å Ni)$_{20}$ | 418 | 0.6 | 316 | 215 |
| (2.3 Å Pt/5 Å Co/2.3 Å Pt/3 Å Ni)$_{20}$ | 522 | 0.76 | 354 | 230 |
| (2.3 Å Pt/5 Å Co/2.3 Å Pt/5 Å Ni)$_{20}$ | 570 | 0.75 | 445 | 270 |
| (2.3 Å Pt/5 Å Co/2.3 Å Pt/7 Å Ni)$_{20}$ | 415 | 0.50 | 406 | 330 |
| (4.6 Å Pt/5 Å Co/4.6 Å Pt/3 Å Ni)$_{20}$ | 750 | 1 | 221 | 205 |
| (4.6 Å Pt/5 Å Co/4.6 Å Pt/5 Å Ni)$_{20}$ | 740 | 1 | 308 | 250 |
| (4.6 Å Pt/5 Å Co/4.6 Å Pt/7 Å Ni)$_{20}$ | 644 | 0.77 | 304 | 305 |

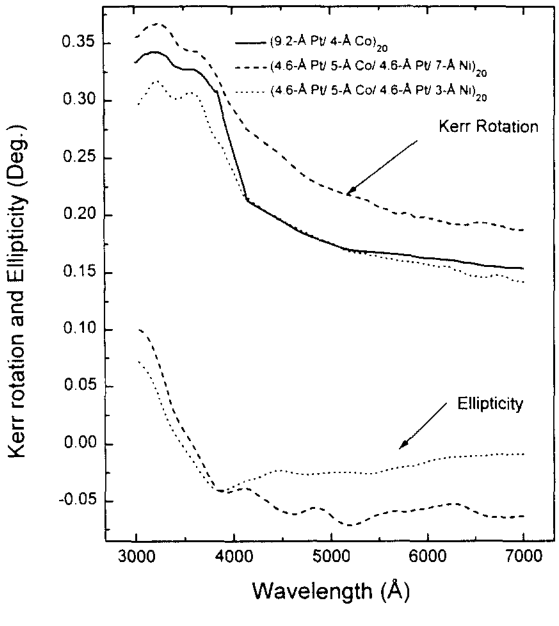

Fig. 3. The spectral dependence of Kerr rotation of (4.6-Å Pt/5-Å Co/4.6-Å Pt/x-Å Ni) multilayers deposited on glass substrates, where x = 3 Å and 7 Å. Also shown is Kerr spectra of (4-Å Co/9.5-Å Pt) multilayer deposited under similar process conditions for comparison.

Figure 3 illustrates typical spectral dependence of Kerr rotation and ellipticity of (Pt/Co/Pt/Ni) multilayers corresponding to (4.6-Å Pt/5-Å Co/4.6-Å Pt/x-Å Ni), where x = 3 Å and 7 Å. Also shown is the Kerr spectra corresponding to (4-Å Co/9.2-Å Pt)$_{20}$. (Pt/Co/Pt/Ni) multilayers show features of $\theta_K$ enhancement at lower wavelengths similar to that of Co/Pt multilayers. We have observed that in general, Kerr rotation increases monotonically with wavelength similar to the spectral dependence of Kerr rotation of Co/Pt multilayers and that $\theta_K$ increases with increase in $t_{Co}$ or $t_{Ni}$ and decreases with increasing $t_{Pt}$. An increase in $t_{Co}$ or $t_{Ni}$ increases total magnetization and therefore $\theta_K$. Increase in $t_{Ni}$ may also increase the total mumber of polarized platinum atoms. The reduction of $\theta_K$ with increase in $t_{Pt}$ is due to the obvious reduction in $M_S$. Another salient feature observed in (Pt/Co/Pt/Ni) multilayers was negligible ellipticity in the spectral range 4000-7000 Å. If the ellipticity is negligible, Kerr rotation is expected to be enhanced. Zero ellipticity dispenses away the need for M-O phase correcting optics in the optical read out-head [17]. We believe that the negligible ellipticity in our films is not due to the thickness dependence but is related to the difference in optical constants and dielectric tensors of Co/Pt and Ni/Pt multilayers. This aspect is being investigated in detail. Though ellipticity is negligible in (Pt/Co/Pt/Ni) multilayers compared to the Kerr rotation, it is important to note that ellipticity increases with increase in $t_{Pt}$ or $t_{Co}$ but decreases with increase in $t_{Ni}$.

## Conclusions

In conclusion, the sputter deposited Pt/Co/Pt/Ni multilayers which combine the attractive features of Co/Pt and Ni/Pt multilayers were examined as possible alternatives for magneto-optical storage applications. (Pt/Co/Pt/Ni) multilayers exhibit very attractive features of low Curie temperature in the range of 150-300 ℃, enhancement of the Kerr rotation at lower wavelengths, negligible Kerr ellipticity, which make them ideal alternatives for magneto-optical storage.

## Acknowledgments

One of the authors (Srinivas) gratefully acknowledges KOSEF (Korea Science and Engineering Foundation) and CISEM (Center for Interface Science and Engineering of Materials) for providing an opportunity to carry out this work and the financial assistance during my stay at KAIST.

## References

[1] P. F. Carcia, W. B. Zeper, H. W. van Kesteren, B. A. J. Jacobs and J. H. M. Spruit J. Magn. Soc. Jpn., **S1**, 151 (1991).

[2] S. Hashimoto and Y. Ochiai, J. Magn. Magn. Mater., **88**, 211 (1990).

[3] P. F. Carcia, Proc. MORIS 94, J. Magn. Soc. Jpn., **19 S1**, 5 (1994).
(and references therein).

[4] S. C. Shin and A. C. Palumbo, J. Appl. Phys., **67**, 317 (1990).

[5] S. C. Shin, Appl. Surf. Sci., **65/66**, 110 (1993).

[6] P. Hansen and H. Heitmann, IEEE Trans. Magn., **25**, 4391 (1990).

[7] P. Hansen, J. Magn. Magn. Mat., **83**, 6 (1990).

[8] K. Fujimoto, A. Maesaka and S. Hashimoto, J. Magn. Magn. Mater., **126**, 587 (1993).

[9] S. Hashimoto, J. Magn. Magn. Mater., **121**, 471 (1993).

[10] S. Hashimoto, J. Appl. Phys., **75**, 438 (1994).

[11] Maarten MES, Cock Lodder, T. Takahata, I. Moritani and Imamura, J. Magn. Soc. Jpn., **17 S1**, 44 (1993).

[12] H. P. J. Wijn, in Magnetic Properties of Metals, Data in Science and Technology, Ed. R. Poerschke, Springer-Verlag, NY, 1991.

[13] G. A. Bertero and R. Sinclair, Appl. Phys. Lett., **64**, 3337 (1994).

[14] F. J. A. M Greidanus, W. B. Zeper, B. A. J. Jacobs, J. H. M. Spruit and P. F. Carcia, Jap. J. Appl. Phys., **28**, 37 (1989).

[15] R. Krishnan, H. Lassri, M. Porte, M. Tessier and P. Renaudin, Appl. Phys. Lett., **59**, 3649 (1991).

[16] R. Krishnan, H. Lassri, S. Prasad, M. Porte, and M. Tessier, J. Appl. Phys. **73**, 6433 (1993).

[17] R Atkinson, P. J. Grundy, C. M. Hanratty, R. J. Pollard and I. W. Salter, J. Appl. Phys., **75**, 6861 (1994).