Obliquely sputtered Co/Cr thin film tape for bidirectional recording

L. T. Nguyen[a)]
SMI, MESA^{+} Institute, University of Twente, Enschede, The Netherlands

A. Lisfi
Department of Physics, Morgan State University, 1700 E. Cold Spring Lane, Baltimore, Maryland 21251

J. C. Lodder
SMI, MESA^{+} Institute, University of Twente, Enschede, The Netherlands

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We report the growth and properties of a thin film tape, which can be equivalently recorded in both directions. The experimental tape consists of a 20 nm thick Co layer grown on top of a Cr underlayer (120 nm). The two layers were consecutively sputtered at incident angle of 70° at room temperature onto a rotating drum covered with a polymer substrate. In such growth geometry the running direction of drum is perpendicular to the incidence plane of arriving atoms. As a result of this configuration, a medium with a good orientation of the easy axis along the recording direction as well as a high coercivity of 180 kA/m has been prepared. Recording measurements have been carried out and illustrate the bidirectional recording behavior of this experimental tape, which seems to be very promising for high-density tape recording. © *2003 American Institute of Physics.*
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I. INTRODUCTION

During the last decade, thin film technology has been applied to obtain high-density magnetic recording tape. A successful application is metal evaporated (ME) tape with high recording performance produced by oblique evaporation of Co and Co alloys in oxygen atmosphere.[1] Nevertheless, ME tape still has some drawbacks in comparison with advanced metal particulate (MP) tape such as a low wear resistibility and a limited coercivity (90–120 kA/m). The moderate coercivity in such media is due to the low anisotropy with the shape of columnar structure as the main source. However, magnetocrystalline anisotropy is not the prevailing form due to random orientation of crystallites. Efforts have been made to induce some texture in such films by introducing CoO seed layer.[2] Another inconvenience of ME tape is the existence of ''good'' and ''bad'' recording directions since the tilted columnar structure is asymmetrical with respect to the head field. Thus, ME tape is not feasible for linear recording. An alternative way to improve performance of thin film for recording tape is to use sputtering. Sputtering technique offers numbers of advantages such as good adhesion between magnetic layer and substrate, possibility to obtain binary and ternary compounds as well as microstructure controllability. However, because the PET substrate cannot be heated above 120 °C, it is quite challenging to use the same sputtering process that is applied to fabricate rigid disk. Recently, using appropriate underlayers, an excellent CoCrPt alloy thin film with high coercivity of 300 kA/m and thin magnetic layer of 20 nm deposited on polymer substrate has been fabricated.[3] However, the film structure, which consists of NiAl underlayer and intermediate layers, is still complicated for application. In this article, we propose a rather simple process to obtain a thin film tape at room temperature by using oblique sputtering of Co with Cr underlayer.

[a)]Author to whom correspondence should be addressed; electronic mail: l.t.nguyen@el.utwente.nl

II. EXPERIMENT

The principle of our process is quite similar to that of the continuously varying of incidence (CVI) method, used to produce ME tape. In CVI method, magnetic materials such as Co or CoNi alloys are obliquely deposited onto a rotary drum covered by a polymer substrate. Using a shield, the incident angle can be varied from 45° to 90° during deposition resulting in banana shape of Co columns. The shadowing effect causes voids between the columns. The magnetic isolation between grains can also be enhanced by the introduction of oxygen during deposition. However, there is a main difference between CVI and our process. In the CVI method and our proposed geometry, the incident plane is parallel and perpendicular to the running direction of drum, respectively. The importance of our configuration is justified by the effects of the Cr underlayer prepared in the same geometry. In a previous work,[4] we have shown that an obliquely sputtered Cr underlayer can induce an in-plane anisotropy in Co film in the direction perpendicular to the incident plane. A similar effect is observed in the case of Co deposited on obliquely sputtered Ta underlayer.[5] Therefore, the geometry of the sputtering system must be arranged as the orientation direction of magnetization coincides with the running direction of the drum, or in the other word, the recording direction. As the film morphology is symmetric with respect to the recording direction, a bidirectional recording behavior in the films is expected. In our experiment, the films were deposited in a system, which consists of two sputtering guns together with a solid drum covered with PET film 10 μm thick. Because the deposition rate can drastically

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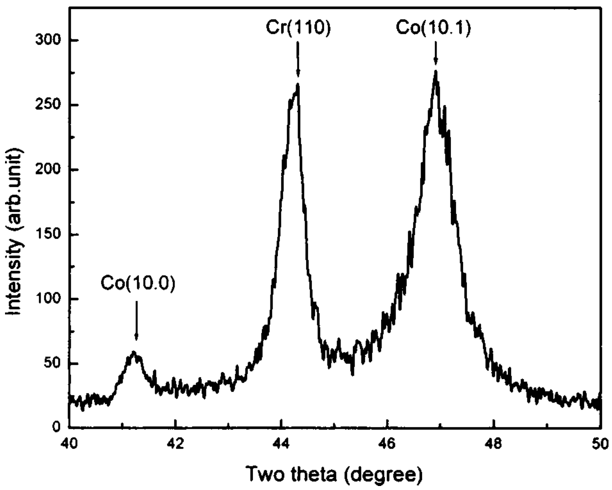

FIG. 1. $\theta/2\theta$ scan of Co (120 nm)/ Cr (120 nm) film deposited on PET.

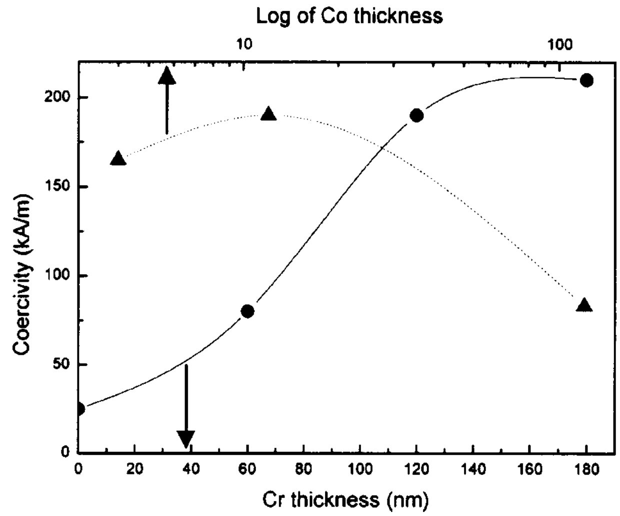

FIG. 2. Dependence of H_c on Cr (circle) and Co (triangle) thicknesses at fixed thicknesses of Co (20 nm) and Cr (120 nm), respectively.

change with the angle, the shields were mounted to limit the sputtered area in order to have a good homogeneity in the film thickness. The distance between the center of guns and the substrate is 5 cm. Prior to each deposition the vacuum chamber was pumped down to base pressure (10^{-7} mb) and Co and Cr layers were consecutively sputtered with the same incident angle ($70° \pm 5°$) at room temperature and a fixed Ar pressure of 4×10^{-3} mb. The sputtering gun power and the velocity of the drum can be varied to obtain desired thickness of Co and Cr layers. After a complete run of drum, an experimental tape with 30 cm long and 1 cm wide was obtained. A series of experimental tapes with different thickness of Co and Cr layers were prepared. X-ray diffraction (XRD) analysis was carried out to reveal the crystallographic properties of the films. Magnetic properties of these samples were investigated using vibrating sample magnetometer (VSM). Hysteresis loops were measured in both directions in the film plane, called longitudinal and transverse (parallel and perpendicular to the running direction of drum, respectively). The switching mechanism of magnetization in the experimental tape was investigated with rotational hysteresis measured with torque magnetometer with maximum field up to 1.6 T. Preliminary recording measurements have been carried out using a drum tester in both directions of the relative movement between the head and medium. In addition, recorded tracks were also observed by MFM.

III. RESULTS AND DISCUSSION

The $\theta/2\theta$ scan of Co on PET and Co on the Cr underlayer is depicted in Fig. 1. The diffraction peak at 44.3° corresponds to the (110) plane of Cr whereas the two peaks positioned at 41.4° and 47° are characteristic of (10.0) and (10.1) planes of HCP Co, respectively. These two planes are known to grow epitaxially on Cr (110).[6] The Co (10.1) plane gives rise to a c-axis orientation tilting 28° out of the film plane whereas the Co (10.0) plane orients the c-axis fully in the film plane. It is evident that Cr promotes the growth of Co with HCP structure. The low mismatch between the two lattices of Co and Cr is responsible for this behavior.

Figure 2 shows the dependence of longitudinal coercivity on Cr thickness at fixed Co thickness (20 nm). Without underlayer Co film is magnetically soft and exhibits a low coercivity (around 25 kA/m). When the Cr layer thickness is larger than 120 nm, the coercivity can reach 200 kA/m, which is an order of magnitude larger than the former case. Therefore, the thickness of the Cr underlayer must be sufficient to ensure a high coercivity medium. The high coercivity in this thin magnetic layer suggests an important role of crystalline anisotropy. The figure also shows the coercivities in longitudinal direction of Co/Cr films with different Co thicknesses (4, 20, and 120 nm) and constant Cr thickness of 120 nm. First, the coercivity increases with increasing the Co thickness. As small grains are expected at low Co thickness, thermal fluctuation will prevail, leading to a considerable decrease in H_c value. However, increasing the Co thickness develops a significant shape anisotropy of column with an important component following the transverse direction. As a result, the total anisotropy is reduced leading to a decrease of coercivity. From the above analyses, an optimized experimental tape was prepared for recording analyses with Cr and Co thicknesses of 120 and 20 nm, respectively.

The in-plane and out-of-plane hysteresis loops of this tape are presented in Fig. 3. The perpendicular loop suggests an out-of-plane component of magnetization. As confirmed by torque measurement, the easy axis of the experimental tape exhibits a tilt of 20° from the film plane. In the film plane, it is obvious that the anisotropy is parallel to the longitudinal direction. In addition, the squareness (M_r/M_s) in longitudinal direction and the orientation ratio (defined as the ratio of the remanent magnetization measured along the two in-plane directions) are quite high, 0.85 and 2.7 respectively, indicating a good orientation in this direction. In oblique deposition, the self-shadowing effect gives rise to a periodic roughness of the film.[5,7] The surface roughness of the film can be influenced by the shape of nuclei in the first stage of growth. It is reported that in some cases of oblique deposition, an elongated shape of the adatom structures following the direction perpendicular to the incidence plane is revealed. This phenomenon was explained by steering,[7] which consists

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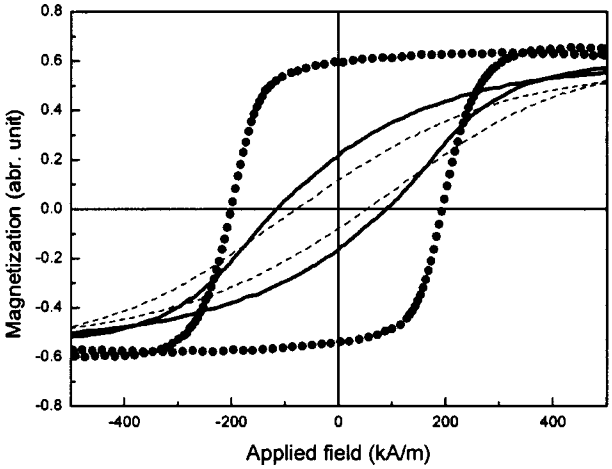

FIG. 3. In-plane [longitudinal (solid circle) and transverse (solid line)] and perpendicular (dashed line) loops of the tape.

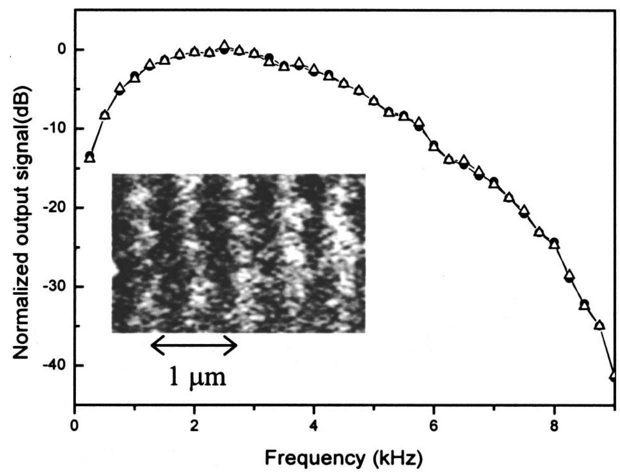

FIG. 5. Output signal vs frequency of the experimental tape. The inset is a MFM image of recorded track with $\lambda = 1\ \mu$m.

of a nonuniform distribution of the flux of the arriving atoms due to protrusions on the surface. Therefore the induced uniaxial anisotropy in the film plane of our tapes can be related to the periodic roughness of Cr layer at the interface with Co layer.

Since the mechanism of magnetization reversal plays a very important role in the quality of a recording medium, rotational hysteresis of the experimental tape was investigated. As shown in Fig. 4, the rotational hysteresis shows a maximum at 300 kA/m and disappears at fields larger than 800 kA/m. The rotational hysteresis integral R_h was estimated to be 1.4, which is quite large in comparison to that characteristic of coherent rotation ($R_h = 0.42$). However, it is a rough value because R_h was estimated without any correction from the demagnetizing field caused by the out-of-plane component of magnetization. Nevertheless, the high value of R_h suggests an incoherent rotation mechanism for the magnetization reversal in this tape.

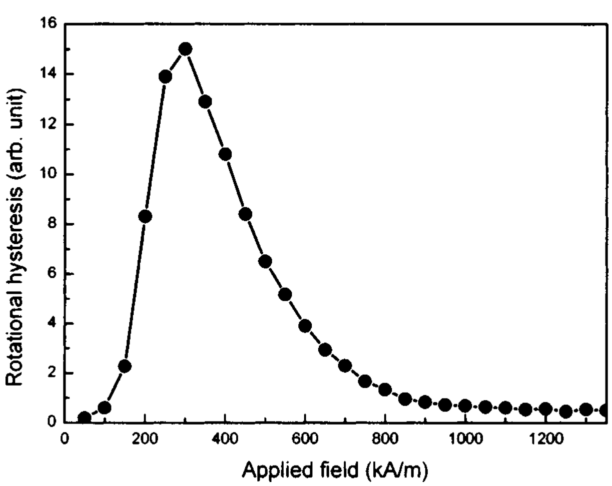

FIG. 4. Field dependence of rotational hysteresis of the experimental tape.

Finally, recording measurements were carried out in the experimental tape. There is no significant difference between the output signals measured in both directions of the relative movement between the head and medium (Fig. 5). The result illustrates the bidirectional recording of our tape. MFM image also indicates a clear transition between the written bits. However, further analyses have to be done in order to obtain an insight in the recording behavior of this tape.

ACKNOWLEDGMENTS

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[1] K. Chiba, K. Sato, Y. Ebine, and T. Sasaki, IEEE Trans. Consum. Electron. **35**, 421 (1989).
[2] Y. Maezawa, H. Yoshida, and K. Shinohara, IEEE Trans. Magn. **35**, 2688 (1999).
[3] B. Bian, J. A. Bain, S. J. Kwon, and D. E. Laughlin, IEEE Trans. Magn. **37**, 1640 (2001).
[4] L. T. Nguyen, A. Lisfi, Kim. P. L, J. C. Lodder, and E. G. Keim, INTERMAG 2002, AQ 09.
[5] R. D. McMichael, C. G. Lee, J. E. Bonevich, P. J. Chen, W. Miller, and W. F. Egelhoff, Jr., J. Appl. Phys. **88**, 3561 (2000).
[6] Y. Hsu, J. M. Siversten, and J. H. Judy, IEEE Trans. Magn. **26**, 1599 (1990).
[7] S. van Dijken, G. Di Santo, and B. Poelsema, Appl. Phys. Lett. **77**, 2030 (2000).

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