Use of Room-Temperature Bias Sputtering to Decrease Intergranular Coupling in Magnetic Media Deposited on Polymeric Substrates

Hwan-Soo Lee, Lin Wang, James A. Bain, and David E. Laughlin

***Abstract*—CoCrPt thin films sputter-deposited on polymeric substrates without explicit heating were investigated as a function of substrate bias. The coercivity and the coercive squareness in the CoCrPt films were strongly dependent on bias voltage. A significant reduction in the coercive squareness S^* from a value near unity was observed with increasing bias voltage, implying a decrease in the degree of intergranular exchange coupling. With the addition of explicit substrate heating, S^* was further reduced, and was associated with a significant improvement of coercivity. This paper presents a possible approach to achieve media with acceptably low exchange coupling deposited at temperatures well below the glass transition temperature of polymeric substrates.**

***Index Terms*—Coercive squareness, coercivity, polymeric substrates, sputtered thin-film tape media, substrate bias.**

I. INTRODUCTION

IN PARTICULATE recording media, the particles are well separated by nonmagnetic polymer constituents (binder). Thus, the effect of interparticle interaction on coercivity H_c and coercive squareness S^* is determined solely by magnetostatic interactions. In contrast, in thin-film media, grains are packed such that both exchange and interparticle magnetostatic interaction influence the hysteretic properties of the media. In this situation, Co grain isolation becomes critical in obtaining low-noise and high-coercivity media that can sustain a spatially sharp magnetization transition.

Previously, we have investigated Co-based alloys as candidates for sputtered thin-film magnetic tape media [1]. In prior work, it was suggested that the rather large values of S^* and the associated large intergranular coupling observed in these films were due to the low temperature deposition needed to avoid damage to polymeric substrates. Typically in sputtered disk media, the intergranular coupling (and the associated medium noise) is reduced through elevated temperature deposition (200 °C–300 °C). However, this is not feasible for the polymeric substrates used in tape fabrication. Thus, for sputtered high-density tape media to achieve acceptable medium noise, the reduction of exchange coupling between neighboring grains through physical separation or compositional segregation must be achieved through methods other than elevated temperature deposition. In this paper, the reduction of intergranular coupling in CoCrPt thin films on polymeric substrates through bias sputtering well below the glass transition temperature of the substrates has been investigated.

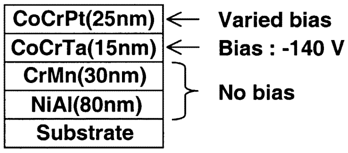

Fig. 1. Sample structure and relevant deposition conditions.

II. EXPERIMENT

Films of CoCrPt were sputter-deposited onto polyethylene naphthalate (PEN) substrates of 7 μm thickness as well as polyimide tape (kapton) of 30 μm thickness. Kapton is used as an exploratory substrate because it can withstand high temperatures when necessary. These polymeric films were held under slight tension over a section of large radius ($\sim$ 30 mm) custom made sample chuck. No thermally conductive films or pastes were used to improve thermal contact between the polymer and the chuck. The chuck body rested on a water-cooled table (no clamps or conductive interlayers), and the deposition sequence was started at room temperature. Additional films were deposited on glass substrates (500 μm thickness) that rested directly on the water-cooled table (again, no clamps or conductive interlayers). For reference, the glass transition temperatures T_g of standard tape substrates are 116 °C, 156 °C, and 272 °C for polyethylene terephthalate (PET), PEN, and aromatic polyamide (ARAMID), respectively [2].

Samples in this paper consisted of the film stack comprising a CoCrPt magnetic layer, a nonmagnetic CoCrTa intermediate layer, and NiAl–CrMn underlayers as shown in Fig. 1. The deposition conditions of the three nonmagnetic layers were chosen to optimize the coercivity of the CoCrPt films. Other details of the sputtering conditions are described elsewhere [3]. Sample temperature during the nominally room-temperature depositions was bounded by using a series of *tempilabels* with different indicator temperatures. These are commercially available, adhesive dots that show an irreversible color change upon exposure to a specific temperature. Magnetic properties of the samples were measured by alternating gradient magnetometry (AGM) and vibrating sample magnetometry (VSM). Structural characteristics were studied by an X-ray diffractometer (Philips X'pert Pro with a X-ray lens) using Cu Kα radiation. Composition was measured using a Tracor Energy Dispersive X-Ray

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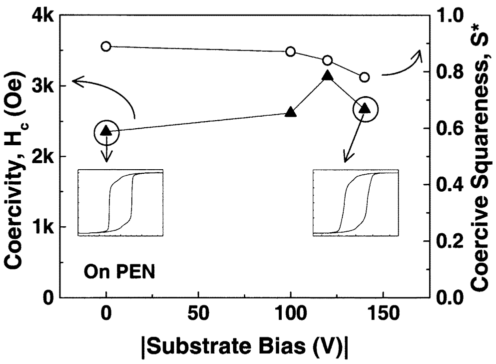

Fig. 2. Dependence of magnetic properties (H_c and S^*) on substrate bias. The CoCrPt media were deposited on PEN substrates.

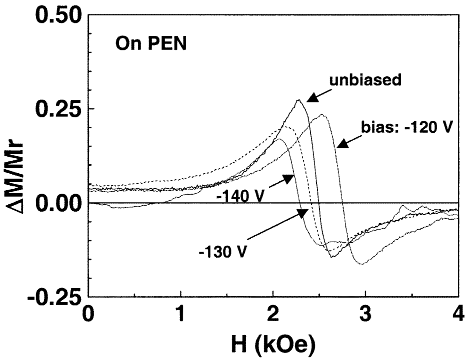

Fig. 3. ΔM curves for the media deposited as a function of substrate bias on PEN substrates.

Fluorescence (EDXRF) system (global) and TEM equipped with a nanoprobe EDX analyzer.

III. Results and Discussion

In Fig. 2, the values of H_c and S^* of the films deposited on PEN are plotted versus the bias voltage applied during the CoCrPt deposition. Both H_c and S^* are strongly dependent on bias voltage, with H_c increasing with increasing bias and S^* decreasing. The quantity S^*, introduced by Williams and Comstock [4], is a good indicator of intergranular exchange coupling in thin-film media. Modeling by Zhu and Bertram [5] demonstrated that the addition of intergranular exchange among randomly oriented particles produces collective switching behavior and an increase in the slope of hysteresis loop at the coercivity (i.e., S^*). In addition to the decreasing intergranular exchange coupling with increasing bias, some of the increase of H_c with increasing bias can be attributed to an observed increase in the Pt content of the CoCrPt films. In going from zero to -140 V substrate bias, the Pt composition was observed increased from 23 at.% to 27 at.%. Pt is known to enhance the magnetocrystalline anisotropy of the alloy [6].

As shown in Fig. 3, the S^* behavior is consistent with that of the $\Delta M/M_r$ peak. Fig. 3 shows that sample deposited on a polymer substrate with higher substrate bias has a smaller $\Delta M/M_r$ peak suggesting the grains' weaker exchange coupling, as seen in [7]. Typically, intergranular exchange is disrupted by nonmagnetic (or weakly magnetic) phases at the grain boundaries, which form due to compositional segregation during deposition. Consistent with this, bias sputtering in these samples was observed to correlate with greater compositional inhomogeneity. In order to verify this, highly biased (-250 V) samples were additionally prepared on glass. Preliminary nanoprobe EDX indicated local compositional fluctuations of Cr in the bias sputtered films of around 14 at.%, while the unbiased films showed fluctuations of around 7 at.%. It appears, then, that bias sputtering can drive composition segregation and produce intergranular decoupling at relatively lower deposition temperatures.

Observations of substrate temperatures suggest that simple heating of the substrates by the bias sputtering is not responsible for the observed effect. Films on PEN substrates deposited without bias showed maximum temperatures during deposition of less than 100 °C. Furthermore, less than 10 °C additional temperature rise was seen on glass substrates for bias values up to -140 V. Additionally, no substantial wrinkling or buckling of the PEN substrate was seen, which is characteristic of exposure to temperature above its glass transition temperature (156 °C).

To examine how much substrate heating would be required to produce comparable effects in the absence of substrate bias, samples were deposited on a thermally robust polyimide tape (kapton) at elevated substrate temperature without bias. Deposition at elevated temperatures influenced the slope of the switching field in the hysteresis loop as expected and as reported elsewhere [8]. However, the effect of temperature over the range examined (up to 230 °C) on S^* on the kapton substrates was not as large as the effect of substrate bias over the range examined on PEN substrates (up to -140 V). The S^* and the $\Delta M/M_r$ peak changed from 0.87 and 0.40 for room-temperature deposition to 0.84 and 0.33 at temperature of 230 °C on unbiased kapton. In contrast, S^* changed from 0.87 to 0.78 in going from 0 to -140 V bias during deposition on PEN (Fig. 2). In low-noise thin-film media, S^* values ranging from 0.7 to 0.8 are typical [9]. Since the effect is greater in the biasing case, and the upper bound on the temperature on the PEN is much lower than the maximum temperature on the kapton, there is strong evidence for the bias having a significant effect directly on adatom mobility.

Some additional evidence in support of the above is provided by a series of samples deposited on glass under the influence of both substrate heating and bias sputtering. For the first bias series of samples on glass, shown in Fig. 4(a) and (b) as filled triangles, no heating other than that from the plasma was imposed, creating a baseline temperature of approximately 100 °C. Additionally, samples preheated to 110 °C (filled squares) and 180 °C (open triangles) were also examined as a function of substrate bias voltage.

As with the films deposited on PEN, the films on glass also show substantial decreases in S^* as a function of bias, in the presence of modest temperature increases. Fig. 4(a) shows that the effect is not very significant for the samples at room temperature (filled triangles), but becomes more pronounced as the temperature is raised. At 180 °C (open triangles), the effect is quite pronounced. This temperature produces almost no change in S^* when bias is not applied, as shown in the figure.

The behavior of H_c for these samples is somewhat more complex, as shown in Fig. 4(b). In this figure, it is seen

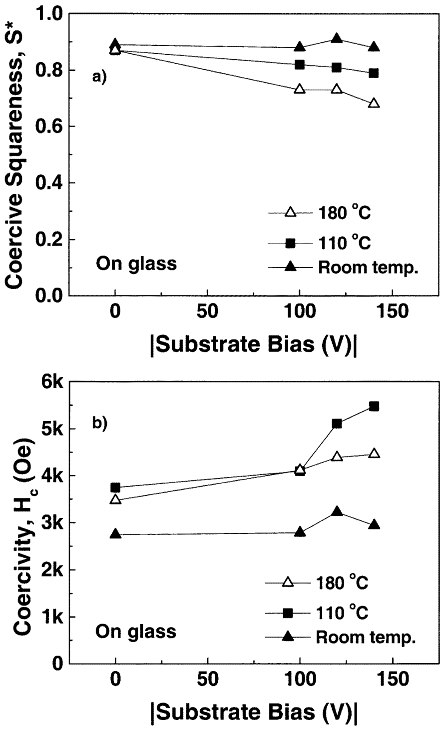

Fig. 4. Variation of magnetic properties of the CoCrPt media on glass versus substrate bias and temperature. (a) S^*. (b) H_c.

that heating to 110 °C, increased the film coercivities by at least 1 kOe for all bias values as compared to the nominally room-temperature deposited films (which heat up to about 100 °C over the course of the deposition). Of particular note is the sample preheated to 110 °C with a substrate bias of -140 V that showed an increase in H_c from 2.9 to 5.5 kOe. This behavior was reproduced on kapton under similar deposition conditions with a similar S^* of less than 0.8. These drastic changes in H_c are attributed to both a decrease in intergranular coupling and also with the enhancement of in-plane crystallographic orientation of the CoCrPt (10.0), which was seen in X-ray diffraction (XRD) measurements. A decrease in H_c for the films preheated to 180 °C (despite the further reduction of S^*) may be explained in terms of microstructural differences as well. XRD showed that the intensity of Co (10.0) texture was significantly degraded for samples deposited at 180 °C, which also showed the presence of Co (11.0) diffraction.

The trends observed in this paper are generally consistent with the results of studies published in the early 1990s, in which bias sputtering was observed to correlate with increases in H_c [10] and decreases in S^* [11], [12] and was attributed to increased compositional segregation. In most cases, explicit attempts to distinguish the effects of substrate heating from direct momentum transfer in increasing atomic mobility were not made. At least one study measured the temperature rise due to parasitic heating and found it to be relatively small even at high bias [13], suggesting a direct momentum transfer effect. These results are to be distinguished from situations where grain isolation is achieved by physical voids in the film, rather than compositional segregation. In this latter case, bias sputtering has been seen to increase coupling (and medium noise) by producing more dense and uniform films [14].

IV. CONCLUSION

The coercivity H_c and coercive squareness S^* of CoCrPt films deposited on polymeric substrates are strongly dependent on bias voltage, with H_c generally increasing with increasing substrate bias while S^* decreases. Furthermore, the substrate bias appears to be most effective when a small amount of substrate heating is used. This combination of modest heating and bias sputtering allows the deposition temperature to be kept below the glass transition temperature of PEN substrates. It is believed that the improvement of S^* in the CoCrPt films is mainly driven by the reduction of the exchange coupling between the grains, due to Cr segregation at the grain boundaries as is traditionally seen in these materials. A strong compositional dependence on bias is observed, which must be accounted for in selecting target composition. With this precaution, however, the use of bias sputtering well below the T_g of conventional tape substrates offers the possibility of achieving low medium noise in sputtered thin-film tape media without causing thermal substrate damage.

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