Effects of substrate bias on CoCrPt-SiO_2 magnetic recording media

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CoCrPt and CoCrPt-SiO_2 magnetic layers were investigated as a function of substrate bias. It was found that the use of substrate bias greatly modified the CoCrPt-SiO_2 film microstructure. This was due to a large change in the SiO_2 content during bias sputtering. Biasing had an effect of reducing the amount of oxide in the growing films and promoting the growth of larger grains, but it was also found to be very effective in decoupling the grains as determined by ΔM curves. In addition, in the biased films, a large dependence of the coercivity on film thickness was observed. The in-plane coercivity nearly doubled its value from 2400 to 4300 Oe as the thickness increased from 5 to 15 nm. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2169536]

I. INTRODUCTION

CoCrPt-SiO_2 granular films are widely accepted in recording media because of their low noise, due to separated grains and good thermal stability due to large uniaxial magnetocrystalline anisotropy.[1,2] However, it still remains important to understand which of the various processing parameters control the media properties. Previously, the effects of bias sputtering on the microstructure of CoCrPt recording media have been reported,[3–5] and our results are summarized as follows. The bias sputtering (1) changes the film composition, (2) eliminates planar defects such as stacking faults, (3) produces large compositional inhomogeneities (locally), and (4) changes the film strain states.

In this paper, two types of media, namely, continuous CoCrPt and granular-type CoCrPt-SiO_2 films were investigated to quantify and understand the effects of bias sputtering in situations where surface mobility of species to the grain boundaries is important.

II. EXPERIMENT

Films were sputter deposited on Corning 0211 glass substrates by rf sputtering with no oxygen added to the argon gas. CoCr alloy targets with bonded Pt (for the CoCrPt) or Pt and SiO_2 chips (for the CoCrPt-SiO_2) were used for magnetic film preparation. In some cases as noted, the CoCrPt films (without oxide) were sputtered at elevated temperatures to achieve reduced intergranular exchange coupling as noted in the text. The underlayer stack used was substrate/NiAl/CrMn/CoCrTa as reported previously.[2] The use of the composite NiAl/CrMn/CoCrTa underlayer produces good in-plane (10.0) texture for both cases of magnetic layers. The Cr content of the CoCrTa intermediate layer composition is large enough that the alloy is nonmagnetic. Other details of the sputtering conditions have been described elsewhere.[3,5]

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The magnetic properties of the samples were measured by an alternating gradient magnetometer (AGM) and by a vibrating sample magnetometer (VSM). The film composition was determined by inductively coupled plasma (ICP) analysis. The film textures and microstructures were characterized by an x-ray diffractometer (Philips X'pert Pro with x-ray lens) using Cu $K\alpha$ radiation and by a JEOL JEM-2010 transmission electron microscope (TEM) operating at 200 kV.

III. RESULTS AND DISCUSSION

Figure 1 shows the effect of substrate bias applied during CoCrPt or CoCrPt-SiO_2 deposition on deposition rate. The CoCrPt deposition rate decreased from 8 to 4 nm/min as the substrate bias was changed from 0 to −200 V, while the deposition rate for the CoCrPt-SiO_2 films decreased from 9 to 2 nm/min. The thicknesses were accurately measured through TEM cross section of the films. We attribute the rate reduction to resputtering of the films after deposition. The inset is a schematic illustration of a bias sputtering system

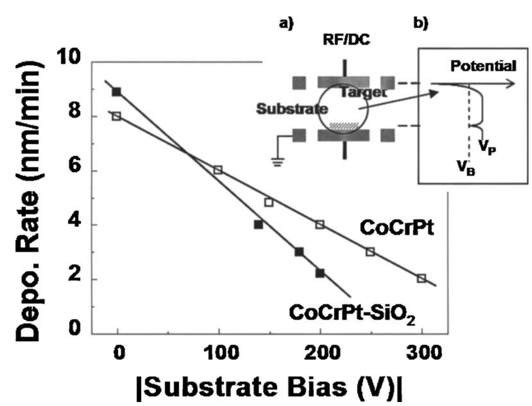

FIG. 1. Dependence of deposition rate on bias voltage for the CoCrPt and the CoCrPt-SiO_2 films. The inset is a schematic illustration of (a) a bias sputtering system and (b) its potential distribution.

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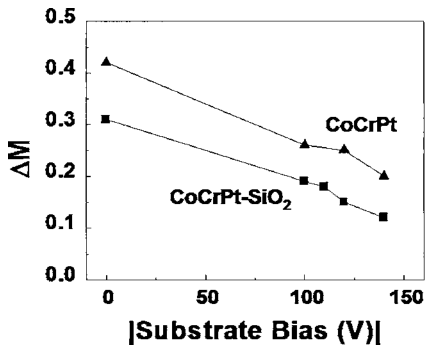

FIG. 2. ΔM values for the CoCrPt and the CoCrPt-SiO_2 films as a function of substrate bias.

and its potential distribution. As shown in the figure, when a sheath of potential difference V_P (plasma potential) $-V_B$ (applied bias) is placed in front of substrate with a polarity such as to accelerate positive ions (Ar^+) onto the substrate, the substrate platform functions, in effect, as a secondary sputtering target, causing resputtering.[6] Even though oxide targets generally have lower sputter yields than metal targets, it appears that the oxide-containing films are *more* susceptible to resputtering. We attribute this to preferential removal of oxide in the grain centers, where it is coordinated mainly by metal atoms.

In Fig. 2, the peak values of the normalized ΔM curve for both of the films are plotted as a function of substrate bias voltage. No explicit substrate heating was carried out for the CoCrPt-SiO_2 deposition while substrates were preheated to about 200 °C for the CoCrPt films. For both of the films, ΔM values are strongly dependent on bias voltage, with ΔM values decreasing with higher substrate bias. The change in ΔM is less pronounced for the CoCrPt films (filled triangles). In going from 0 to -140 V bias, the peak value changed from 0.31 to 0.12 for the CoCrPt-SiO_2 films while it varied from 0.42 to 0.20 for the CoCrPt films. It should be noted that this observed effect was only attainable when the substrate temperature was over 200 °C for the CoCrPt films. Room-temperature bias sputtering did not produce reductions in ΔM for the CoCrPt films.

Previously, we have attributed this behavior in ΔM to be related to Cr segregation to the grain boundaries,[3] but noted that an elevated temperature was required in order for the bias to be effective in driving the segregation. In this case with SiO_2, an increase in mobility may be at work in helping to increase the mobility of the SiO_2 molecules on the growing surface such that they reach grain boundaries. Additionally, SiO_2 in the grain boundaries, where it is coordinated with other SiO_2 molecules, may have a lower sputter yield than that of SiO_2 molecules at the center of growing metallic grains. In this case, preferential resputtering of the SiO_2 not at the grain boundaries would lead to an increased fraction of the SiO_2 in the grain boundaries. Both of these phenomena may be at work.

The effect of bias sputtering on the CoCrPt-SiO_2 microstructure can be observed by the TEM micrographs in Fig. 3. In the plan-view TEM images, the oxide grain boundaries are shown as white contrast between contiguous grains. First, it should be noted that the microstructure for the unbiased

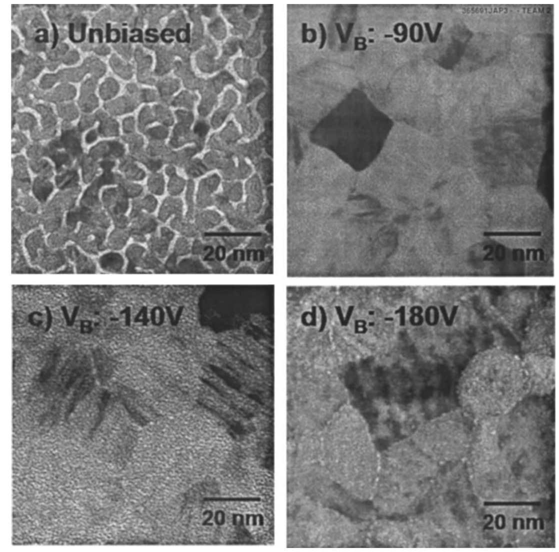

FIG. 3. Plan-view TEM images of the CoCrPt-SiO_2 films deposited on glass substrates as a function of bias voltage (V_B). The white contrast between adjacent grains indicates the presence of the oxide phase (SiO_2) along grain boundaries.

CoCrPt-SiO_2 media [see Fig. 3(a)] is distinct from the others. The SiO_2 content is about 10 at. % (~21 vol. %), and the micrographs reveal that most grains are structurally interconnected, giving rise to the inhomogeneous grain boundaries. This sample displayed a large value (0.31) of normalized ΔM and small coercivity (960 Oe). This suggests that a large increase in SiO_2 content in order to decouple the grains can result in an increasing tendency to form interconnected agglomeration on a fine scale, which allows the magnetic cluster size substantially larger (highly exchange coupled).

Even with a small bias voltage of -90 V, the film microstructure was dramatically changed consistent with the behavior of the ΔM measurements. The grains become well isolated, though substantially larger than in the unbiased case. The grain boundaries seem to get thicker with higher substrate bias, which indicates more grain boundary separation by the oxide phase, consistent with the above discussion.

When substrate bias was applied, a similar trend was seen in perpendicular CoCrPt-SiO_2 media deposited on Ru underlayer (not shown). For the perpendicular CoCrPt-SiO_2 films, the Ru underlayer seems to improve the microstructure of the magnetic layer even at high SiO_2 content. However, some grains are still not well isolated. Substrate bias led grains to be well separated in a similar fashion, but grain-size reduction is necessary to utilize this approach.

For the longitudinal CoCrPt films (not shown), bias sputtering appeared to be moderately effective in reducing grain diameter (GD) and, more noticeably, the grain-size distribution (σ) of the magnetic layers.[7] The GD and σ of the biased CoCrPt media are 12.8 and 5.2 nm while those of the unbiased media are 14.6 and 7.7 nm, respectively.

Finally, we note an important dependence of coercivity on thickness in CoCrPt films (no oxide) sputtered at room temperature. Care was taken to ensure that no significant temperature increase occurred during deposition, even when bias was applied. Because of the room-temperature deposi-

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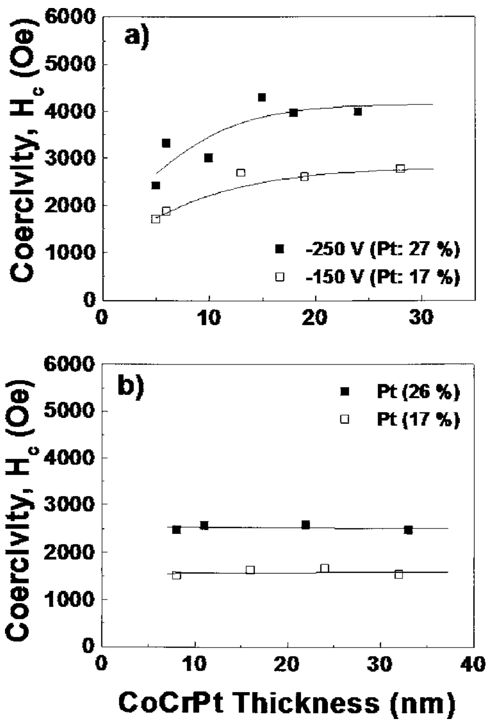

FIG. 4. In-plane coercivity H_c vs CoCrPt thickness as a function of bias voltage and Pt content (at. %). The CoCrPt films in (b) were prepared without substrate bias using different target composition with that used in (a) to allow for the bias-induced composition shift. The bias sputtered samples were deposited at room temperature and thus had intergranular coupling similar to the unbiased samples ($\Delta M = 0.4$).

tion, these films showed high values of ΔM of about 0.4. Figure 4 shows in-plane coercivity H_c of these CoCrPt films deposited as function of substrate bias voltage and the film thickness. A strong H_c dependence on the film thickness was observed only in the bias-sputtered films. The H_c increased about 80% as the film thickness changed from 5 to 25 nm for substrate bias of −250 V. The Pt content for the media was 27 at. %. In contrast, for the films deposited without substrate bias [see Fig. 4(b)], H_c is nearly the same as the thickness increased. A similar trend was observed for the CoCrPt-SiO_2 media as well. The mechanism for this effect is not yet understood, but we raise the possibility that stress and therefore stress-induced anisotropy may be a strong function of anisotropy. Previously, we have shown that bias sputtering induces significant stress in CoCrPt media.[5] Another possible explanation for this behavior is simply thermally assisted switching. Changing the film thickness from 5 to 15 nm triples the effective switching volume, and may eliminate coercivity reductions due to thermally induced switching. However, this effect was not seen in the unbiased films where the effect should be similar.

IV. CONCLUSIONS

In this study, effects of substrate bias on the microstructure of the CoCrPt and CoCrPt-SiO_2 films have been presented and discussed. The dramatic change in microstructure of the CoCrPt-SiO_2 media was due to preferential oxide removal during bias sputtering. With regard to the magnetic properties, substrate bias appears to be more effective in reducing intergranular exchange coupling when the CoCrPt-SiO_2 media is adopted. However, the observed thickness dependence of coercivity in the biased films seems to be similar for the two media.

ACKNOWLEDGMENTS

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[1]T. Oikawa, M. Nakamura, H. Uwazumi, T. Shimatsu, H. Muraoka, and Y. Nakamura, IEEE Trans. Magn. **38**, 1976 (2002).
[2]Y. Xu, J. Ping, and Y. Su, J. Appl. Phys. **87**, 6971 (2000).
[3]H.-S. Lee, D. E. Laughlin, and J. A. Bain, J. Appl. Phys. **91**, 7065 (2002).
[4]H.-S. Lee, L. Wang, J. A. Bain, and D. E. Laughlin, IEEE Trans. Magn. **41**, 654 (2005).
[5]H.-S. Lee, D. E. Laughlin, and J. A. Bain, Appl. Phys. Lett. (unpublished).
[6]D. E. Laughlin, B. Cheong, Y. C. Feng, D. N. Lambeth, L.-L. Lee, and B. Wong, Scr. Metall. Mater. **33**, 1525 (1995).
[7]H.-S. Lee, Ph. D. dissertation, Carnegie Mellon University, Pittsburgh, 2004.

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