Effects of substrate bias on CoCrPt-SiO₂ magnetic recording media

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CoCrPt and CoCrPt-SiO₂ magnetic layers were investigated as a function of substrate bias. It was found that the use of substrate bias greatly modified the CoCrPt-SiO₂ film microstructure. This was due to a large change in the SiO₂ 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-SiO₂ 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. 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, 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-SiO₂ 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 SiO₂ chips (for the CoCrPt-SiO₂) 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. 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.

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 Kα 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-SiO₂ 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-SiO₂ 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.
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 $\Delta M$ 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, $\Delta M$ values are strongly dependent on bias voltage, with $\Delta M$ values decreasing with higher substrate bias. The change in $\Delta M$ 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 $\Delta M$ for the CoCrPt films.

Previously, we have attributed this behavior in $\Delta M$ to the 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 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 $\Delta M$ 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 $\Delta M$ 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 ($\sigma$) of the magnetic layers.\(^7\) The GD and $\sigma$ 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-
tion, these films showed high values of $\Delta M$ of about 0.4. Figure 4 shows in-plane coercivity $H_c$ of these CoCrPt films deposited as function of substrate 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 ($\Delta M=0.4$).

![Graph](image)

**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 ($\Delta M=0.4$).

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.

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