Co Alloy-SiO_2 Granular-Type Longitudinal Media for Sputtered Tape Applications

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We investigated bias-sputtered Co alloy-SiO_2 films (CoCrPt-SiO_2 and CoPt-SiO_2) for high density magnetic tape media. We used bias sputtering to achieve desirable properties (good in-plane orientation and low noise) in these media. The CoCrPt-SiO_2 sputtered tape media showed a flat frequency response with a D_{50} of 160 kfci and a corresponding signal-to-noise ratio of 21 dB. The overwrite performance was better than 40 dB for an overwriting frequency of 12 MHz (90 kfci) and overwritten frequency ranging from 1 to 10 MHz (8–75 kfci). An overcoat (carbon nitride) with a thickness of 6 nm resulted in a 4–5 dB spacing loss in the roll-off curve at high recording densities, and a 3–4 dB lower overwrite ratio. In addition, the CoPt-SiO_2 media with no Cr present produced a maximum output 4–5 dB higher, but also higher noise power compared to the CoCrPt-SiO_2 media.

Index Terms—**Bias sputtering, Co alloy-SiO_2 films, sputtered tape media.**

I. Introduction

Low transition noise sputtered tape media that can be deposited at room temperature on polymer substrates will have a major impact on the future of tape storage and is the subject of active research [1]–[5]. A reduction in exchange coupling between neighboring grains through physical separation or compositional segregation needs to be achieved through methods other than elevated temperature. Previously, CoCrPt-SiO_2 perpendicular media fabricated without heating has been shown to produce fine grains that are decoupled by SiO_2 at the grain boundaries, leading to low noise performance in disk drive media [6]. This approach is appealing for longitudinal tape media because it is produced with no heating, in contrast to the well established Cr segregation mechanism.

In this work, Co alloy-SiO_2 tape media was investigated in terms of the recording performance as well as the physical properties. Two distinctive features in fabricating the Co alloy-SiO_2 media in our work are as follows. First, in [6], as in many others, an (0002) textured Ru underlayer was used to produce the perpendicular texture in the CoCrPt-SiO_2 layer, but a different underlayer (substrate/NiAl/CrMn/CoCrTa) was needed for longitudinal media. Our work suggested that Ru does not work well as a replacement for CoCrTa in the underlayer, and the Ru itself does not develop good in-plane texture, even on a BCC underlayer. This is somewhat different from previous reports where Ru underlayer was directly deposited onto substrates [3], [4]. This is probably because its lattice ($a = 0.271$ nm and $c = 0.428$ nm) appears too large to match well to the CrMn alloy used here. Secondly, as previously reported [7], bias sputtering was used to achieve desirable media properties (good in-plane orientation and low noise) in the Co alloy-SiO_2 longitudinal media. The in-plane texture was also maintained with bias sputtering. The use of bias sputtering was very effective in decoupling grains in oxide composite recording media [8]. This approach was utilized through this work.

As can be seen in this work, the process examined here is relatively complex (four layers) and is likely to be expensive to commercialize. The considerations, so far, are focused on the technology demonstration of sputtered tape media. However, in order to answer which medium will eventually prevail for future high density recording media, commercial aspects such as the Pt content or the deposition rate must also be taken into account.

II. Experimental Setup

CoCrPt-SiO_2 and CoPt-SiO_2 longitudinal films were sputter-deposited on either glass or tape substrates. For the tape substrate, a smooth aromatic polyamide (ARAMID) was used to lower modulation noise [9]. The Pt content was 20–25 at.%. A composite underlayer stack used to produce the in-plane texture was substrate/NiAl/CrMn/CoCrTa [10]. The deposition rates for NiAl, CrMn, CoCrTa, CoCrPt-SiO_2, and CoPt-SiO_2 were 8, 11, 8, 5, 3 nm/min, respectively. For manufacturing purposes, deposition rates of 10 nm/s would be desirable, however such high deposition rates can provide some challenges, including realization of the correct microstructure [11].

Our results also showed that the deposition dwell time is primarily determined by the NiAl layer since the NiAl underlayer should be thick enough to preserve the in-plane coercivity. The minimum thicknesses for NiAl, CrMn, and CoCrTa are 45, 6, and 4 nm, respectively [12].

The CoCrTa composition is high enough in Cr that the alloy is paramagnetic. If necessary, a protective carbon nitride (CNx) layer with a thickness of 6 nm was added. The CNx thin film was deposited by a reactive sputtering process in an environment of pure nitrogen. The CNx seemed to provide a more robust head-tape interface for testing although the interface without it was sufficient for short testing. A substrate bias voltage of -120 V was applied for the magnetic layer deposition. The bias voltage was determined not to degrade the coercivity of the magnetic layer. Table I shows the details of the sputtered tape media employed in the experiment.

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TABLE I
SPECIFICATIONS OF MEDIA

<Media>	
Type	Co alloy-SiO_2 sputtered
Coercivity (Oe)	2200-2500
$\Delta M/Mr$	~ 0.2
Thickness of mag. layer (nm)	12
$Mr \cdot \delta$ (memu/cm^2)	0.6

The magnetic properties of the samples were measured by an alternating gradient magnetometer (AGM) and a vibrating sample magnetometer (VSM). Film textures and microstructures were characterized by an X-ray diffractometer (Philips X'pert Pro with X-ray lens) using Cu K_α radiation and by a transmission electron microscope (TEM) operating at 200 kV.

Recording measurements were performed on a drum tester at a head-medium velocity of 6.8 m/s, using a metal-in-gap (MIG) write head with an effective gap length of 0.2 μm and a track width of 17 μm. For readback, an anisotropic magnetoresistive (AMR) read head was used with a shield-to-shield distance of 0.23 μm and a track width of 7 μm. The resolution bandwidth (RBW) for the measurement was chosen to be 30 kHz for the spectral analysis. Other details for the recording measurements are described elsewhere [2].

III. RESULTS AND DISCUSSION

Fig. 1(a) shows the relationship between CoCrPt-SiO_2 longitudinal media microstructure and SiO_2 content. As indicated from the X-ray diffraction (XRD) spectra, increasing the SiO_2 content (not using substrate bias) produced a 3-D randomly oriented magnetic layer and resulted in a smaller in-plane H_c. A significant deterioration in the preferred Co (10.0) grain orientation was observed with a SiO_2 content greater than ~6 vol.%.

At higher values of SiO_2 content, precipitation of SiO_2 within the magnetic grains smaller than 10 nm was also observed, but with still substantially larger magnetic switching volume (highly exchange-coupled). Further increasing the SiO_2 content, the SiO_2 was eventually formed in a shell pattern around the Co-alloy spheres with a network structure [11].

Fig. 2 shows a plot of the coercivity, H_c and ΔM as a function of SiO_2 content. With increasing SiO_2 content, a significant degradation in H_c was observed, and the corresponding ΔM values remained high (~0.4). The micrographs [see Fig. 1(a)] show that most grains are structurally interconnected even at high SiO_2 content of ~20 vol.%, giving rise to the inhomogeneous grain boundaries. The observed small H_c and the large exchange coupling are ascribed to this interconnected agglomeration on a fine scale.

Bias sputtering was used to attain in-plane orientation and low exchange coupling in the Co alloy-SiO_2 longitudinal media. As indicated by open and filled squares in this figure, compared to the unbiased films, the bias-sputtered CoCrPt-SiO_2 films on polymeric substrates showed desirable media properties ($H_c \sim$ 2300 Oe and $\Delta M \sim 0.2$). It is seen that biasing decreased the intergranular exchanging coupling as determined by ΔM. The squareness (S) for the biased media is typically 0.75–0.8. For longitudinal disk media, CoCrPt showed large positive (>0.5) ΔM values, whereas CoCrPtTa or CoCrPtB media typically had a small ΔM of ~0.1, implying much weaker intergranular interactions [13].

Note also that there is a small difference in H_c between the films sputtered on glass and flexible substrates. The CoCrPt (10.0) oriented media on tape substrates exhibit significantly wider range orientation than media on rigid substrates due to the apparently large morphological differences between them. This is in part attributable to the difficulty in producing well-oriented NiAl/CrMn (112) underlayers on tape substrates. A 20%–30% lower resultant H_c was typically observed on tape substrates [9].

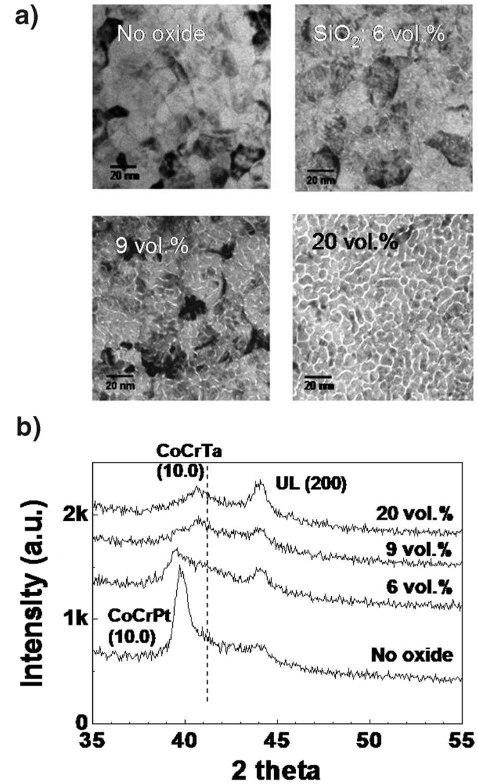

Fig. 1. Microstructure of the CoCrPt-SiO_2 thin films as a function of SiO_2 content (vol.%): (a) TEM plan-view and (b) x-ray diffraction spectra. A significant degradation in in-plane (10.0) orientation was observed with a SiO_2 content greater than 10 vol.%. The sample structure was glass/underlayers/CoCrTa (15 nm)/CoCrPt-SiO_2 (15 nm). The underlayers (UL) were NiAl (60 nm)/CrMn (30 nm).

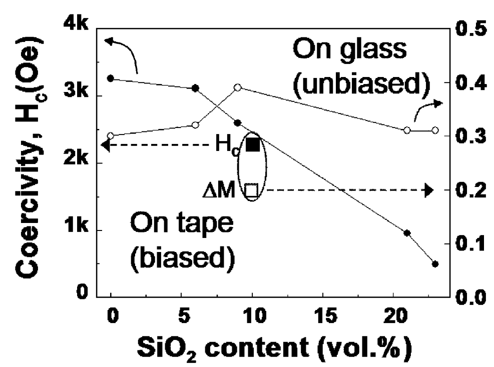

Fig. 2. In-plane coercivity (H_c) and ΔM as a function of the SiO_2 content (vol.%). The bias-sputtered CoCrPt-SiO_2 films on polymeric substrates showed H_c of ~2300 Oe (filled square) and ΔM of ~0.2 (open square).

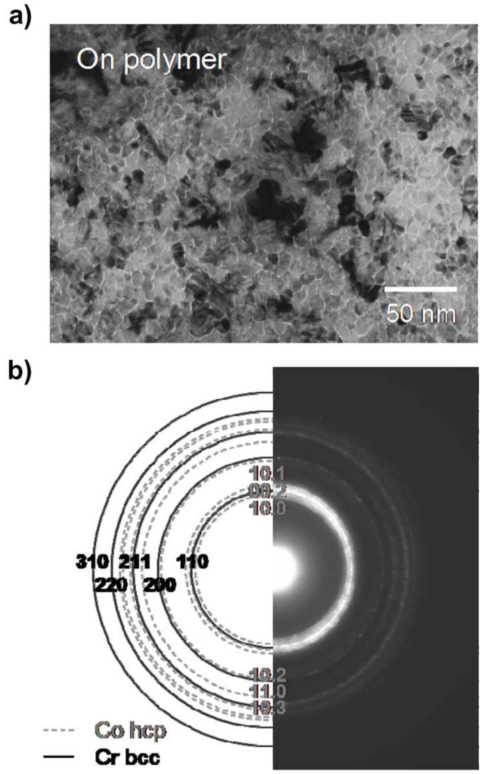

Fig. 3. (a) Plan-view TEM image and (b) selected area electron diffraction (SAED) of typical bias-sputtered CoCrPt-SiO_2 tape media. Grains with average grain size less than 10 nm were seen from the plan-view TEM. The SAED pattern shows the weak (10.0) ring, the presence of the (10.1) ring along with a strong (00.2), indicating the prominence of (10.0) texture but containing some range of spread in their orientation.

In Fig. 3(a), bright-field TEM observation of the bias-sputtered CoCrPt-SiO_2 tape media showed grain size to be less than 10 nm. Of particular note is the grain size that is notably smaller than the observed value of $\sim$13 nm for biased CoCrPt-SiO_2 media on rigid substrates [7] where biasing had an effect of reducing the total amount of oxide (SiO_2) in the growing films, and promoting the growth of larger apparent grains. Interestingly, use of bias sputtering does not result in promoting the growth of larger grains for the CoCrPt-SiO_2 films on tape substrates. It appears that the CoCrPt-SiO_2 films on tape substrates are less susceptible to resputtering as compared to CoCrPt-SiO_2 films on rigid substrates. For the CoCrPt-SiO_2 tape media, the SiO_2 content decreased from 20 to about 10 vol.% as bias-sputtered with a substrate bias of -120 V whereas, even with a small substrate bias voltage of -90 V, it was observed that the most of the SiO_2 was resputtered from the growing films on rigid substrates [7]. This may be due to the reduced momentum transfer on polymeric substrates, in part because of the less perfect substrate surfaces in tapes as compared with rigid disks.

On a closer look, slightly better-defined grains with boundaries than the unbiased media with a SiO_2 of 9 vol.% [see Fig. 1(a)] are seen. This is consistent with the lower exchange coupling in the biased media shown above. The actual SiO_2 content of the biased samples is $\sim$10 vol.%. In most cases, it is thought that bias sputtering can help to increase mobility of the SiO_2 molecules such that they reach grain boundaries with better segregation.

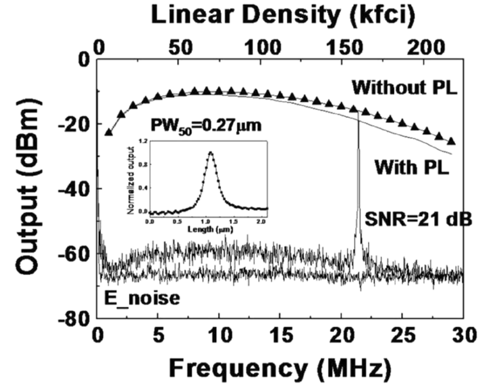

Fig. 4. Spectra of signal and noise for the CoCrPt-SiO_2 sputtered tape media with the AMR head. The solid line corresponds to the case that a 6-nm-thick carbon nitride protective layer (PL) was deposited onto the magnetic layer. The inset indicates the isolated readback pulse of the CoCrPt-SiO_2 media. Signal-to-noise ratio (SNR) of 21 dB was observed at a linear density of 160 kfci.

In Fig. 3(b), electron diffraction (ED) pattern of NiAl/CrMn/CoCrTa/CoCrPt-SiO_2 films is shown with CoCrTa/CoCrPt (10.0), (00.2) texture and NiAl+CrMn (110), (112) texture. The sputtered tape media have a good lattice match to obtain a strong Co (10.0) growth texture, and contain a weak Co (00.1) orientation. The innermost two extra rings are Co (10.0) and Cr (110), respectively. The calculated hcp and bcc ring patterns are superposed in the figure.

Recording tests were performed on the bias-sputtered tape media described above. In Fig. 4, the roll-off curve showed a D_{50} value of 160 kfci, with a corresponding SNR of 21 dB. The sputtered tape media was nearly free of modulation noise about the fundamental harmonics due to the smooth substrates [14].

The isolated readback pulse width at 50% of maximum amplitude (PW_{50}) was shown to be 0.27 μm (see the inset) with a nearly symmetrical pulse waveform. One important recording characteristic associated with the easy axis direction is the output voltage waveforms. Perpendicular components of magnetization can be a cause of an asymmetry of the baseline on either side of the isolated peak [15]. From the corresponding XRD spectra (not shown), the intensity ratio of the measured c-axis in-plane I(10.0) and out-of-plane I(00.2) components was 1.5. Asymmetry of the isolated peak was less than 3% as defined by taking difference of the baseline on either side of the isolated peak divided by the peak height.

With a 6 nm-thick protective layer (PL), the signal loss of 2–3 dB due to spacing was seen at higher recording densities, which is displayed as the solid line. Using the equation ($-99 \cdot \mathrm{d}/\lambda$ in dB) known as *spacing loss factor* where d is spacing, and λ is wavelength, an increase in head-to-medium spacing due to the overcoat was measured to be 8 nm, which is in reasonable agreement with a nominal thickness of the overcoat (6 nm).

Overwrite measurements were carried out as shown in Fig. 5. Good overwrite was present over the whole frequency range. The overwrite performance of the sputtered tape media was better than 40 dB for an overwriting frequency of 12 MHz (90 kfci) and overwritten frequency ranging from 1 to 10 MHz (8–75 kfci). With the PL (the solid line), the overwrite ratio was decreased with about 3–4 dB lower values in the frequency ranges of interest. An increase in spacing by the PL broadens

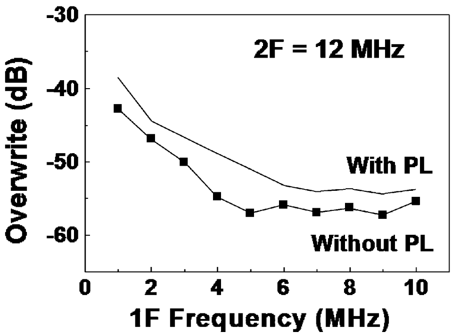

Fig. 5. Overwrite (OW) performance for the CoCrPt-SiO_2 sputtered tape media. The OW was better than 40 dB for an overwritten frequency ranging from 1 to 10 MHz (8–75 kfci). The overwriting frequency was 12 MHz (90 kfci). A 6-nm protective layer (PL) yielded a 3–4 dB lower overwrite performance.

the transition width due to the broader *effective* head field gradient. This can give rise to an increased effect of the magnetostatic field from overwritten transitions and lead to the poorer overwrite performance [14].

In Fig. 6(a), output roll-off curves as a function of recording density are shown for the CoCrPt-SiO_2 and the CoPt-SiO_2 sputtered tape media. The overcoat was deposited onto the two media for this measurement. The shapes of the roll-off curves for these two media are similar, displaying a D_{50} value of 150 kfci. The signal output of the CoPt-SiO_2 media was enhanced by eliminating Cr, and a maximum output was shown to be 4–5 dB higher in wide frequency ranges than that of the CoCrPt-SiO_2 media. However, the benefit of the increased signal output of the CoPt-SiO_2 to the CoCrPt-SiO_2 media seems to be limited by the increase of the media noise with density. This may be due to the similar level of exchange coupling in these media. The output signal and the media noise increase, being proportional to the medium remanent magnetization (M_r) unless there is a notable difference in exchange coupling.

In Fig. 6(b), SNR and integrated noise power with respect to recording density are shown for the two media. The noise power of the CoPt-SiO_2 media was significantly larger (3–4 times) than that of the CoCrPt-SiO_2 media. The noise power for the CoCrPt-SiO_2 changed from 1.0 to 4.9 mV^2 in going from 30 to 140 kfci while that for the CoPt-SiO_2 increased from 3.3 to 21.0 mV^2. As a result, no obvious advantage in SNR was seen by adopting either the CoPt-SiO_2 or the CoCrPt-SiO_2 media. This also suggests that SiO_2 molecules (not Cr atoms) which segregate to Co alloy grain boundaries, forming oxide phases, play a primary role in reducing exchange coupling. This is generally consistent with the results of studies previously published [16]. For Cr segregation, high substrate temperature during deposition process was typically required. However, Cr may aid in the SiO_2 segregation to the grain boundaries.

In order to help us further characterize the biased media in terms of recording performance, we make some comparisons with the related works [3], [5]. Recently, higher SNR at similar linear densities and sharper PW_{50} for CoCrPt-SiO_2 longitudinal media on flexible disk have been demonstrated by Moriwaki *et al.* [3] and Palmer *et al.* [5]. A giant magnetoresistive (GMR) head with a shield-to-shield distance of 0.125

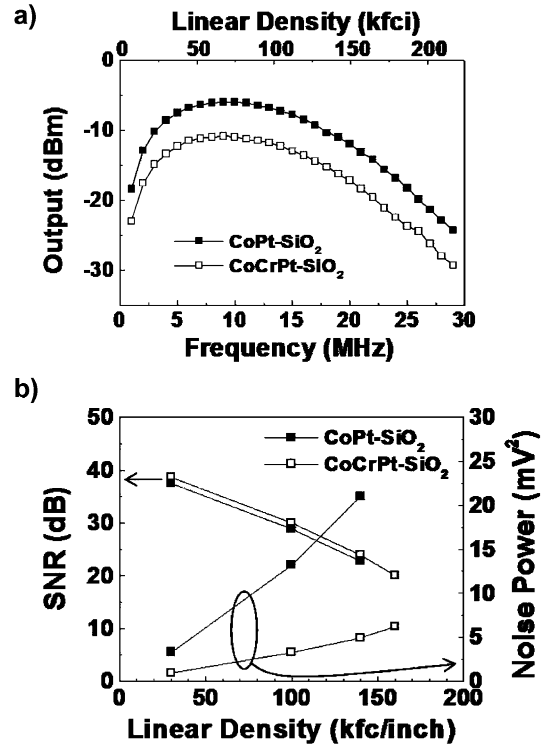

Fig. 6. Recording performance for the CoCrPt-SiO_2 and the CoPt-SiO_2 tape media: a) roll-off curve and b) signal-to-noise ratio (SNR) and noise power as a function of linear density. The CoPt-SiO_2 media showed a maximum output 4–5 dB higher but noise power also higher compared to the CoCrPt-SiO_2 media. This resulted in the similar SNR for the two media.

μm, which is nearly one half of that employed here, was used for readback. They showed a PW_{50} of 0.13 μm and a D_{50} of 310 kfci. Such media produced a SNR of 22 dB at a linear density of 200 kfci. The media was almost 3-D random in orientation. The media surface roughness was 24 nm in R_z as determined by an atomic force microscope.

D_{50}, which is one of the fundamental parameters that determine the possible recording density, is known to be inversely proportional to the PW_{50} of the isolated pulse [17], [18] as given by (1)

$$D_{50} \cong \frac{1.45}{PW_{50}} = \frac{1.45}{\sqrt{\left(\frac{1}{2}g^2 + 4(a+d)(a+d+\delta)\right)}} \quad (1)$$

where g is the shield-to-shield gap of the read head and δ is the magnetic layer thickness. Obviously, reducing the read head gap leads to the narrower PW_{50}.

For the bias sputtered tape media, the measured power spectrum (in dB) of the fundamental component with respect to recorded wavelength, using the *loss factor*, gave a rough estimate of the spacing [14], which is about 25–30 nm. We also estimate the transition parameter a to be about 40–50 nm from the observed D_{50} value. The medium thickness was 12 nm.

Plugged a shield-to-shield gap of 0.125 μm into (1), the reduction by nearly half from the current gap length of 0.23 μm (by possibly adopting an GMR read sensor) gives rise to an increase of 10%–30% in D_{50}, which is in the range of 180–210 kfci.

While this represents only a rough analysis, it also suggests better grain isolation in the biased media would need to improve the linear density further. Thicker oxide grain boundaries for better physical separation in the biased media may be attainable by controlling the morphology of the underlayer [8]. A strong influence of underlayer on the morphology of the magnetic layer was observed as bias sputtered in [8].

Finally, SNR was considered for further comparison. Assuming that a factor of two in read track width would correspond to 3 dB in SNR, a read track width of 0.28 μm as in [3] will give rise to a loss of 14 dB (with all else being equal), taking into account the 7 μm track width. However, the use of a GMR head produces higher sensitivity than an AMR head, and leads to considerably improved recording performance [19], which makes a direct comparison of SNR difficult in this case.

IV. Conclusion

We have discussed the application of sputtered CoCrPt-SiO_2 and CoPt-SiO_2 thin films for advanced tape media. The Co alloy-oxide granular-type media seems to be the media of choice for tape applications due to the fact that magnetic grain isolation can be achieved by using a nonheating process. Moreover, bias sputtered CoCrPt-SiO_2 tape media appears to offer the good performances with in-plane orientation and media noise acceptably controlled.

Acknowledgment

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