Role of Oxygen Incorporation in Co-Cr-Pt-Si-O Perpendicular Magnetic Recording Media

M. Zheng, B. R. Acharya, G. Choe, J. N. Zhou, Z. D. Yang, E. N. Abarra, and K. E. Johnson

***Abstract*—The effect of oxygen incorporation on the crystallographic, magnetic, and recording performance of perpendicular magnetic recording (PMR) oxide media was investigated. The media were prepared by dc-magnetron sputtering of CoCrPt-SiO_2 targets in an Ar/O_2 gas mixture. X-ray photoelectron spectroscopy (XPS) detected Cr-O peaks in the sputtered film, whereas no strong evidence of SiO_2 is seen. Moderate oxygen incorporation in the film ($\sim$15 at%) promotes Cr-O formation in the grain boundary and results in a dramatic increase of coercivity H_c and signal-to-noise ratio (SNR). However, as the O_2 content is further increased, oxide incorporates into the core of the grains, resulting in decreased H_c, magnetization and SNR.**

***Index Terms*—Oxide media, oxygen content, perpendicular recording, recording performance.**

I. Introduction

PERPENDICULAR magnetic recording is believed to be the next magnetic recording paradigm to achieve areal densities over 1 $\mathrm{Tbit/in^2}$ [1]–[3]. CoCrPt-O based media designs are being actively pursued for high-density perpendicular recording [4]–[7], [9]. Because of the well-isolated fine grain structure, such media provide higher coercivity and better SNR compared to other PMR media candidates [5], [8]. Oxide media can be fabricated by either rf or dc-magnetron sputtering of CoCrPt-SiO_2 targets in a pure Ar-gas or in an Ar/O_2 gas mixture. Early papers on rf-sputtered media showed that SiO_2 precipitates to the grain boundary and segregation of Cr to grain boundaries was not observed [4], [9]. In this work, we investigated the effect of oxygen incorporation on the crystallographic, magnetic, and recording performance of media prepared by reactive dc-magnetron sputtering. The percentage of O_2 in the film can be varied as a function of target-composition or O_2 partial pressure in the sputtering gas.

II. Experiment

The media were deposited onto NiP-plated aluminum substrates using an Intevac MDP250B system. All films were sputtered at low substrate temperature (about 60 °C). Ta/Ru was used as intermediate layer. Co-Cr-Pt-Si-O recording layer was dc-magnetron sputtered using a CoCrPt-SiO_2 target. A 160-nm-thick CoZrTa soft magnetic underlayer is used as keeper layer when measuring recording performance. The grain morphology was investigated by transmission electron microscopy (TEM). XPS was used to analyze the oxygen content in the media and oxide forms. Magnetic properties were measured by a vibrating sample magnetometer (VSM) and a magneto-optical polar Kerr magnetometer. Recording performance was evaluated on a Guzik tester with single-pole writer and GMR reader.

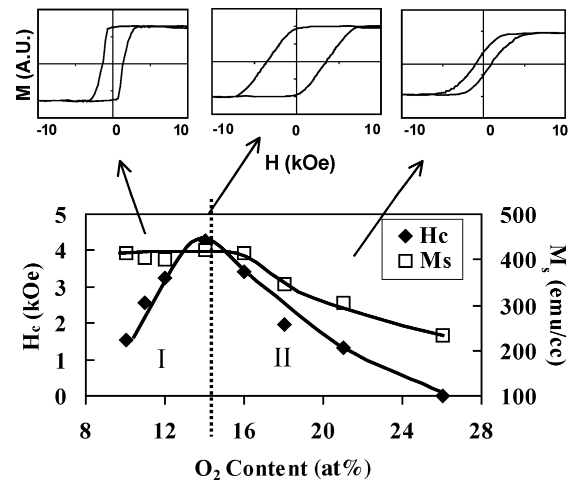

Fig. 1. H_c and M_s dependence on oxygen content for Co-Cr-Pt-Si-O PMR media. Selected VSM hysteresis loops are shown as well.

III. Results and Discussion

A. Magnetic Properties and Microstructure

Fig. 1 shows the coercivity H_c and magnetization M_s dependence on the oxygen content in the film as determined by XPS. The graph can be divided into two zones: Zone I, where the oxygen content <15 at%, the M_s of the media remains constant while H_c increases dramatically, and Zone II, where both M_s and H_c deteriorate with increasing oxygen in the film. Selected VSM loops are also shown in Fig. 1.

Fig. 2 shows the XPS spectra of Si in the film. Unlike the rf-sputtered CoCrPt-SiO_2 media [4], [9], no strong evidence of SiO_2 is seen in these dc magnetron reactively sputtered media.

Fig. 3 shows the Cr spectra for the media with oxygen content of 21 at%. The spectra have been de-convoluted into the spectra of Cr and Cr-O and the fitted curve is shown as well. CrO_2 and Cr_2O_3 peaks are at 576.3 and 576.9 eV, respectively, and cannot be differentiated. Similar analysis has been done on the media with 10 and 15 at% oxygen. It was found that the intensity ratio of Cr-O peak to Cr peak is about 1:4, and 1:3 for media with 10 and 15 at% oxygen, respectively, indicating that a minor portion of the Cr is in the oxide form. The Cr-O ratio for media

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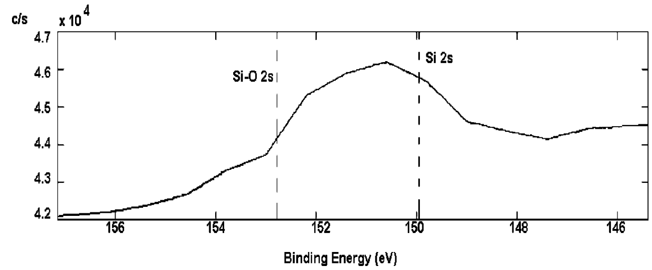

Fig. 2. XPS spectra of Si in Co-Cr-Pt-Si-O PMR media.

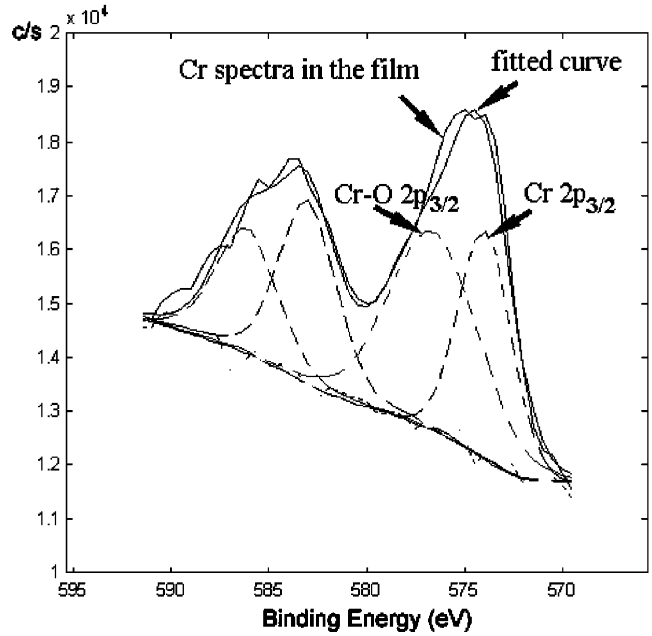

Fig. 3. XPS spectra of Cr in Co-Cr-Pt-Si-O PMR media with 21 at% O. The spectra has been deconvoluted to the spectra of metal Cr and Cr-O. The fitted curve is shown as well.

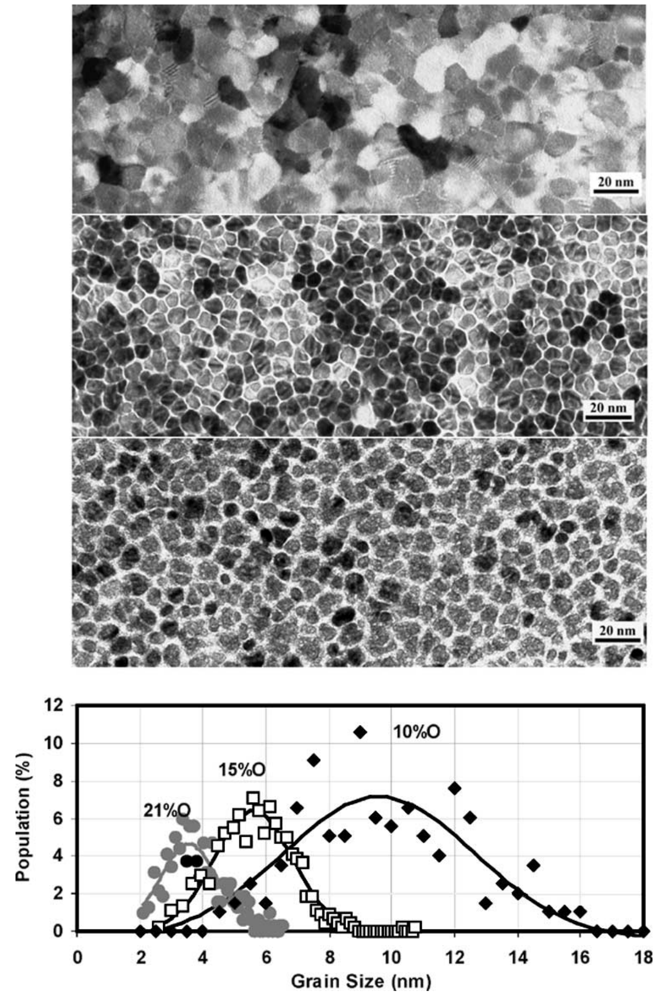

Fig. 4. TEM images for the media with 10 (top), 15 (middle) and 21 (bottom) at% oxygen. The grain size exhibits Gaussian distribution. The average grain size is about 9.5, 5.9, and 4 nm for the media with 10, 15, and 21 at% oxygen, respectively.

with 21 at% increases very rapidly to 1:1 showing that 50% of Cr is in the oxide form. Also, there were no significant changes in the Si and Co spectra when the oxygen content is less than 15 at%; both show mostly Si and Co phases. Only when the oxygen content is ∼21 at%, the Si spectra shift to higher energy (corresponding to Si-O) and a Co-O peak appears on the shoulder of the Co 2p metallic peak.

Fig. 4 shows plane view of TEM images and grain size distribution of the media with oxygen content of 10, 15 and 21 at%. Gaussian fit is used for the grain size distribution. The grain size decreases and the grain boundary increases with oxygen content. When the oxygen content is low, the average grain size is about 9.5 nm, the grains are more coupled with each other and the grain boundary is very thin. This is consistent with smaller H_c and lager loop slope in Zone I in Fig. 1. At the optimum oxidization state (i.e., 15% O), the grains are smaller (∼5.9 nm), well-isolated, and exhibit a narrower size distribution. With more oxygen incorporation, the grain boundary gets thicker but "white dots" can be observed inside each grain. We speculate those "white dots" should be some oxides, consistent with the XPS observation of steep increase of Cr-O along with the presence of some Co-O. These oxides could physically make each active Co grain get smaller, magnetically reduce Co anisotropy and both lead to superparamagnetic state for the media. This is accompanied by both M_s and H_c reduction as shown in Fig. 1.

The above results suggest that in Zone I, grain boundaries have mostly Cr-O. Since the grain boundary is amorphous, the oxides of Cr are most likely in the boundaries providing magnetic isolation as the recording performance data indicates (see below). This is consistent with the large grain size at low oxygen content as potential boundary material is reduced; the low coercivity and steep M-H slope indicate significant exchange coupling. Current experimental data cannot predict whether oxygen combines with Cr and diffuses to the grain boundaries or combines with the Cr already at the boundaries. In Zone II, oxidation of Cr and Co within the core of the grain is possible. The anisotropy is reduced as evidenced by the lower H_c and the slope of the M-H loop, suggesting an oxygen-rich grain core. Exchange coupling reduces H_c in Zone I but is not the mechanism in Zone II.

TABLE I
PARAMETRIC DATA AT 550 KFCI FOR THE MEDIA WITH DIFFERENT OXYGEN CONTENT

O in media	SpSNR (dB)	S_o/N_m (dB)	SMNR (dB)	Res. (%)	PW_{50} (μin.)	LF (mV)
10%	13	29.9	11.1	35.7	3	0.84
15%	14.5	31.4	13.1	36.8	2.93	0.83
21%	12.3	31.6	13.0	32.3	3.24	0.75

B. Recording Performance

The recording performance of the media is strongly dependent on their structural and magnetic characteristics due to oxygen incorporation. Table I shows the parametric data for media in Zones I, II, and in between. So/Nm is the isolated pulse signal divided by the rms media transition noise at the highest frequency tested (1T), SpSNR is signal at half the maximum frequency (2T) divided by total noise at 2T, SMNR is 2T signal over media noise at 1T, and resolution (Res.) is a measure of the media's ability to sustain high frequencies. The signal at low frequencies is also listed TAA (LF). The pulse width PW_{50} was measured by differentiating a low frequency signal. The media having the optimum oxygen content shows the best overall recording performance. The low-oxygen content medium in Zone I has the lowest So/Nm and SMNR which can be attributed to the larger grain size and exchange coupling compared to the other media. For the high-oxygen content medium in Zone II, smaller grain sizes and good grain segregation result in good So/Nm and SMNR. However, excessive oxidization reduced the magnetic anisotropy and magnetization. As a result, the medium has the lowest LF and the poorest SpSNR. The low coercivity resulted in a wide PW_{50} and low resolution. Therefore, oxidation cannot be carried on indefinitely on PMR oxide media to reduce either grain size or reduce exchange coupling.

C. Oxidization Process on Media Properties

Aside from the oxygen content, another key factor for making good oxide media is the oxygen introduction process itself. The percentage of O_2 in the film can be varied as a function of target-composition or O_2 partial pressure in the sputtering gas. Fig. 5 shows the coercivity dependence on oxygen partial pressure (calculated from oxygen percentage in the total gas pressure) for the media made from two different SiO_2-containing targets. All other sputtering conditions were maintained. For the media using a target with a significant vol.% of SiO_2, higher coercivity and optimum condition can be achieved at relatively lower O_2 partial pressure compared to using a target with half the SiO_2 content. For the latter, the optimum seems to have not been achieved even at 3 mTorr O_2 partial pressure. This significantly impacts uniformity of the media as the higher the O_2 partial pressure is, the more difficult it is to achieve uniform oxidization.

IV. CONCLUSION

The effect of oxygen incorporation on the crystallographic, magnetic, and recording performance of PMR oxide media was investigated. When oxygen content is low, adequate grain segregation is not achieved which results in low H_c and poor SNR. Moderate oxygen incorporation in the film (~15 at%) promoted Cr-O formation in the grain boundary and resulted in a significant improvement in H_c and recording performance. However, as the O_2 content is increased, the data suggest that the excess O_2 goes to the core of the grains, dropping both the H_c and M_s, and adversely affects the media resolution. Proper SiO_2 content in the target helps to achieve optimum oxidization at relatively lower partial oxygen pressure, which has an important bearing on producing uniform PMR oxide media.

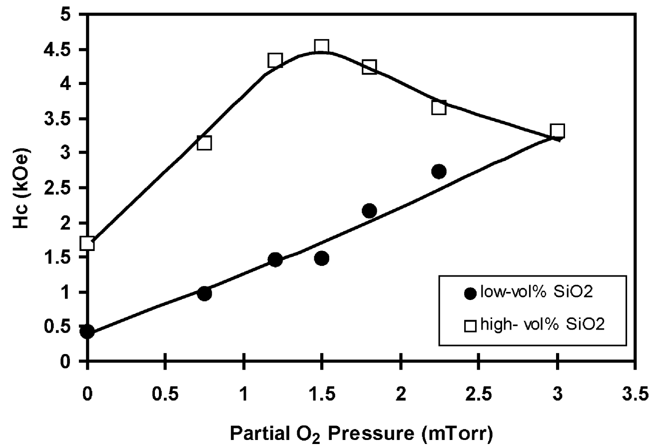

Fig. 5. H_c dependence on partial O_2 pressure. The only difference is that the media were sputtered using low and high vol% SiO_2-containing target.

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