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Magnetic properties and microstructure of evaporated Co oxide tape media

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Abstract

The magnetic properties and microstructure of Co oxide tape media were studied. The intrinsic in-plane and out-of-plane anisotropy constants of metal evaporated CoO tape media were measured from the in-plane torque and the out-of-plane torque curves. It was found that after considering the tilting effect of the column, the total intrinsic anisotropy constant, calculated from the in-plane torque curve, is much less than that calculated from the out-of-plane anisotropy constant. TEM electron diffraction studies indicate that the Co *c*-axes are randomly oriented. However, from the in-plane hysteresis loop measurements, the easy axes are pretty well parallel to incident beam plane. The cross sectional TEM micrograph shows that the column is tilted 30° out-of-plane and has a diameter of 10 nm.

1. Introduction

Today, thin film media are the state of art in rigid disk systems. However, flexible systems are still dominated by particulate media. The first metal evaporated tape thin film media were put on the market in 1989, but this product is only for video tape and digital audio tape (DAT). However, data tape media require much higher storage densities, much higher data rates and longer durability/archivability than consumer analog systems. In seeking high volume density for tape storage, it is critical to find magnetic media that can support high linear storage densities. Current commercial ME tape media, CoNiO [1], suffer from a coercivity and a coercivity squareness that are too low and an $M_r t$ that is too high to support 1 Tbyte/in^3 volume density. Recently, Co/CoO has shown potential as a new ME tape due to its good magnetic and recording properties [2–4]. Many investigations have been undertaken to determine the magnetic properties of ME tape media and their influence on recording performance [5–8].

This paper reports the magnetic properties and microstructure of Co/CoO media.

2. Experimental

Pure Co was obliquely evaporated in an oxygen gas environment onto 4.5 μm TEONEX(PEN) substrates, transported on a bi-direction roll coater, at an average evaporation rate of 90 Å/s [2]. The incident angle of the evaporants was greater than 65°. The magnetic properties were measured by a DMS-1660 dual VSM/torque magnetometer, and the δM curves were measured by a alternating gradient magnetometer MicroMag™ 2900. A Philips 400T TEM was used to study the microstructure of the Co–O films using conventional bright field and dark field techniques. The cross-section samples were prepared by the method described in Ref. [9], and the plane view samples were as-deposited and then ion milled.

3. Results and discussion

3.1. Anisotropy and in-plane loop

The sample anisotropy was measured from both in-plane and perpendicular torque measurements. The starting point for each torque measurement was with the field applied to the sample plane along the column direction. The perpendicular torque for a 600 Å film, deposited at 1.6 μTorr oxygen pressure, showed its extrinsic easy axis to be tilted 20° out of the film plane [2]. After correcting for the effect of the demagnetizing field, the anisotropy constant, $K_{\mathrm{u,intrinsic}}$ was calculated to be 3.4×10^6 erg/cm^3. Assuming that the film has an uniaxial anisotropy, the anisotropy constant $K_{\mathrm{u,intrinsic}}$ of the film can also be derived from in-plane torque: $K_{\mathrm{u,intrinsic}} = K_{\mathrm{u,in\text{-}plane}}/\cos^2\gamma$. Here, γ is the column angle with respect to the film plane, which is approximately 30°, observed by cross-section TEM. For the same sample, it was found that $K_{\mathrm{u,in\text{-}plane}} =$

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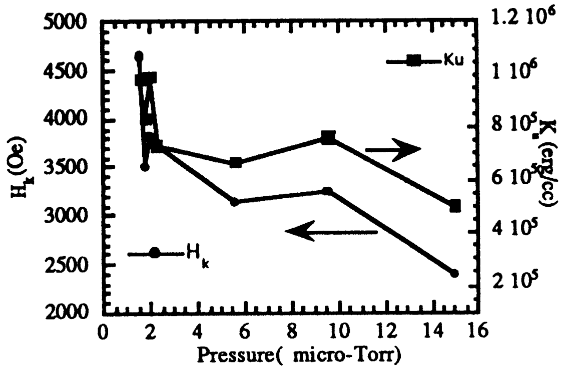

Fig. 1. In-plane anisotropy field and anisotropy constant versus oxygen pressure.

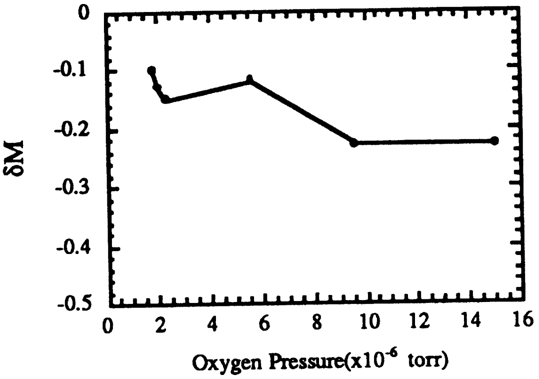

Fig. 3. δM peak hight versus oxygen pressure.

9.8×10^5 erg/cm^3, which yields $K_{\mathrm{u,intrinsic}} = 1.38 \times 10^6$ erg/cm^3 from the in-plane torque measurement, which is only one-third of the $K_{\mathrm{u,intrinsic}}$ from the out-of-plane torque measurement. This discrepancy suggests that the crystalline anisotropy plays a significant role in the out-of-plane torque measurements. The in-plane anisotropy constants and anisotropy field are plotted versus oxygen pressure in Fig. 1. Oxygen is seen to reduce the in-plane anisotropy constant and the anisotropy field. By measuring the hysteresis loops while rotating the sample in the film plane, the coercivity, remanence squareness Sq and coercivity squareness S^* of the film deposited at 1.6 μTorr can be determined, and these are plotted versus the angle with the incident beam plane in Fig. 2. The remanence squareness Sq has a value of 0.9 along the in-plane easy axis and 0.2 along the in-plane hard axis. The hard axis coercivity is only one-half of the easy axis coercivity. This suggests that the columns are well aligned.

3.2. In-plane extrinsic δM

It is difficult to measure the intrinsic δM value due to the tilted intrinsic easy axis in ME media. But the same principle [10] could be applied to the in-plane component. The samples were initially ac demagnetized in the sample plane. The extrinsic in-plane δM peak value versus the oxygen pressure is plotted in Fig. 3. The higher the oxygen doping, the more negative δM becomes, indicating that increasing oxygen decreases exchange coupling between grains.

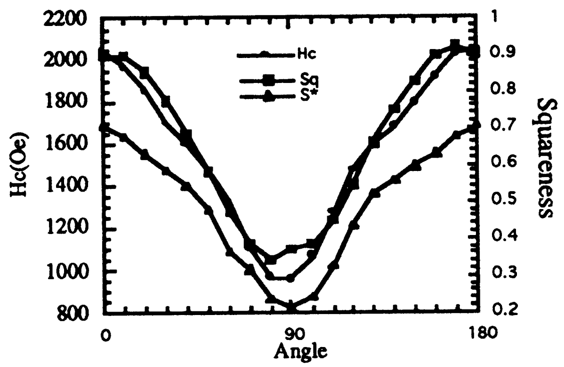

Fig. 2. In-plane coercivity, remanence squareness and coercivity squareness versus rotation angle.

3.3. Microstructural investigations

The electron diffraction patterns of two films deposited at different oxygen pressures are shown in Figs. 4 and 5(a).

Table 1 lists the diffracting planes of Co and CoO in the order in which they appear in the diffraction patterns, starting with those of largest d spacing. From these diffraction data, it appears as if the film is a combination of Co and CoO. When the oxygen pressure increases, the intensity of the diffraction rings from the CoO increases. Thus, the CoO content in the film increases with oxygen pressure. Fig. 5 shows the diffraction patterns of the film at 0°, 10°, 20° tilted around an axis in the film plane.

That the Co(0002) diffraction ring does not break into an arc when the sample is tilted suggests that the c-axes are randomly orientated in three dimensions [11]. Therefore, the extra term in the out-of-plane torque should not

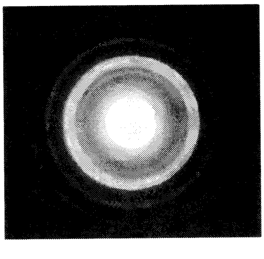

Fig. 4. Electron diffraction pattern of the film deposited at 1.6 μTorr.

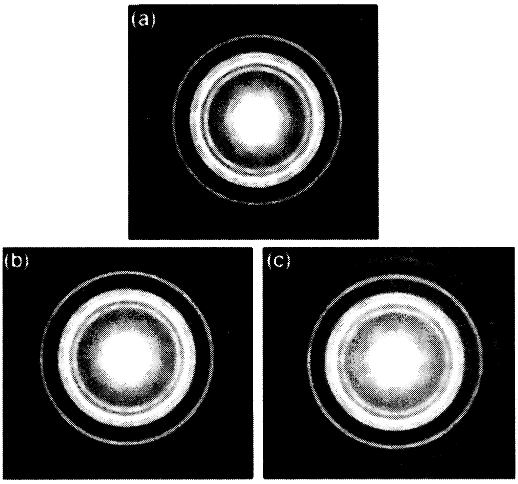

Fig. 5. Electron diffraction pattern of the film deposited at 2.3 μTorr, film tilted (a) 0°, (b) 10° and (c) 20°.

Table 1
Diffracting planes of Co and CoO

Ring No.	hcp Co $a = 2.507$ Å $c = 4.070$ Å	fcc CoO $a = 4.26$ Å
1		111
2	$10\bar{1}0$	200
3	0002	
4	$10\bar{1}1$	
5	$10\bar{1}2$	220
6		311
7	$11\bar{2}0$	222
8	$10\bar{1}3$	
9	$20\bar{2}0$	400

come from the crystalline anisotropy; its origin is still an open question to us. The cross-sectional view of the film deposited at 2.3 μTorr is shown in Fig. 6. The columns are tilted by 30° out of the film plane. The average diameter of the column is seen to be only 10 nm.

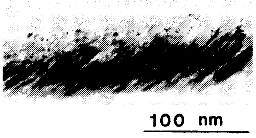

Fig. 6. Cross sectional view of the film.

4. Conclusions

Assuming that Co oxide film has a uniaxial anisotropy, the intrinsic anisotropy constant was determined to be different from in-plane torque and out-of-plane torque measurements. However, the TEM electron diffraction patterns show that the Co *c*-axes are randomly oriented. Therefore, the extra term in the out-of-plane torque could not be from crystalline anisotropy. Further investigations are needed to determine its origin. The cross-sectional micrograph shows that the columns were tilted 30° out of plane and have a diameter of 10 nm. The δM curve of the film becomes more negative with increasing oxygen pressure, indicating less exchange coupling.

Acknowledgements

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