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Effects of Bias-Sputtering on Magnetron-Sputtered Magneto-Optical Recording Media

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ABSTRACT Effects of substrate bias on the magnetic properties and microstructure of both rf-magnetron and dc-magnetron sputtered magneto-optical recording thin films of TbCo were investigated. It is shown that as an applied rf-substrate bias voltage (V_b) becomes more negative, argon entrapment in the TbCo films increases precipitously and the deposition rate decreases. Applying V_b more negative than - 30 V (at a cathode voltage of - 0.5 kV) results in the formation of voids and columnar microstructure in magnetron sputtered films. The diffraction patterns of these amorphous films reveal traces of microcrystallities a few nm in size. One detects, in addition to the dominant perpendicular anisotropy, evidence of in-plane magnetization. In contrast to what has been found for rf-diode sputtering, substrate-bias thus adversely affects the properties of magnetron sputtered films.

Introduction Sputter deposition has been widely used to fabricate rare earth-transition metal (RE-TM) magneto-optical (MO) thin films. Sputtering involves some form of energetic particle bombardment of the growing films. Most often, an enhanced ion bombardment of the substrates can be conveniently provided by a rf-bias voltage (V_b) applied to the substrate table (anode) to develop an effective negative bias relative to the glow discharge.[1] The degree of ion bombardment may be altered by controlling substrate bias conditions, and has been found to greatly influence the properties of rf-diode sputtered films.[2]

Magnetron sputter deposition is more efficient in generating ions than rf-diode sputtering because the magnetic field is used to confine electrons to the vicinity of the targets. As compared to rf-diode sputtering, magnetron sputtering thereby permits higher deposition rates, operates at a lower gas working pressure and lower target voltage, and generates less substrate heating from secondary electron bombardment, all of which are highly desirable in producing MO disks. In this paper, we report on the effects of substrate bias on the material properties and microstructure of dc and rf magnetron sputtered TbCo films.

Experimental Methods Binary thin films of TbCo were sputtered by using a planar circular magnetron from a 20 cm diameter Co-base mosaic target using a Leybold Z-650 sputtering system. The nominal areal composition of the target was $Tb_{26}Co_{74}$. Both the target and substrate table were water-cooled to eliminate substrate temperature as a variable. The target to substate spacing was 5 cm. The deposition chambers were evacuated to 2×10^{-7} mbarr prior to introducing argon to a dynamic pressure of 8×10^{-3} mbarr monitored by a capacitance manometer. A cathode voltage of - 0.5 KV, target power density of 1.54 W/cm^2, and substrate turntable rotation of 15 rpm with respect to the central axis of the target were used in both dc and rf magnetron sputter depositions. In this study, the TbCo films were deposited with a negative rf-bias voltage (V_b) applied onto the substrate table through an independent rf power generator. The substrates were Corning 0211 1" square glass and 3 mm diameter copper grids coated with amorphous carbon for transmission electron microscopy (TEM) studies. Films on glass substrates (2 minutes deposition time) were overcoated with 100 nm thick rf-diode sputtered SiO_2 *in-situ*; the films on copper grids were about 50 nm thick and had no passivating overcoat.

Polar Kerr MO hysteresis loops of the films on glass substrates were measured as a function of temperature from both the film and glass sides of the samples at a HeNe laser wavelength. B-H hysteresis loops were characterized along easy and hard axes by a vibrating sample magnetometer (VSM). The composition and thickness were determined by x-ray fluorescence spectroscopy, using an argon ion-implanted garnet as a standard to quantify argon content. For microstructure and morphology studies, we used a Philips EM420T TEM operating at 120 KV to obtain bright field images and diffraction patterns.

Experimental Results At a cathode voltage of - 0.5 KV, applying a V_b of - 30 V or less does not cause much change in composition or deposition rate in magnetron sputtered TbCo films. Moreover, a small substrate bias does not result in much difference in composition between dc and rf magnetron sputtered films; although the deposition rate of the dc-magnetron sputtering is a factor of two higher than that of the rf-magnetron, as shown in Fig. 1. When V_b becomes more negative than - 30 V, the entrapment of argon increases precipitously causing a decrease in Co and Tb contents regardless of whether the films are sputtered by dc or rf magnetron. However, V_b has more pronounced influence in films deposited by rf-magnetron than dc-magnetron sputtering: in rf-diode sputtering the deposition rate decreases faster and argon incorporation increases more rapidly causing decreasing Tb and Co contents.

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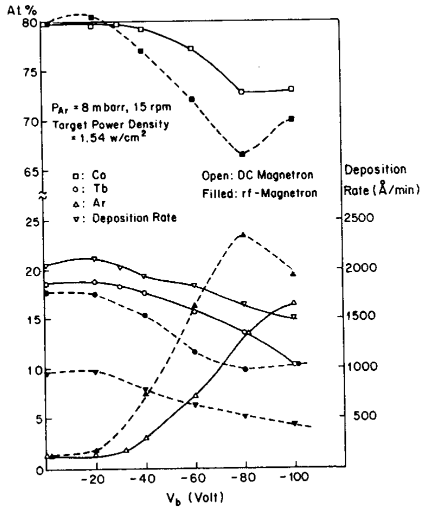

Fig. 1: Composition, deposition rate of dc and rf magnetron sputter deposited TbCo films as a function of V_b.

The MO hysteresis loops and VSM measured B-H hysteresis loops of both dc and rf magnetron sputtered films at V_b = 0 and -100 V are depicted in Fig. 2. Room temperature compensation is achieved in the dc and rf magnetron sputtered films at V_b = - 60 and - 20 V, respectively. The hard-axis VSM loops for all the films deposited at V_b less than - 60 V are straight lines, indicating no in-plane hysteresis. As V_b is made more negative than - 60 V, in-plane hysteresis develops in the hard axis VSM loops, and MO hysteresis loops are no longer rectangular. This is seen, for example, in the loops shown in Fig. 2 for the films deposited at V_b = - 100 V.

Film morphology and microstructure are critically affected by bias conditions. TEM micrographs of dc-magnetron sputtered TbCo films, as illustrated in Fig. 3, show that the morphology of the film deposited at V_b = 0 is denser, smoother and more featureless than the film deposited at V_b = - 100 V. Selected area diffraction (SAD) patterns display a diffuse ring - a characteristic of amorphous films, and convergent beam electron diffraction (CBED) patterns reveal no crystalline reflections in the films sputtered at V_b = 0. As V_b is made more negative, CBED patterns are found to contain a few "bright spots" within several diffuse rings; SAD patterns consist of more than one ring, and morphology appears to be columnar.

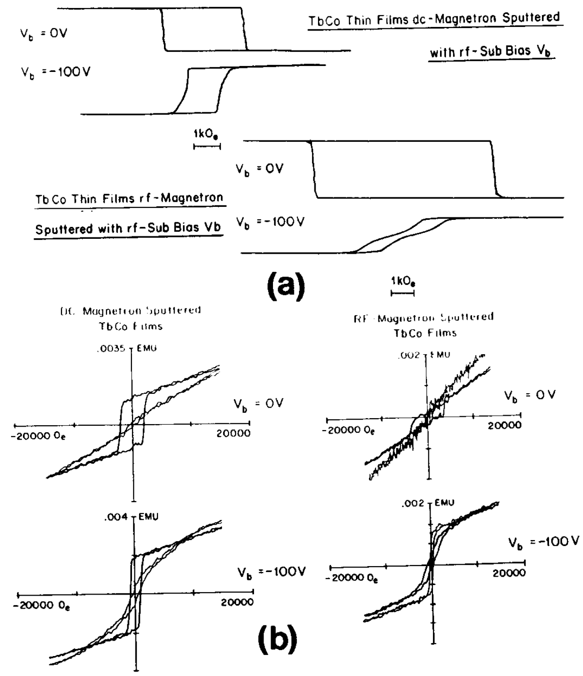

Fig. 2: (a) MO hysteresis loops and (b) VSM measured B-H hysteresis loops of TbCo films dc and rf magnetron sputtered at V_b = 0 and - 100 V.

Discussion Bias-sputtering provides an enhanced ion bombardment during sputter deposition. In the high working-gas pressure and low deposition rate environments of rf-diode sputter deposition, the incoming coating flux is more scattering. In this case, substrate bias-sputtering is useful because it promotes backsputtering. Atoms accumulating around a void structure are thereby easily dislodged by the bombardment of the substrate which preferentially removes overhanging atoms and causes the void regions to open until filled by newly deposited atoms.[2] Therefore, films with a columnar microstructure surrounded by voided regions hardly result. Instead, dense and featureless amorphous films can be fabricated by rf-diode sputtering when the proper substrate bias is applied.[3] Moreover, substrate bias was also reported to affect the composition, perpendicular magnetic anisotropy, and other properties of rf-diode sputtered RE-TM thin films.

For magnetron sputter deposition at a cathode voltage of - 0.5 KV, the application of substrate bias has been shown to influence the properties of the deposited films when V_b is more than 10 % of the cathode voltage. The most noticeable effect of large negative V_b on the magnetron-sputtered films is a markedly higher argon content. As much as 13 (23) at.% of argon is incorporated into dc (rf) magnetron sputtered TbCo films deposited at V_b = - 80 V. It is noted that argon inclusion in rf-magnetron sputtered films is twice as much as that in the dc-magnetron sputtered films, but the rf deposition rate is only one half of the dc deposition rate. In both cases, the deposition rates decrease as more negative V_b is applied, due to the increase in backsputtering.

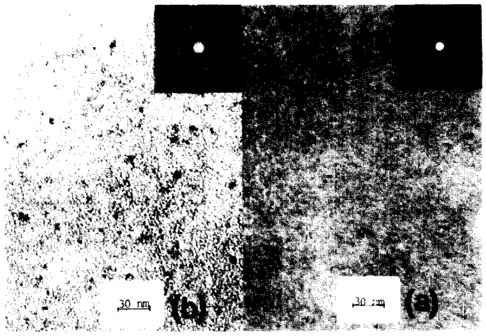

Fig. 3: TEM micrographs of bright field image and CBED patterns for TbCo films dc-magnetron sputtered at (a) $V_b = 0$ and (b) $V_b = -100$ V.

The application of a negative substrate bias affects the microstructure of magnetron sputtered TbCo films, as shown in the TEM micrographs of Fig. 3. As V_b becomes more negative than - 60 V, the surface topography of the TbCo films becomes rougher and columnar microstructure becomes more distinct. Similarly, for the films deposited at high V_b, the presence of microcrystallities in "amorphous" films is revealed by CBED patterns, but not in the film sputtered at $V_b = 0$. The presence of crystallities in the films deposited at high V_b is also confirmed by the distinct multiple-ring SAD patterns.

The changes of microstructure in the magnetron-sputtered films adversely affect the magnetic properties, as determined from the VSM measured B-H hysteresis loops depicted in Fig. 2. In addition to the dominant perpendicular magnetization, in-plane hysteresis becomes more evident as V_b becomes more negative. It is believed that the in-plane magnetization occurs because of oxidation associated with the voids and microstructure in the films deposited with large negative V_b.

The microstructure of the sputter deposited films depends largely on the deposition rate, ion energy, substrate temperature, mobility of adatoms, etc.[4] To obtain a highly disordered amorphous structure, the adatom surface diffusion needs to be negligibly low so that the atoms come to rest at their point of impingement and subsequent surface diffusion processes are too small to redistribute the atoms on the growing films. As low gas pressure (less than a few μbar) is commonly used in magnetron sputter depositions, sputtered atoms encounter fewer collisions with background gases. Most of the incoming coating flux thus impinges normally on the growing films. Consequently the atoms impinge on the growing films more energetically than in higher gas pressure depositions such as rf-diode sputtering. In addition, a significant fraction of the incoming coating flux is backsputtered. The large flux of normally incident energetic atoms in magnetron sputtering causes reduced surface diffusion. The columnar voided growth structure is thus largely suppressed so that highly disordered amorphous films are formed without a substrate bias. Additional energetic ion bombardment produced by V_b damages the films, increases trapping of gas, and increases substrate heating which promotes surface diffusion, all of which are undesirable if morphologically dense, featureless and smooth amorphous RE-TM films are to be formed.

Conclusion Magnetron sputtering with zero substrate bias produces amorphous TbCo films which are dense, featureless and have strong perpendicular anisotropy. The application of a negative substrate bias during both rf and dc magnetron sputter depositions, on the other hand, has been found to promote voids and columnar microstructure, to increase argon content, and to result in in-plane hysteresis in the films. This result is in contrast to that of rf-diode sputtering where a moderate negative substrate bias is generally necessary to produce dense, featureless morphology, although at the expense of increased argon content in the films. A high deposition rate, a low gas pressure and a sufficiently high cathode voltage are among the essential parameters to control ion bombardment on the growing films so that highly disordered, dense, smooth and featureless amorphous RE-TM films can be magnetron sputtered with no substrate bias.

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