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Effects of Target Structure on the Properties of MO Recording Media Produced in a Large-Scale Vertical In-Line Sputtering System

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ABSTRACT The metallurgical states of rare earth-transition metal targets were found to be essential to produce high performance magneto-optical recording thin films. Our study indicates that in a vertical in-line sputtering system, a rectangular alloy target of TbFeCo containing about 25 % of the intermetallic phase produces negligibly small composition gradient in dc-magnetron sputtered films. With a proper aperture to mask off oblique incident coating flux, coercivity and thickness variations of less than ±5 and ±2 % have been achieved reproducibly on 5.25" disks.

INTRODUCTION Amorphous thin films of rare earth-transition metal (RE-TM) have been demonstrated to be favorable for high density, high capability, erasable and reusable magneto-optical (MO) data storage applications.[1] Active layers of MO thin films, and antireflection and passivation layers of dielectric materials can be conveniently sputter-deposited onto various substrates in specific layer-stacks in laboratories. Recent development of a large-scale vertical in-line MO production machine has shown that it is feasible to transfer the promising features of MO recording media developed in laboratories into a high through-put mass production environment.[2]

A major concern in the production of MO disks is a high requirement on the tolerances of the physical properties of each individual layer over a large area. For a 5.25" MO disk comprised of a nominal thickness of 80 nm and coercivity of several KOe RE-TM (TbFeCo for example) film, it is generally required to keep tolerances of the MO layer in thickness of ± 2 %, in coercivity of ±5 %, and in compensation temperature (T_{comp}) of ± 10 °C reproducibly. These requirements impose not only stringent demands on the capability of a production machine but call for a strict control of the fabrication processes. Equally important is the target which not only requires to have sufficient mechanical strength to prevent cracking during sputtering, but also contains virtually no oxygen or oxides. Moreover, the metallurgical properties of the targets need to be controlled and adapted to the demands of the sputtering systems and the processes.

Using a large-scale vertical in-line sputtering system - Leybold A-400, MO samples were fabricated from different RE-TM alloy targets in static as well as in dynamic modes. In this paper, we report the effects of the metallurgical states of TbFeCo alloy targets on the properties of deposited thin films.

EXPERIMENTAL METHODS All the TbFeCo films were dc-planar-magnetron sputtered from TbFeCo alloy targets by a Leybold A-400 vertical in-line sputtering machine. The details of the sputtering system have been reported elsewhere.[2] Targets size was 488 x 88 mm^2 with the small extension in direction of the carrier motion. Target-substate spacing was 70 mm, and aperture and substrate carrier spacing was 3.5 mm. The deposition chamber was evacuated to a background pressure below 2×10^{-7} mbar before introducing argon to a dynamic pressure of 5×10^{-3} mbar. Cathode power density of 4.3 W/cm^2 was used for MO layer deposition at a substrate carrier linear speed ranging from 2 to 70 mm/sec. All the films used for the study have a trilayer configuration of dielectric layer, TbFeCo, and dielectric layer on micro-slide glass substrates. Dielectric layers of Si_3N_4 or Al_3N_4 were sputtered in dc-reactive mode from a Si or Al target in the environment of argon and nitrogen. The whole deposition system and processes were controlled by a PDP 11-73 microcomputer.

Three TbFeCo alloy targets were used. Target I ($Tb_{27}Fe_{65}Co_8$) was made by sintering from prealloyed TbFeCo powder. In contrast, Targets II and III ($Tb_{24}Fe_{68}Co_8$) were fabricated by sintering from prealloyed FeCo and FeTb powders. Subsequent annealing at a defined temperature profile led to the formation of a defined amount of intermetallic phase (IMP) in the target plates. The amount of IMP is 100%, 45% and 25% in targets I, II, and III, respectively.

Polar Kerr MO hysteresis loops of the films were measured as a function of temperature at a HeNe laser wavelength. B-H hysteresis loops were measured by vibrating sample magnetometer (VSM) at the room temperature. The composition was determined by electron spectroscopy for chemical analysis (ESCA) and Rutherford backscattering spectroscopy (RBS).

RESULTS AND DISCUSSION The distribution of the metal constituents of the target in front of the MO cathode was found to strongly depend on the targets used for sputtering. Figure 1 depicts VSM measured B-H hysteresis loops of the TbFeCo films sputtered from the three targets. The films were deposited at a substrate carrier linear speed of 2 mm/sec and an aperture opening of 80 mm along the carrier motion direction. As seen in the figure, the amount of IMP in the target materials has a strong impact on the magnetic properties of the films. At an IMP content of 100 %, the B-H loop measured along an easy axis (⊥)

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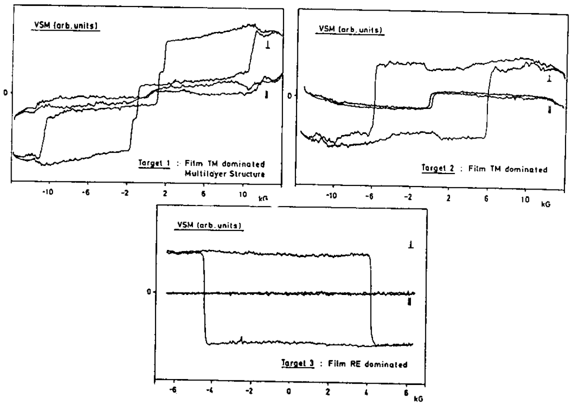

Fig. 1: VSM measured B-H hysteresis loops for the TbFeCo films sputtered from targets I, II, and III in a dynamic mode at a carrier linear speed of 2 mm/sec.

is anomalous, similar to the loop reported for multi-layered films.[3] Additionally, in-plane hysteresis develops in the hard-axis B-H loop. The tendency to form multilayer structures as well as the in-plane hysteresis vanishes with decreasing IMP content. The films sputtered from target III (25 % IMP) exhibit rectangular easy-axis hysteresis loops and straight line hard-axis loops.

To further investigate the effect of the target on the properties of deposited films, TbFeCo films were also fabricated in a static mode. No apertures were used to mask off oblique particle flux during the deposition. Coercivity and composition as a function of substrate position with respect to the center of the target are depicted in Figures 2 and 3. Strong modulations of H_c are found in the front of targets I and II. The MO loop sense reveals that the coating flux changes from TM-dominated in the vicinity of the targets center to RE-dominated at both ends of the targets. The distribution of the coercivity is correlated with the composition distribution: a significant enrichment of Tb content in incoming coating flux at the outer ends of the deposition area as compared to those at the center. The positional gradients in coercivity and composition decrease with decreasing IMP content in the target. Samples sputtered from target III have a much weaker positional gradient in coercivity. The MO loop sense indicates that coating flux is RE-dominated in a largely extended area in front of the cathode. Rare earth content decreases slightly toward compensation composition, causing coercivity to increase at the both ends of the target. The large variation in coercivity is primarily due to that the composition is in the vicinity of compensation composition. The $\pm$ 20 °C T_{comp} variation amounts to about $\pm$ 0.5 at.% Tb variation in the region from - 40 to + 40 mm in front of the cathode. The trend for the coercivity distribution is also confirmed with the Tb content distribution analyzed by ESCA.

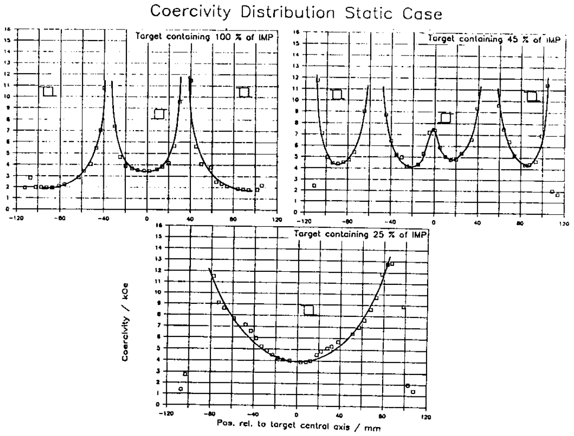

Fig. 2: Coercivity measured as function of position with respect to the center of the targets for the TbFeCo films sputtered from the three targets in a static mode.

As depicted in Fig. 1, the Tb-loss increases with increasing IMP content. The 7 at.% reduction of Tb content in the deposited films sputtered from target I in the static mode is within the range reported by Asari et al on the similar target.[4] In contrast, composition of the films sputtered from targets III is very close to that of the target.

From the static mode results shown in figures 2 and 3, the very different results obtained in the samples deposited in dynamic mode from the targets become clear. In case of target I, a substrate approaching the target is coated by a Tb-rich particle flux which soon changes to Tb-poor as approaching the center of the target. A corresponding structure is formed when the substrate leaves the coating zone and the multi-layered films is thus formed. As for target II, the particle flux is Tb-poor and significant Tb gradient is formed, causing the B-H hysteresis loops deviated from rectangular. In addition, the presence of in-plane hysteresis is undesirable for MO recording application. For target III, a proper aperture (60 mm opening) is found to effectively mask the oblique incident coating flux and to confine Tb and TM (Fe and Co) distributions to produce uniform films in dynamic mode. As a result, the distribution of coercivity and thickness of MO films can be kept within $\pm$5 and $\pm$2 %, respectively sputtered at a carrier speed ranging from 2 to 70 mm/sec. Figure 4 is a plot of coercivity distribution on 5.25" disks sputtered at a substrate carrier speed of 2 mm/sec.

The recording performance for the MO films sputtered from these targets is expected to be quite different. As shown in TABLE I, even at a lower read/write/erase laser power and bias field, the MO disk produced by target III has a significant higher carrier-to-noise ratio than those fabricated by target I and II.

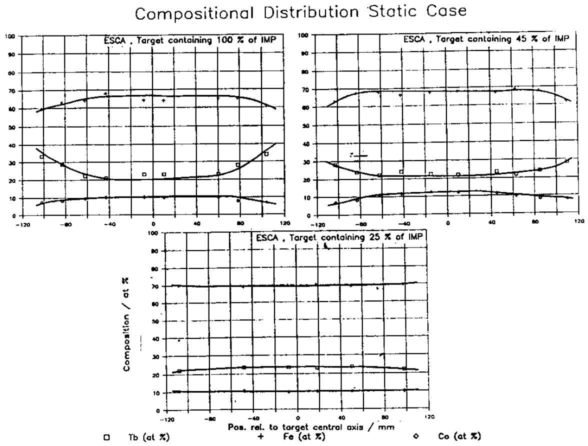

Fig. 3: Composition characterized by ESCA for the samples used to plot Fig. 2.

TABLE I: Recording performance of MO disks produced from the three targets.

Target No	Test Cond.		CNR	read/write	
	(MHz)	(Oe)	(db)	(mw)	
1	2	350	41.8	2	8
2	2	350	47.4	2	7
3	2	300	50.4	1	5.5

The contrast results obtained from these targets suggest that the metallurgical states of targets be essential to the distributions of sputtered constituents. The SEM micrographs of the targets shown in Fig. 5 reveal major differences between the two types of target used in this study: the target textures of targets II and III are much rougher than that of target I. Targets II and III consist of elemental Tb "grain" (white isolated region) typically 100 μm in diameter, surrounded by a region of IMP (gray region), embedded in a pure FeCo matrix (dark patches). By comparison, much finer grain of constituents is uniformly mixed in target I, and no clear compound grain boundary is visible in the SEM micrographs. During target erosion, the surface of target I remains smooth but targets II and III become granular.

The different metallurgical properties of target I and III also lead to very different permeabilities of the target material which results in drastic difference in the magnetron magnetic field strength on the target surface. For otherwise identical conditions (identical magnet set, backing plate, and target thickness), the maximum field strength for the magnetic field normal to the target surface in targets I and III were found to be 72 and 28 KA/m, respectively. Data collected so far indicate that the strength of the magnetic field affects the distributions of particle flux in front of a cathode, but has less effect on lateral distribution of the coating flux.

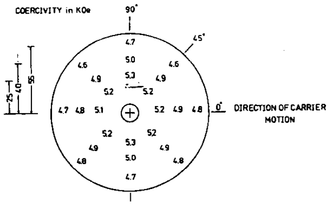

Fig. 4: Coercivity distributions on a 5.25" MO disk sputtered from target III at a linear speed of 2 mm/sec.

The different lateral distributions of the composition in front of the targets suggest the importance of the amount of IMP in the target material. It is necessary to extend the study to develop a quantitative understanding on the relationship of IMP of alloy targets on the distribution of the metal constituents. Moreover, experiments are being carried out to understand the effects of the metallurgical properties of the targets, the strength of magnetic field of magnetron, and the geometry of sputtering system on the magnetron-sputtered RE-TM magneto-optical films.

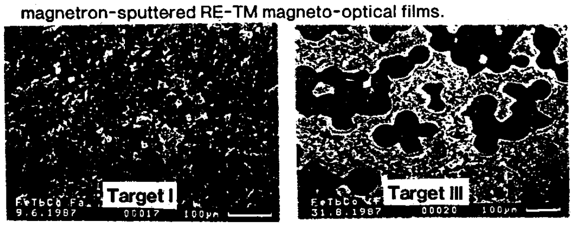

Fig. 5: SEM micrographs of targets I and III used in this study. The intermetallic compound is the gray region.

CONCLUSION The effects of the characteristics of the target on the properties of deposited films suggest that the metallurgical states of the targets are as important as other means used to produce RE-TM films for MO recording media. With a given sputtering system, the distribution of metal constituents from the target onto substrates depends on the geometry, target substrate spacing, deposition mode, sputtering parameters of the sputtering system, etc. Given an alloy target of TbFeCo containing 25 % of IMP employed a in vertical in-line MO production machine, variations in coercivity and thickness of TbFeCo MO disks within ± 5 % and ± 2 %, respectively can be reproducibly obtained.

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