Effect of grooves on magnetization reversal in amorphous TbFeCo thin films

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Abstract. We have investigated the effect of grooves milled by argon ions in soda lime glass substrates on the magnetic behavior of amorphous TbFeCo films deposited onto these substrates. The domains are shown to expand along the grooves when the groove depth exceeds 10 nm. The effect originates from the difference in the coercivities of the film on the land and on the groove, as well as from the pinning of domain walls by the side-walls of the grooves.

1. Introduction

The uncertainty about the position of a recorded domain wall in magneto-optical (MO) recording is partly responsible for the observed jitter in readout. The jitter originates from a number of different factors, but is always manifested as a shift of the actual position of the magnetic domain wall relative to its intended position along the track.[1-3] By patterning the substrate (i.e., creating small, regular features on the substrate at the time of injection molding) it might be possible to pin the domain walls and thus control the jitter problem. Shallow grooves along the disk's radial direction represent one such structure. The present work is devoted to a study of the effect of shallow grooves etched on glass substrates on the magnetic reversal processes of amorphous TbFeCo films.

2. Experimental Procedures

Grooved soda lime substrates were fabricated using a photolithographic method. The grooves were etched by argon ion milling of a photoresist layer, which was coated onto the substrate and exposed to an optical interference pattern. The two types of grooves studied had periods of 0.4 μm and 1.0 μm respectively, with a variable depth which, depending on the milling time, varied from 3 nm to 40 nm. The ratio of land to groove width varied from 1:1 to 1:3, and the slope of the side-walls was nearly 45°. The MO film structure on these substrates is depicted in Fig. 1. The first and third layers are SiN with thicknesses of 10 nm and 80 nm, protecting the magnetic layer against oxidation. The 50 nm-thick MO layer itself is an amorphous Tb-rich TbFeCo film having a saturation moment M_s = 190 emu/cm^3 and a coercivity $H_c \simeq 3$ kOe, at T = 300 K.

The magnetic properties of the samples were studied using vibrating sample magnetometry in fields up to 14 kOe. The magneto-optic loops and initial magnetization curves were obtained

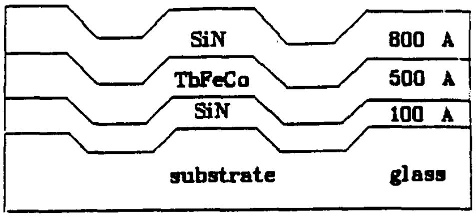

Fig. 1. Thin film stack on grooved substrate.

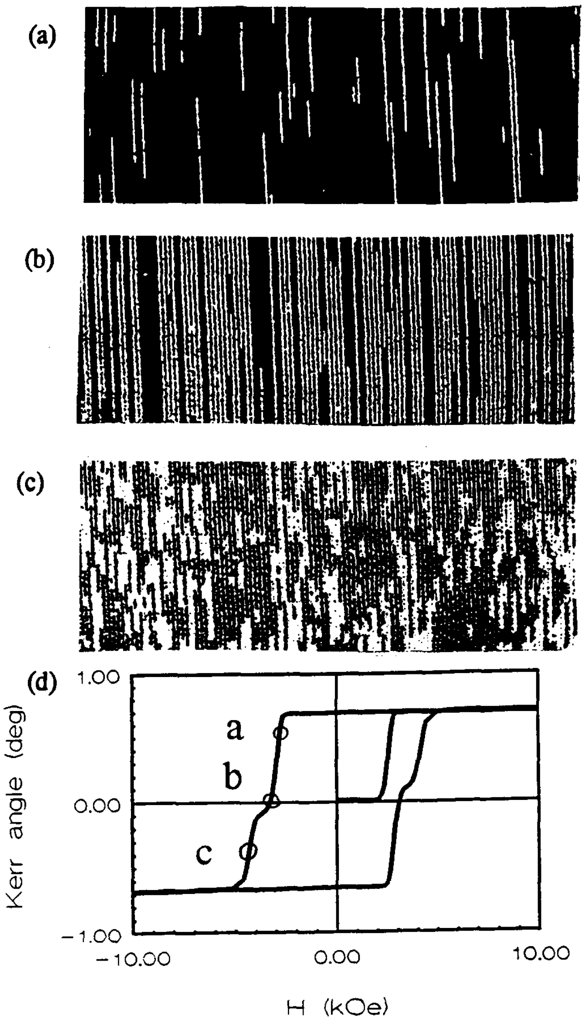

Fig. 2. Domain structure in TbFeCo film, developing in the grooved region of the sample. (a) H_{ext} = 3 kOe, (b) H_{ext} = 3.4 kOe, (c) H_{ext} = 4 kOe. (d) Magneto-optical loop, showing the three points at which the domain patterns in (a), (b), and (c) were obtained.

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in a loop-tracer in fields up to 20 kOe [4]. Domain structures were observed in a polarized-light microscope using a 100× oil immersion objective. The observations were recorded with a PC-based frame grabber that allowed image processing for noise reduction [5]. A single-pole conical tip electromagnet having a maximum field capability of 5 kOe was mounted under the microscope's *XY* stage to provide the necessary fields for domain growth and contraction. The profiles of the grooves and the roughness of the substrates were measured using atomic force and scanning electron microscopy.

3. Results and Discussion

The magnetic behavior of the TbFeCo film on grooved substrates depends on the period and depth of the grooves. The critical depth appears to be around 10 nm, below and above which different magnetic behavior is observed. Under the polarized-light microscope the grooves themselves appear as low contrast black and white stripes. (That the white stripes correspond to grooves and dark stripes to lands was ascertained by observing the sample under an electron microscope, and noting the position of the grooves relative to certain defects that were also visible in the optical microscope.) The magnetic patterns, however, have a much larger contrast and, to a large extent, obscure the underlying grating structure.

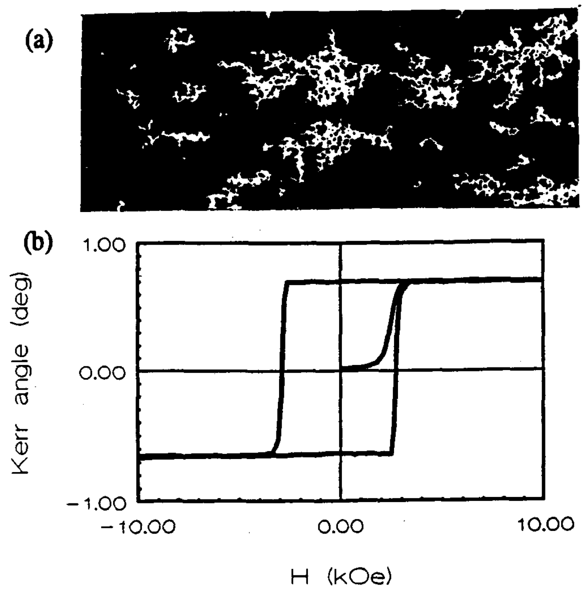

Fig. 3. (a) Domain structure and (b) magneto-optical loop in a flat region of the sample.

Figure 2 shows a pattern of domains developing at different bias fields in a sample with 21 nm-deep grooves. These observations reveal the directionality of domain expansion along the grooves: no motion of domain walls across the grooves was observed. The reversal initially occurs in the grooves, as shown in Fig. 2(a). Once the grooves have become saturated, Fig. 2(b), there is an interval of magnetic fields, $\Delta H_c \simeq 500$ Oe, where no reversal occurs. Further increases of the field give rise to reversal in the lands, as shown in Fig. 2(c). The reversal in the lands is different from that in the grooves in that it appears to be nucleation dominated. When a reverse nucleus appears in a groove, it expands rapidly and covers the entire groove within the field of view of the microscope. On a land, however, the nuclei tend to expand over short distances (10–30 μm), causing the land to be reversed by simultaneous nucleation and growth of multiple nuclei. This behavior also manifests itself in the slightly different slopes of the MO loop, Fig. 2(d), in the segments marked *a* (reversal in the grooves) and *c* (reversal in the lands). The two segments are separated by a kink, marked as segment *b*, where no reversal occurs.

The unidirectionality of domain expansion is rooted in the different coercivities of the land and the groove, aided by the

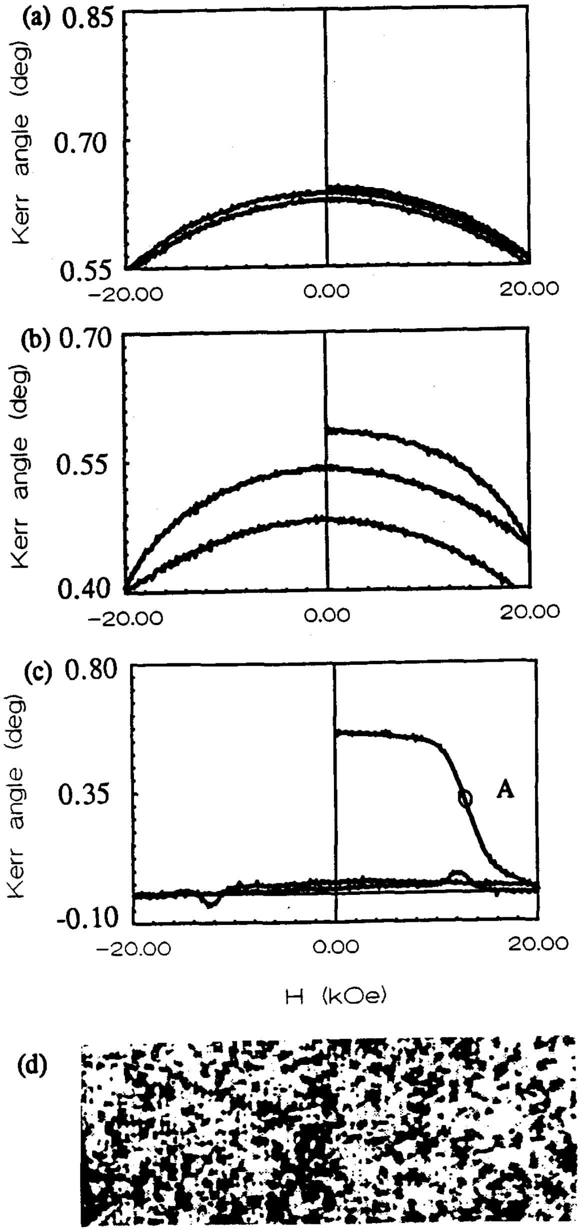

Fig. 4. Polar Kerr MO signal versus an applied in-plane field, $\mathbf{H}_{ext}$. (a) In the flat region of the sample. (b) In the grooved region, with $\mathbf{H}_{ext}$ parallel to the grooves. (c) In the grooved region, with $\mathbf{H}_{ext}$ perpendicular to the grooves. (d) Magnetization pattern in the grooved region after partial demagnetization in an in-plane field, corresponding to the point labeled A on the curve in (c).

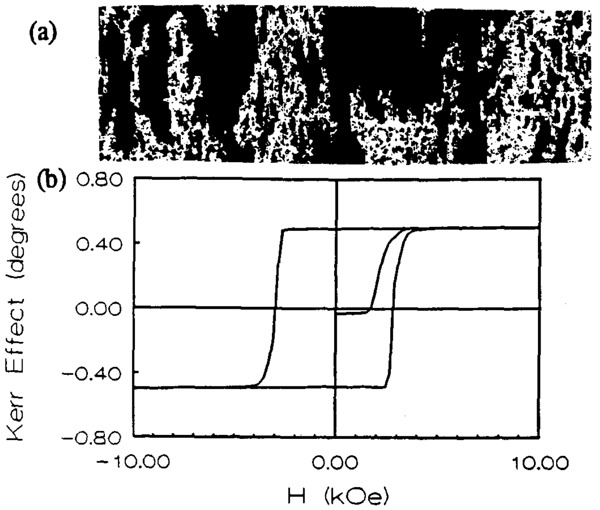

Fig. 5. (a) Domain structure and (b) magneto-optical loop for a grooved sample having 1 μm period and 3 nm depth.

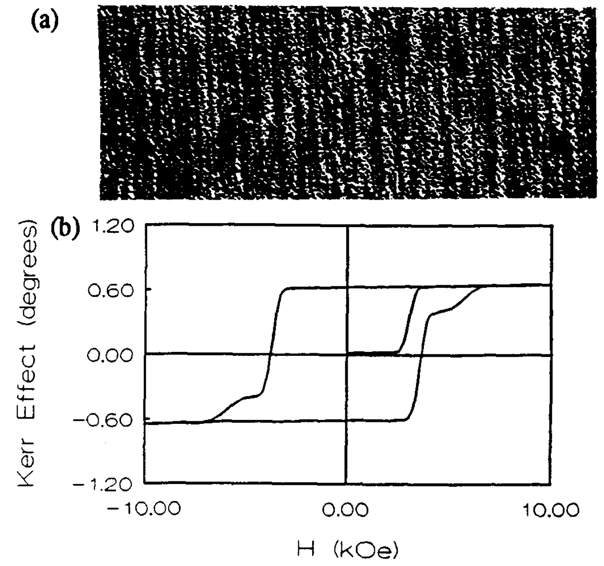

Fig. 6. (a) Domain structure and (b) magneto-optical loop for a grooved sample having 0.4 μm period and 20 nm depth.

pinning of the domain walls at the side-walls. Argon ion bombardment affects the grooves while the lands are still covered by photoresist. (The residual photoresist on the lands is subsequently removed by chemical cleaning.) The bombardment changes the roughness of the substrate in the milled regions and brings about a coercivity difference between the lands and the grooves. The pinning at the side-walls may arise from a reduced film thickness, a tilted easy axis, or an increased jaggedness at the side-walls.

The magnetic behavior of the same sample in one of its flat (i.e., non-grooved) regions is substantially different from the above, as may be observed from the domain pattern and the MO loop shown in Fig. 3. In the flat region the domains expand uniformly in all directions, creating a maze-like pattern. The MO loop shows no kinks, and the coercive field is somewhere between the coercivities of the land and the groove regions.

Results of measurements of the polar Kerr effect versus an applied in-plane field are depicted in Fig. 4. These results also show striking differences between the grooved region and the flat region of the same sample. In the flat region, Fig. 4(a), the in-plane field produces only a small tilt of the magnetization vector away from the normal direction; even a 20 kOe field fails to demagnetize the sample in this case. If the in-plane field is applied to the grooved region and parallel to the grooves, it causes a slow demagnetization, as shown in Fig. 4(b). However, when the in-plane field is applied perpendicular to the grooves, it begins to demagnetize the sample at about 12 kOe (see Fig. 4(c)). The demagnetization process was observed to begin within the grooves, followed at a later stage (H_{ext} > 16 kOe) by demagnetization of the lands. At H_{ext} = 20 kOe both the lands and the grooves are covered with small domains that cannot be easily resolved by the optical microscope. Figure 4(d) shows the domain structure after partial demagnetization of the grooved region by an in-plane field perpendicular to the grooves; the corresponding point on the in-plane loop of Fig. 4(c) is marked with the letter A. We speculate that the reversal process in this case is controlled by reversal on the side-walls, since the applied magnetic field has a 45° angle with the normal to the side-wall, whereas its angle with the easy axis of the lands and the grooves is 90°.

In samples with very shallow grooves (e.g. less than 10 nm) the directionality of domain expansion is not as obvious as that in deeper grooved samples. Generally, the domains expand along the grooves but there is also domain movements over and across the side-walls, as seen in Fig. 5(a) for a sample with 3 nm-deep grooves. The coercivities of grooves and lands in this case are very close to each other, as can be inferred from the lack of a kink on the MO loop of Fig. 5(b). Also, measurements of the polar Kerr effect versus an in-plane field for shallow grooved samples (with the field either parallel or perpendicular to the groove direction) yield results that are very similar to those obtained for a flat region, shown in Fig. 4(a). In general, shallow grooved samples exhibit less directionality during domain expansion when compared with deep grooved samples. However, when compared with flat samples, there is a certain directionality to the process of domain growth and wall movement in shallow samples.

Figure 6(a) shows the domain pattern in a sample with a groove period of 0.4 μm and a depth of 20 nm. The limited resolution of the optical microscope does not allow the observation of very small features, but it clearly shows the directionality of the domain growth process. The kink in the MO loop of Fig. 6(b) is further evidence that the lands, the grooves, and the side-walls do not reverse simultaneously. The width of the kink in this case is greater than that in samples with 1.0 μm period; this may be due to a stronger influence of the stray and demagnetizing fields in samples with small groove periods.

4. Conclusions

The present study shows that the magnetic behavior of the MO film can be significantly affected by the patterning of its substrate. When the groove depth exceeds about 10 nm, preferential domain expansion along the direction of the lands and the grooves is observed. This directionality of domain growth is caused by domain wall pinning at the side-walls, as well as by the difference in the coercivities of the land and the groove regions. The coercivity difference is rooted in the different roughnesses of the milled and unmilled regions of the substrate, and is somewhat enhanced by the demagnetizing effects.

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