High Resolution Measurement of Coercivity Variations in Magneto-Optical Recording Media

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ABSTRACT - The coercivity of amorphous rare earth-transition metal magneto-optical (MO) recording media has been measured as a function of position on the films utilizing a micro-Kerr-hysteresis-loop-tracer with an effective measuring aperture of 0.5 μm. The local variations of wall motion coercivity (H_c) in the films whose magnetization reversal was dominated by nucleation were as large as 20 %. In contrast, H_c in the films whose magnetization reversal was dominated by domain wall motion exhibited a negligibly small variation from place to place in the films. It was found that the fields required to collapse μm-sized domains were typically 20 % less than H_c as measured above. The predominant magnetization reversal mechanism in a RE-TM films is mainly determined by film fabrication processes.

INTRODUCTION The most promising magneto-optical (MO) recording media nowadays are rare earth-transition metal (RE-TM) amorphous thin films prepared by sputter-deposition. To achieve high signal-to-noise ratio from these media, it is necessary that the written μm-sized domains be highly reproducible and regular.[1] Domains are written into the media by means of a thermomagnetically induced magnetization reversal which occurs on the scale of 1 μm. Spatial variations of magnetic parameters may cause variations in domain size and shape. As a consequence, noise levels rise, recording margins decrease, and bit error rates increase. It is therefore essential to characterize magnetic and MO properties of MO recording media with μm or better spatial resolution. Of the magnetic properties, coercivity is one of the most important parameters. Wall motion coercivity (H_c) plays a critical role in the formation of regular and reproducible domains.[2]

Coercivities measured by using a vibrating sampling magnetometer (VSM) or a Hall hysteresis loop tracer are "bulk" volume averaged values of the entire sample. On the other hand, coercivity characterized by a MO hysteresis loop tracer is a skin-depth-averaged value over the region defined by a probe beam, typically a few mm in diameter. In view of the 1 μm scale of thermomagnetic recording, it is essential to measure coercivity with resolution comparable or smaller than the domain size. In this paper, we report the measurements of wall motion coercivity and domain collapse and nucleation fields by using a MO hysteresis loop tracer with sub-micrometer spatial resolution.

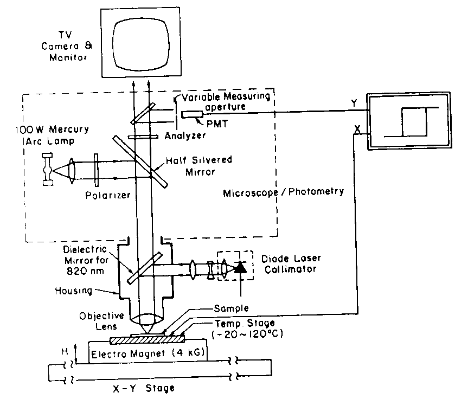

Fig. 1: Schematic diagram of micro-Kerr-hysteresis-loop-tracer with μm spatial resolution.

EXPERIMENTAL METHODS The micro-Kerr-hysteresis-loop-tracer with sub-micrometer spatial resolution, shown schematically in Fig. 1, is comprised of a Leitz MPV-3 polarized light microscope system and an electromagnet providing a magnetic field up to 4 KOe on the samples. The microscope system, having a 20 mW diode laser coupled into the microscope objective, may also be used for thermomagnetic writing into MO films. The photometry module has a photomultiplier tube (PMT) and a variable measuring aperture. By placing an aperture in the magnified image plane of the objective lens (100x/0.90), the MO properties of a localized spot smaller than the size of the focused beam can be selectively measured. Since the PMT only senses the light from the demagnified spot on the sample, spot sizes on the samples as small as 0.5 μm can be measured.[3] By sweeping a magnetic field, a MO hysteresis loop of the region defined by the measuring aperture can be obtained. In addition to the photometric detection, all the MO activities are also detected by a silicon-intensified-target TV camera and displayed on a TV monitor.

Two RE-TM samples were used in this work: a DC-magnetron sputtered SAMPLE 1 and a RF-diode sputtered SAMPLE 2. Both of them were deposited onto Corning 0211 1" square glass substrates and overcoated with 100 nm rf-diode sputtered SiO_2 *in situ*. For the deposition of the MO thin films, a target voltage of -280 V and deposition rate of 50 nm/min were used in dc-magnetron sputtering; while -1.2 KV and 50 nm/min were used in rf-diode sputtering. In addition, -170 V of rf-bias was applied onto the substrate table during the rf-diode deposition. The values of nominal coercivity of the films characterized by a VSM or a MO loop tracer were 1.3 KOe. Before each measurement, the films were saturated with a 4 KOe field.

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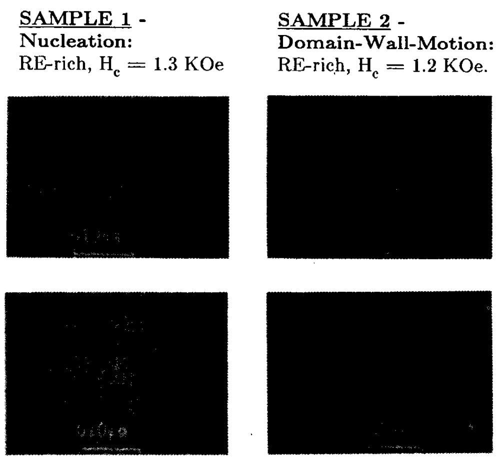

Fig. 2: Domains patterns of films whose dominated magnetization reversal process is (a) nucleation and (b) wall-motion.

EXPERIMENTAL RESULTS The magnetization reversal process is distinctly different in these two films as illustrated in Fig. 2. In SAMPLE 1, when an applied field is near or equal to the nucleation field, regions of reversed magnetization are observed to nucleate randomly on the sample. An increase of the applied magnetic field promotes more nuclei and the subsequent dendritic growth of reversed domains. Eventually, at a high field, the entire field of view is filled with reversed domains. In SAMPLE 2, in contrast, magnetization reversal is observed to occur not by the nucleation of large numbers of domains, but by the growth of two domains, previously nucleated by laser writing.

As a consequence of different magnetization reversal processes, MO hysteresis loops of these two films also appear to be different. For SAMPLE 1, the magnetization reversal detected within the measuring aperture by the PMT depends on the occurrence of nuclei and/or growth of reversed domain walls to cause magnetization reversal, resulting in changes of MO contrast. The coercivity variations measured within μm-sized regions are found to be relatively large, $\pm$10 % on average, depending upon the probability of having nuclei within the regions or having domain walls move through the regions as the applied magnetic field is increased. Films exhibiting such nucleation-dominated reversal process have non-rectangular hysteresis loops when measured through large measuring apertures. But the loops become rectangular as measured by an aperture of 1 μm or less. The changes in the shape of hysteresis loops as a function of measuring spot size are shown in Fig. 3. Keeping the reverse applied field near the nucleation field, magnetic aftereffect[4] was observed as the nucleation and dendritic growth of magnetic domains randomly occurred in the film.

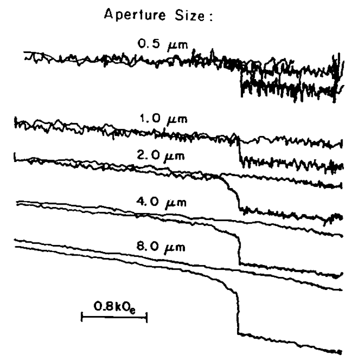

Fig. 3: MO hysteresis loops measured as a function of the size of measuring aperture.

In SAMPLE 2, by comparison, the shape of the MO hysteresis loop is far less dependent upon the size of the measuring spot. When an applied field exceeded the nucleation field, most often one only observed domain walls moving rapidly throughout the film, producing very rectangular MO hysteresis loops which were independent of the measuring spot size. The domain growth could be impeded immediately when the applied field was reduced, and started again by raising the magnetic field above the wall motion threshold.

Wall-motion coercivity, defined as the magnetic field required to initiate a magnetization reversal in a measuring spot, was measured as a function of position on the samples. By moving the measuring aperture in 0.5 μm steps within μm-sized regions, H_c was sampled. It was found that local variations in H_c depended on the measured sites on SAMPLE 1. Variations of $\pm$ 5 % and $\pm$ 10 % were measured at the center and periphery of the 1" square sample, respectively. In contrast, the variation in H_c measured in SAMPLE 2 was negligible.

In SAMPLE 1, with a thermomagnetically nucleated 1 μm-sized domain or 1 μm wide stripe domain in the neighborhood (within 2 μm) of a measuring spot (Fig. 4(a)), the measured coercivity was consistently 12 - 18 % less than that without reverse domains in the films. When the 1 μm-sized measuring aperture was at the center of two 1 μm-sized thermomagnetically nucleated domains (3 μm center-to-center spacing) (Fig. 4(b)), H_c was, likewise, measured to be about 13 - 16 % less than that measured in the absence of the reversed domains. On the other hand, by positioning the measuring aperture within μm-sized domains (Fig. 4(c)), the collapse fields of the domains were measured to be 17 - 24 % less than the field required to force the domain wall to move outwardly. By comparison, H_c in SAMPLE 2 was relatively independent of whether a domain was in a close proximity to the measuring aperture, because the reversal was dominated by wall motion, not nucleation.

In SAMPLE 2, the presence of small pin holes or "defects" (few μm or less) in the neighborhood of the sampled area does not result in a measurable change in coercivity as determined by using the 1μm size aperture. However, depending upon the locations of the measured spot with respect to large defects, H_c can vary by as much as 10 %. In SAMPLE 1, the measured coercivity varies up to 20 %, and is independent of the presence of visible "defects".

DISCUSSION The degree of variation in coercivity strongly depends on the dominant magnetization reversal processes - some films reverse primarily through the nucleation of many domains while others have very few nuclei, but reverse mainly through the growth of domains. Although the occurrence of nucleation sites depends on the history of magnetization,[5] domains nucleate quite randomly in the films whose magnetization reversal is dominated by nucleation, even when the film is pre-magnetized with a 15 KOe saturating field. The randomness results in as large as $\pm$ 10 % variations in H_c within regions only a few μm in size. Having up to $\pm$ 10 % variation in coercivity, the recording performance is expected to be unpredictable.

Magnetization reversal often occurs by the random nucleation and growth of small narrow-walled domains in MO films. The nucleation sites, which initiate the reversal process, are usually intrinsically "weak points" of the films.[5] These weak points may be caused by defects or inhomogeneities in the magnetic properties.

The causes of the different defects and/or inhomogeneity density in the two films described above are not yet fully, understood. Investigations of a large number of samples indicate that whether the magnetization reversal in a film is predominantly by wall motion or nucleation is mainly determined by the film fabrication process and weakly affected by rare earth constituents in the films. Different RE-TM thin films deposited under the same conditions exhibit similar magnetization reversal processes, whereas films of similar composition, but made by different methods have different reversal processes. Data collected thus far indicate that higher deposition rates (50 - 300 nm/min) and sufficiently high ion bombardment and backsputtering (determined by cathode voltage, working gas pressure, system geometry, etc.) produce films with a lower density of nucleation sites. The dominant mechanism for magnetization reversal in the films is hence the growth of domains, and the coercivity distribution tends to be small.

It is also noted that the field required to collapse a μm-sized domain is 20 % less than that to cause the domain to grow. This result implies that the dynamic forces on the domain walls from wall surface tension (acting to shrink the domain) dominate over those from demagnetization (acting to enlarge the domain).

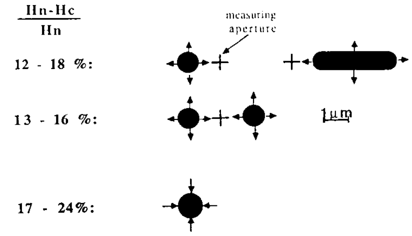

Fig. 4: Domain patterns and the positions of the measuring aperture.

CONCLUSION A micro-Kerr-hysteresis-loop-tracer has been demonstrated to be capable of determining coercivity with μm spatial resolution as a function of position on a MO sample. The MO effect, reflectivity and birefringence may, in principle, also be measured with the comparable spatial resolution.

Using this apparatus, it was found that local variations in coercivity correlate with the dominant magnetization reversal mechanism of the MO films. The films whose magnetization reversal is dominated by nucleation have up to $\pm$ 10 % variations in coercivity as a function of position on the sample. Such films have non-rectangular hysteresis loops when measured on a large scale. Films in which the magnetization reversal proceeds by domain wall motion exhibit negligibly small variations in coercivity. Such films have rectangular hysteresis loops. It may be expected that variations in coercivity as large as $\pm$ 10 % will adversely affect the recording performance and SNR during readback.

Whether the magnetization reversal of a film is predominantly by random nucleation of domains or by wall motion depends mainly on the fabrication processes. Sufficiently high ion bombardment and deposition rates produce RE-TM films whose magnetization reversal is predominantly by wall motion, and coercivity variations in these films tend to be very small.

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