MFM Observation of Magnetization Reversal Process in Recording Media with Lithographically Defined Texture

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Abstract — Periodically textured magnetic recording media with different groove depths are investigated. A spatial map of variation in the switching field and switching field distribution are derived from a series of MFM images. When the reversing field is applied along the texture, long chains of reversal are formed and channeled by the texture grooves. Most grains switch within a relatively small range of applied fields. For fields applied transverse to the texture, short chains of reversal form along the textured grooves, and switching occurs over a broader applied field range.

Index terms — magnetic recording, MFM, magnetization reversal, texture.

I. INTRODUCTION

Texturing of disk substrates is known to induce an anisotropy in the magnetic easy axis of the recording layer [1], but the physical mechanism for this effect is not well understood. Magnetic force microscopy (MFM) is particularly applicable for the investigation of texture effects because it can image the topology of the texture as well as the magnetic behavior of the sample. In this paper, we describe a method for mapping the microscopic spatial variation of switching fields for magnetic recording media using MFM. The switching field map (SFM) is derived from the pair-wise differences of successive images. A switching field distribution (SFD) is then constructed from the map. By comparing the SFDs for photolithographically-patterned samples with different groove depths, we can relate the spatial variation in switching field to the texture.

II. MAPPING SWITCHING FIELDS WITH MFM

To investigate the magnetization reversal process in recording media with lithographically defined substrates [2], we acquire a series of MFM images whose magnetization is reversed incrementally by successively applying fields using an electromagnet [3]. The series of MFM images of the sample are determined at different remanent states ranging from positive saturation remanence to negative saturation remanence. Examining the difference between successive MFM images, individual microstructural reversals can be identified if the applied field increments are sufficiently small. The location and switching field of magnetic reversals are identified in this way and collected to produce a submicron-scale switching field map for the sample [4]. Figure 1 shows two successive MFM images and their difference from Sample C taken after application of magnetic fields of 79.92 kA/m and 80.46 kA/m. The spatial resolution of this switching field map may be greater than a single MFM image because of image differencing. Differencing successive MFM images highlights small domain changes involving individual or small clusters of grains.

![Image of MFM images](http://teola.wustl.edu/MISC)

Figure 1. MFM images and differenced image for sample C. (a) Remanence after 79.92 kA/m; (b) remanence after 80.46 kA/m; (c) differenced image.

Samples consisted of Cr/CoCrPt films sputtered at 250 °C on oxidized silicon substrates, which have been photolithographically patterned with grooves of period 200 nm and depths of up to 50 nm. These samples have the same Cr(200)/CoCrPt(1120) crystallographic orientation and magnetic anisotropy that are seen in longitudinal media sputtered onto mechanically grooved Al/NiP hard disk substrates. The Cr thickness is 50 nm and the CoCrPt is 25 nm thick. The differences in coercivity and other properties may be understood since the samples were usually sputtered separately. The periodic textures were designed with different groove depths to help identifying the effect of the texture on the magnetic reversal process. The groove depths and coercivities along and across the texture direction are summarized in Table I.
TABLE 1. PROPERTIES OF TEXTURED SAMPLES USED IN THIS STUDY

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groove depth</td>
<td>12nm</td>
<td>20nm</td>
<td>22nm</td>
<td>50nm</td>
</tr>
<tr>
<td>$H_{c,\text{ave}}$ (kA/m)</td>
<td>59.8</td>
<td>53.3</td>
<td>73.4</td>
<td>50.9</td>
</tr>
<tr>
<td>$H_{c,\text{max}}$ (kA/m)</td>
<td>40.1</td>
<td>37.9</td>
<td>46.7</td>
<td>36.5</td>
</tr>
</tbody>
</table>

The relative insensitivity to groove depth of the along-thegroove coercivity, $H_{c,\text{ave}}$, may be a result of two competing factors: the increased stress-induced anisotropy associated with greater groove depth which would increase $H_c$, and the greater tendency to chain formation, which would reduce it.

III. RESULTS AND DISCUSSION

The switching field maps, switching field distributions and the corresponding substrate texture for 5 \( \mu \)m x 5 \( \mu \)m areas of Sample C are shown in Figure 2. The MFM results show the switching behavior depends strongly on the orientation of the substrate texture. The horizontal line near the bottom of the image maps is an artifact arising from the experimental procedure used to expedite image collection. The magnetization reversal in the textured samples progresses preferentially along the texture grooves. When the reversing field is applied along the texture, long chains of reversal are formed and channeled by the texture grooves. Most grains switch within a relatively small range of applied fields. For fields applied transverse to the texture, short chains of reversal form along the textured grooves, and switching occurs over a broader applied field range.

Textured samples display some dramatic effects of the regular patterned grooves. Particularly in the deeply grooved sample, the reversal has a strong tendency to progress along individual texture grooves. This indicates that the deep texture features may have disrupted the coupling between grains. Furthermore, there is some progression of the magnetization reversal along the texture lines rather than in the field direction while the field is applied transverse to the texture. These effects are seen to a lesser degree in the reversal of the less deeply textured sample. In the sequence of samples A through D, with increasingly deep texture grooves, the natural tendency for the magnetization reversal to expand in the direction of the applied field is increasingly directed along the texture lines. The c-axes inclination correlate with stress in the magnetic films. It was determined that grooves cause higher stress and greater alignment of c-axes along the grooves [5]. These all promote the magnetization along the grooves.

The formation of reversal chains was also observed in untextured isotropic control samples, with a preference for progression in the applied field direction [4]. This behavior is attributed to magnetostatic interactions. In the absence of texture grooves, the reversal process is less directed, spreading gradually in the transverse direction as the chains grow along the field. Magnetic switching units may be larger than physical grains due to intergranular coupling.

The general characteristics of the switching field distributions are consistent with the hysteresis loops measured by VSM. The squarer hysteresis loops of oriented media result in narrower measured SFDs as shown in Figure 3. Note that sample D has a bi-modal SFD as field is applied along the texture. This correlates with the steps (kinks) in the corresponding hysteresis loop and may arise from significant sidewall deposition of these samples.

The centers (median) of the distributions correspond approximately to the coercivities measured in the VSM. However, since the MFM measurements are made in zero applied field, a more fitting comparison, as shown in Fig. 4, is with the macroscopic remanence curve. Moreover, the integration of the SFD is coincident with the scaled remanence curve as illustrated in Fig. 4(b).

The guiding effect of the texture grooves supports a model in which the texture interrupts the interactions between the grains. Micromagnetic models of both isotropic and oriented media with only magnetostatic interactions [6] have predicted the filamentary expansion of magnetization reversal in the direction of applied field. When a grain in the sample is reversed, magnetostatic interactions favor the reversal of neighboring grains in the direction of the applied field while inhibiting the reversal of grains to the side. This promotes a reversal process in which filaments of reversed grains expand in the direction of the applied field as illustrated in Fig. 5(a). The effect is more pronounced in oriented samples because of the relative scarcity of grains with transverse anisotropy. The effect of such grains is to break the reversal chains, as shown schematically in Fig. 5(b).
Figure 3. (a) Major hysteresis loops for fields applied parallel (outer loop) and transverse (inner loop) to the texture. (b) Switching field maps and (c) switching field distributions for field applied along the texture for samples A, B, and D.

Figure 4. (a) MFM switching field distribution (SFD) and macroscopic remanence curve, (b) comparison of remanence curve (*) with the integrated SFD versus field applied along the texture for Sample C.

Figure 5. (a) Filamentary expansion of magnetization reversal in oriented media with field applied along orientation direction after saturation in opposite direction. (b) Disruption of chain formation when field is applied transverse to orientation direction after saturation in opposite direction.

IV. CONCLUSION

In textured magnetic medium samples, there is a strong tendency to channel the magnetic reversal process along the texture grooves. MFM images of the reversal process show that magnetic switching units may be larger than physical grains. There is also evidence of attenuated inter-grain coupling across the texture lines that may explain the bulk magnetic anisotropy.

REFERENCES