Nanoscale Magnetic Characterization of FIB Patterned Bits on Perpendicular Magnetic Recording Media

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Abstract:

Patterning perpendicular magnetic recording media is one of the methods being investigated currently in order to increase magnetic storage capacity, and allow the next generation of recording devices to attain storage densities above 300 Gb/in^2. Work has been done with patterning CoCrPt perpendicular media, but so far there has been no work done patterning CoCrPt-oxide media. This type of film is considered to be a strong candidate for perpendicular recording media due to its magnetically decoupled grain structure.

In this project we examine two sizes of patterned magnetic bits with sizes ~225 nm and ~115 nm, created by patterning conventional CoCrPt-oxide thin-film perpendicular recording media using focused ion beam (FIB) milling. FIB-patterned structures are characterized by using atomic force microscopy (AFM). Using magnetic force microscopy (MFM) we determine the magnetic characteristics of the patterned bits. These results give us insight into how useful it will be to pattern CoCrPt-oxide perpendicular magnetic films for use in the next generation of hard disks.

Introduction:

Magnetic storage devices are used in almost every modern computer, and increasing demands require improvements in this technology. In most conventional magnetic storage devices, the magnetization direction of magnetic grains used to store data is in the plane of the magnetic film. The grains in these films have a hexagonal close-packed (hcp) structure and develop magnetizations with the c-axis orientation [1], so perpendicular media employ grains with c-axes and magnetizations oriented out of the plane.

By physically isolating magnetic bits in the film using an easily controlled process like lithography, a scanning head encounters much less noise, and higher storage densities become practical. This project investigates the properties of magnetic bits patterned into a perpendicular magnetic film, employing both of these solutions to achieve the higher storage densities.

Procedure:

CoCrPt-oxide film was used for our magnetic media. We investigated the magnetic domain structure of patterned bits with different dimensions, since domain behavior is dominated by size for isolated pieces of a given ferromagnetic material. Patterning was accomplished using focused ion beam (FIB) milling at 1pA beam current, using different mill times to see when the milled trenches began decoupling bits. Patterns of squares with 300 nm and 160 nm bit-periods were examined. The film we used was composed of a 20 nm magnetic layer with a 5 nm-thick protective surface layer of carbon. We cut FIB-milled trenches 4 nm deep into this layer, but, as observed by Rettner et al. [2], the Ga^+ ions used in the FIB process penetrated the film and decoupled the film, creating bits. After patterning the film, the physical and magnetic characteristics of the bits were determined using atomic force microscopy (AFM) and magnetic force microscopy (MFM), respectively. The sample was ac-demagnetized before the AFM and MFM analysis.

Results:

The trenches cut into the film were observed to be ~ 4 nm deep after patterning for 60 seconds at 1pA beam current. In the SEM images, grids patterned for 10 to 20 seconds seemed to be the cleanest with the most well-defined bits, but MFM data showed there was not sufficient decoupling of the magnetic domains.

In the patterned grids with bit periods of 300 nm, the actual bits we measured were ~ 220 nm across, with trench line widths of ~ 80 nm. Figure 1 shows the cross section profile one 220 nm square grid, and Figure 2 shows the AFM image of the same grid. In these bits, multi-domain behavior was observed in the MFM image, as shown in Figure 3. In many of these bits, as Figure 3 shows, the majority of a bit is magnetized in one direction (into or out of the film plane) and a separate domain becomes magnetized in the opposite direction near the center of the bit. This is expected to be the case in multi-domain bits since two uncoupled

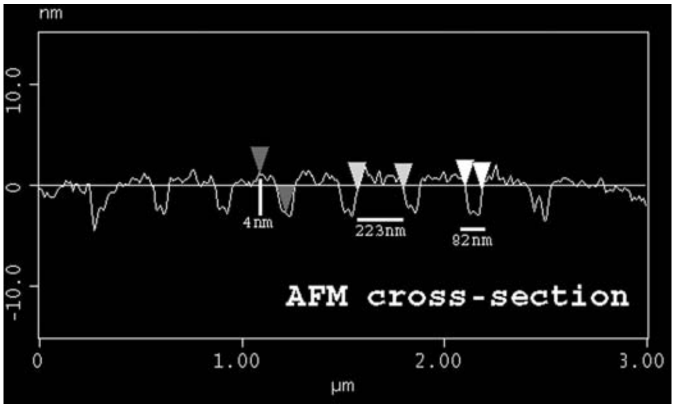
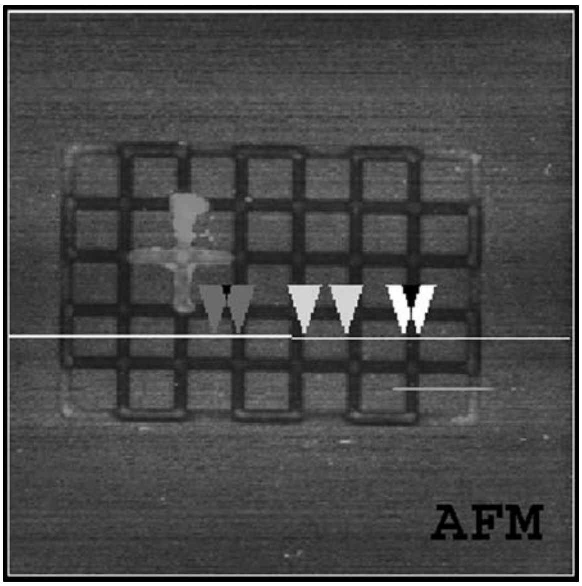


Figure 1, above: Cross section of 300 nm bit period pattern showing topography of bits.

Figure 2, below: AFM image of 300 nm pattern, indicating line which Figure 1 details.



domains would tend to become magnetized in opposite directions to reduce the magnetostatic energy. This behavior is often seen in the center of a bit since the flipping force on a domain would be strongest at the center of an oppositely magnetized domain.

In the grids with a 160 nm bit period, the squares measured 110 nm, with trench widths of 50 nm. The MFM data in Figure 4 shows that these bits are in single domain states, and two of the bits in the pattern are magnetized in the opposite direction. The MFM data shows that the domain boundaries lie neatly along the trenches we cut.

Discussion and Conclusions:

Since only two sizes of bits were investigated, it is impossible to say exactly where the single-domain threshold lies for CoCrPt-oxide perpendicular recording media. We do know that single-domain bits were observed for 110 nm squares, and this may be larger than we initially expected. The patterning process has room for improvement, and with more time it should be possible to mill narrower trenches and further increase bit density in the sample. Finally, after investigating a wider range of bit sizes, it should be possible to determine where bits make the transition from multi-domain to single domain, which is necessary for any application in future storage devices.

Acknowledgements:

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References:

[1] CA Ross Annu. Rev. Mat. Res, 31:203-35, 2001.
[2] Rettner et al. IEEE Trans. Mag. Vol. 38, No. 4, July 2002.

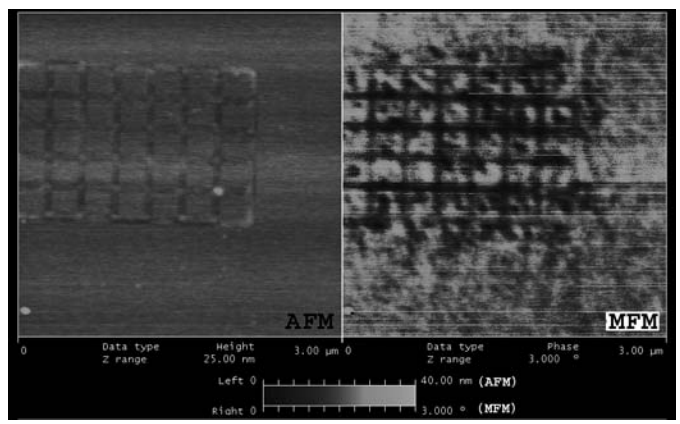

Figure 3, above: AFM/MFM image of 300 nm pattern. Images show the same area.

Figure 4, below: AFM/MFM image of 160 nm pattern.