Nanoscale Focused Ion Beam Patterning and Characterization of Perpendicular Magnetic Recording Media

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Abstract:

A potential approach to higher storage density for magnetic recording is patterning the thin film magnetic medium into arrays of physically isolated islands, which can then be magnetized to represent bits. In this study, we produced prototype patterned media by using a focused ion beam (FIB) to cut arrays of islands into a CoCrPt-alloy perpendicular magnetic thin film. We then examined the physical properties and magnetic characteristics of the islands with atomic force microscopy (AFM) and magnetic force microscopy (MFM), respectively. By varying the milling time of the patterns, we were able to produce trenches with various depths. Results indicated that even trench depths as shallow as 2-3 nm were able to sustain proper magnetic isolation of islands. Attempts at patterning smaller islands demonstrated the necessity of shallow, narrow trenches for well-defined islands with smaller periods.

Introduction:

Magnetic recording, widely used for data storage in modern electronic devices, involves representing a bit of data by the alignment of a magnetic domain in a thin magnetic film. However, data density is limited because the bits must exceed a certain volume to avoid the superparamagnetic effect, in which random thermal energy eventually causes the magnetization to spontaneously switch direction. Patterned media, in which the bits are physically isolated, may be able to overcome this limitation because the increased stability of the domains allows smaller bit volume and therefore greater data density [1].

FIB is a patterning method that involves using a focused Ga+ ion beam to cut trenches in the media. The irradiated regions are unable to sustain magnetization in the absence of field, thus isolating the islands. Decreasing milling (exposure) time allows for narrower trenches, which are advantageous for patterning smaller islands; however, insufficient exposure may lead to shallow trenches and incomplete island isolation [2].

In this work, we varied milling time of the patterns to produce trenches of various depths and widths, and analysed the resulting island magnetizations to determine the trench depth necessary for magnetic isolation. We also produced patterns with islands of various sizes to determine the trench parameters necessary for small, well-defined islands. Doing so will help us develop optimal parameters for FIB patterning of thin magnetic film.

Procedure:

Using the FIB to accelerate a 1 pA Ga+ current through a 30 keV voltage, 10 x 10 uniform square grids were patterned on a 20 nm thick CoCrPt-alloy thin film. Patterns with a period of 500 nm were milled for 43.5 s, 2 min 32 s, and 4 min 21 s. Milling time scaled to size, allowing equivalent dosage, was applied to produce patterns with period of 300, 230, 180, 150, 120, and 100 nm. The sample was then dc-magnetized, and physical parameters and magnetic characteristics were confirmed with AFM and MFM, respectively.

Results and Discussion:

Trench width and depth varied with the patterns, but were on the order of 50-60 nm and 2-3 nm width and depth, respectively, for the lowest dosage, 60-80 nm and 3-4 nm for the middle, and 100 nm and 4-5 nm for the highest. Previous studies indicated that trench depths of around 4-5 nm were required for magnetic isolation of islands [2]. However, as apparent from the cross section of a 230 nm period pattern in Figure 1 and the corresponding MFM scan in Figure 2, even depths of around 2-3 nm appear to be sufficient for this media. In fact, MFM data demonstrated proper magnetic isolation for almost all patterns.

It has been hypothesized that the vanishing of magnetic properties in trenches, leading to magnetic isolation of islands, results not only from media removal, but also from disruption from collisions and ion implantation [2]. Thus, even though the media is 20 nm thick, these shallow trenches are already sufficient for magnetic isolation.

For the smaller patterns ($p <= 180$ nm), a higher

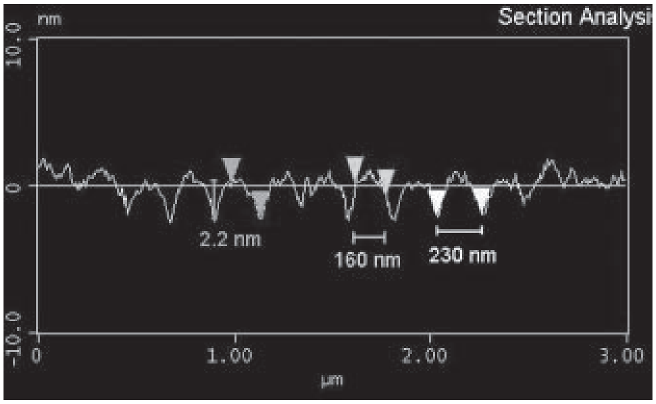
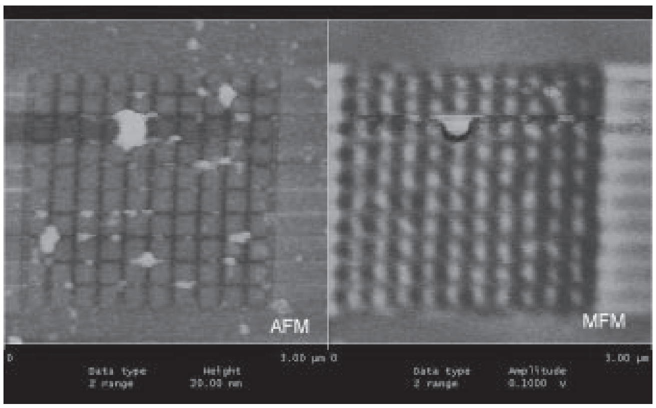


Figure 1: AFM cross section of 230 nm period pattern at lowest dosage.

Figure 2: AFM/MFM image of 230 nm period pattern at lowest dosage.



dosage caused the trench depth to decrease, possibly due to the overlapping of trenches shaving off the tops of islands. This can be seen in Figure 3, which compares the cross sections of 100 nm period patterns with different dosages. Nevertheless, even with this loss of definition, patterns with longer milling time still showed some magnetic isolation, as shown in Figure 4.

Conclusion:

Dosage producing trenches as shallow as 2-3 nm appears to be sufficient to magnetically isolate islands. With lower dosage, trenches are also narrower, allowing patterns with smaller periods. However, reducing the period further requires reducing trench width even more to prevent loss of physical definition. Thus, to achieve good patterns with smaller periods, increasingly low dosages are required.

The smallest pattern produced here, with p = 100 nm, corresponds to a data storage density of 64.5 Gb/in^2. A much smaller period would be required for patterned media to be competitive with current technology; p = 50.5 nm is required for 230 Gb/in^2, the expected data density of perpendicular magnetic recording by 2007. However, as already stated, there are substantial difficulties in scaling down period. Further studies involving even less dosage are necessary to determine the absolute minimum for magnetic isolation. This then determines the minimum trench width, and therefore the smallest period, achievable at the current ion beam size.

Acknowledgements:

Unoh Kwon; Professor Sinclair; the Sinclair group; Joon Seok Park; Max Gage; Mike Deal; the REU staff; National Nanotechnology Infrastructure Network (supported by NSF).

References:

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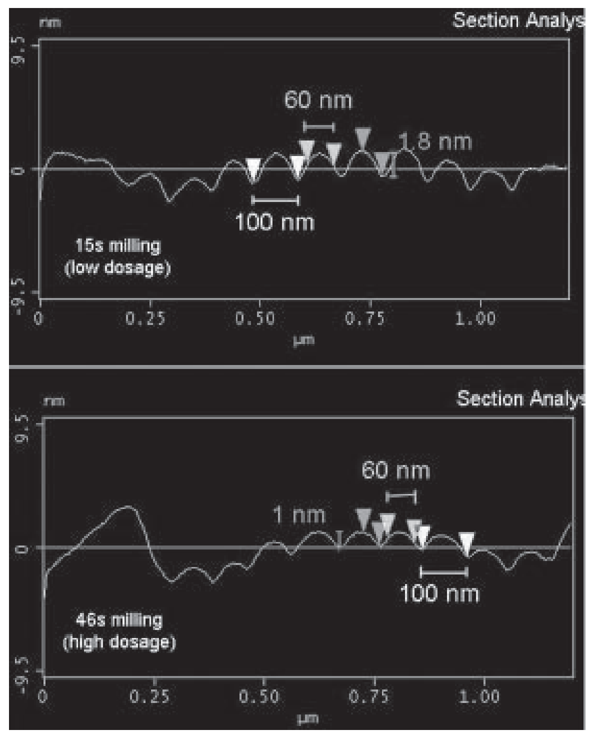

Figure 3: AFM cross sections of 100 nm period patterns with low and high dosage.

Figure 4: AFM/MFM image of 100 nm period pattern at highest dosage.