Investigation of Patterned Media Concept for Very High Magnetic Storage Density

B. D. Horton* and J. L. Streator**

*Caterpillar, Inc., Cary, NC 27511, horton_brian@cat.com
**G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology
Atlanta, GA 30332-0405, jeffrey.streator@me.gatech.edu

ABSTRACT

A patterned media concept for very high density magnetic recording is investigated. Extremely dense patterns, corresponding to 700 Gbit/in^2, are created via nanometer scale self assembled thin film lithography with wet chemical etching. Lower density patterns are created with focused ion beam etching. Strain gage, capacitance and acoustic emission sensors are used to characterize normal load, tangential load, and interface contact. It is demonstrated that loss of hydrodynamic lubrication is small for small pattern regions with high conserved surface area ratio. Flyability results suggest that patterned media look promising for magnetic recording applications.

INTRODUCTION

Since the first hard disk device, the IBM RAMAC, the density of magnetic storage has grown 25% or more per year. Recently, that growth rate has increased to 100% per year [1]. At this rate, the physical limit of areal density in longitudinal media, known as the superparamagnetic limit, will be reached in the near future. Superparamagnetism becomes important when the stored energy per magnetic grain starts competing with thermal energy [2]. In this condition, magnetic domains representing bits of data can spontaneously change polarity causing loss of stored information. An upper limit to densities achievable in longitudinal media has been estimated at 36 Gbit/in^2 [3].

Patterned magnetic storage media separates the bit domains so that exchange coupling can be limited and improve thermal stability. Yet, it is not known if current technology slider heads can generate sufficient hydrodynamic pressure fields to avoid head to disk contact, or "fly" over the media. Therefore, the focus of this work is to experimentally characterize the flyability of current production slider heads over patterned media.

Keywords: magnetic storage, patterned media, thin film self assembly

1 TEST APPARATUS

A test stand was designed and built to test the flyability of current generation sliders over patterned media. The test stand measures friction, acoustic emission, and head to disk interface capacitance. In doing so it has three concurrent measurements to determine if the slider head is flying over the disk, sliding in contact with the disk, or some combination of the two. In addition the apparatus measures the normal load on the slider head and rotation rate of the disk.

Eight individual strain gages, (Vishay Micro Measurements, Raleigh, NC) were attached to a dual cantilever beam and wired into two sets of four active arm Wheatstone bridge configurations. The dual cantilever beam allows measurements of both friction and normal load acting on the slider head. Direct physical contact between the slider and the disk is associated with high friction as compared to when the slider is flying.

A second type of flyability sensor involved the measurement of electrical capacitance. For this purpose the slider-disk interface was made to be a part of an electrical circuit, the slider and disk each serving as capacitor plates. Since, with parallel plates, the capacitance is inversely proportional to the spacing, interface capacitance is indicative of fly height. A circuit model outlined by Streator et al. [4] was used to find the capacitance from the degree of voltage attenuation in voltage divider circuit.

In conjunction with friction and capacitance transducers, acoustic emission sensors (Physical Acoustics, Princeton Jct., NJ) were also employed. These sensors were used to qualitatively compare the intensity of vibrations at the head to disk interface for different testing conditions. The chosen sensor exhibited good response at frequencies from 100 kHz to 800 kHz.

An optical reflectivity sensor focused on a reference mark on the disk surface provided a means to detect the period of disk rotation as well as determine the angular position of the disk corresponding to a particular feature in a recorded signal (i.e., friction, capacitance, or acoustic emission). The ability to identify the disk location in question was particularly helpful for experiments involving focus ion beam etch patterns that covered only a small portion of the disk.

2 EXPERIMENTAL METHODOLOGY

Experimental specimens were prepared using two methods. Focused ion beam (FIB) milling was used on 1" diameter commercially available magnetic disks, while thin film self-assembly was used to pattern on silicon wafer substrates.

2.1 Focused Ion Beam Patterns

Two different FIB patterns were designed. A low density, relatively large pattern area was made such that the entire slider would be over the patterned area at one time. The low density pattern measured 1.23 mm by 1.82 mm. Comparatively, the slider had a footprint of 1.0 mm by 1.3 mm. A section of a representative low-density pattern is illustrated in Figure 1. In this figure, one observes squares delineated by etched grooves. Each square represents a single recording domain or bit. As observed there are approximately 16 bits in the 100 μm^2 area, which corresponds to a 100 Mbit/in^2. A second pattern was made at the highest density capability of the FIB technique. The high density pattern corresponds to a density of 10 Gbit/in^2, and covers a disk region that is 1.1 mm by 0.064 mm.

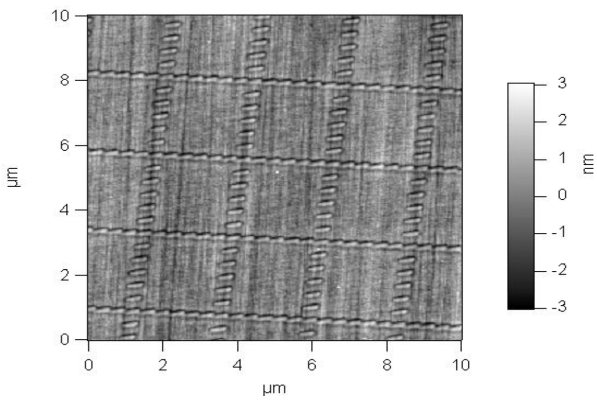

Figure 1: Low Density FIB Sample

2.2 Thin Film Self-Assembly Patterns

The thin film self-assembly process, which is based largely on previous work by others [5, 6], is described in detail in Figure 2. The RSMMA listed in the figure denotes a random copolymer while the SMMA denotes a diblock copolymer (Polymer Source, Inc., Montreal, Canada). After the last step in Figure 2 (Ti sputter), the pattern is ready to be used as a test specimen.

An example of the finished product is depicted in Figure 3. In addition to the smaller, dark circular domains, which comprise the nominal high density pattern, there are a number of defects, where the holes have merges to form serpentine grooves. The nominal density is 700 Gbits/in^2

2.3 Flyability Measurements

Post processing was performed on data from the three sensors to determine flyability. Friction measurements were averaged over the sample period. A technique outlined by Streator et al. [7] was used to mathematically remove cantilever beam vibration effects from the friction data.

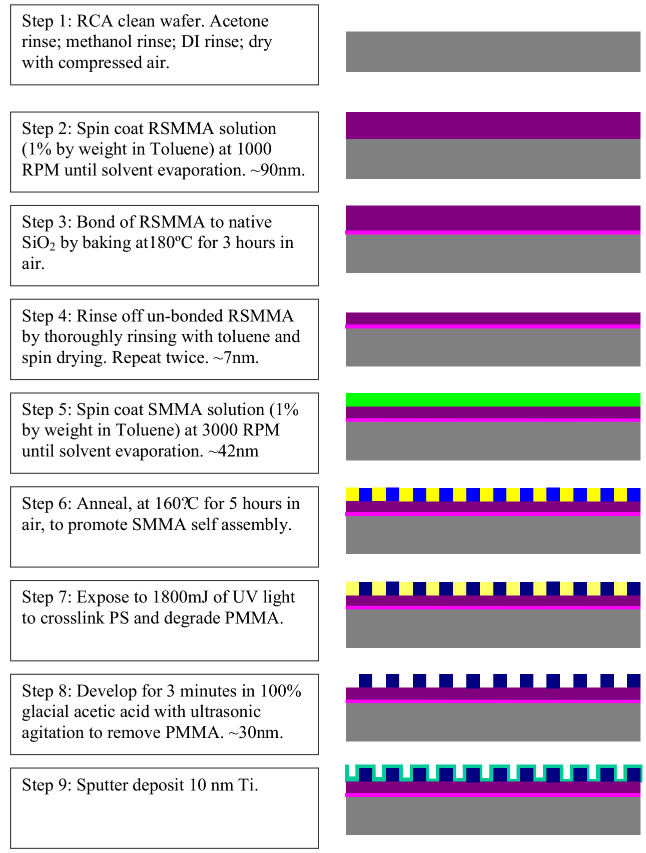

Figure 2: Thin Film Self Assembly Process

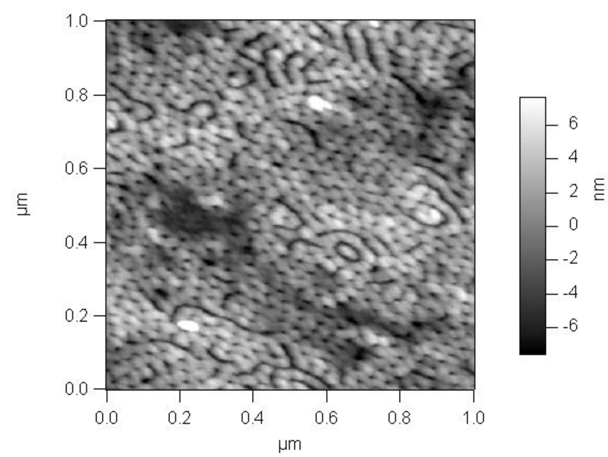

Figure 3: AFM Image after Ti Sputter

Capacitance calculations start with FFT of 10 data point windows calculated for both input and output data. From the FFTs, the maximum amplitude signal is chosen. Next, the input voltage amplitude is divided by its corresponding output voltage amplitude. This voltage ratio is used to calculate slider head to disk interface capacitance that is summarized, like friction, by taking the average.

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The output of the acoustic emission sensor is left as voltage and is evaluated only relative to baseline data. Root mean square (RMS) AE voltage signal is plotted.

RESULTS AND DISCUSSION

Baseline data, Figures 4, 5 and 6, demonstrate slider lift off as speed increases. Figure 4 shows friction as a function of sliding speed for two data series. The first is no-load data taken with the slider head out of contact with the disk. Compared to that result is loaded data where the slider has been loaded to full design load, 2.5 g. The friction at speeds lower than ~7 m/s is significantly higher that above 7 m/s. This difference in friction measurements is interpreted as the difference between not flying and flying. The friction is constant from 7-11 m/s then increases slightly but steadily until 31 m/s, which is like due to viscous effects from the air film. This result is consistent with information on take off speed provided by the head manufacturer (Western Digital, Lake Forest, CA).

Figure 5 shows capacitance as a function of sliding speed. Since capacitance can be considered as inversely related to fly height, one arrives at the conclusion that the loaded capacitance data series in Figure 5 shows take off speed at the same point as indicated by friction, ~7 m/s. Past 7 m/s capacitance decreases slightly to a minimum at 31 m/s.

Figure 6 shows acoustic emission as a function of sliding speed for no load and loaded conditions. RMS acoustic emission is considered an indicator of the intensity and frequency of head to disk intermittent contact. The plateau observed at around 7 m/s is consistent with the apparent take off speed suggested by the friction and capacitance records.

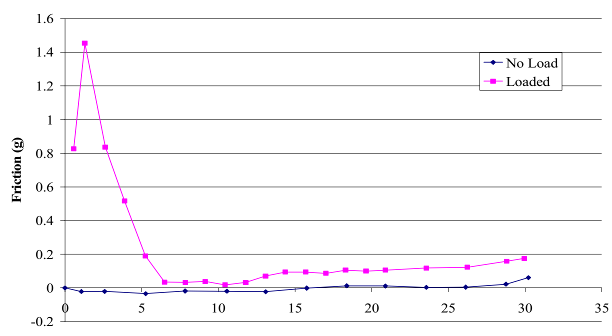

Figure 4: 4” Disk Baseline Data – Friction

Figures 7, 8 and 9 characterize the high density FIB results. Results are shown for both patterned and non-patterned samples. The data correspond to localized regions of 1 mm length containing the pattern. In Figure 7, the patterned curve generally looks similar to but less smooth than the non-patterned line. Additionally, the point where friction appears to show lift off is slightly delayed.

High density FIB capacitance results, presented in Figure 8, show a dip at 5 m/s which corresponds to friction and AE decreases and could be considered lift off.

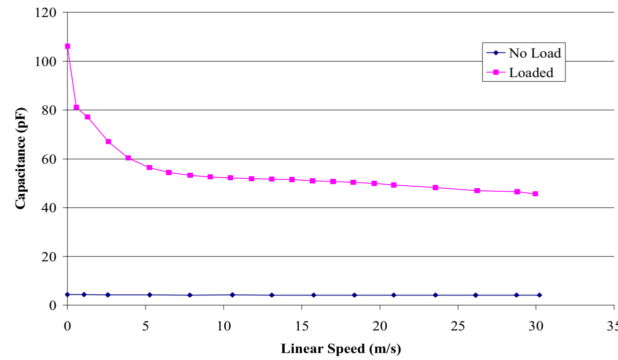

Figure 5: 4” Disk Baseline Data – Capacitance

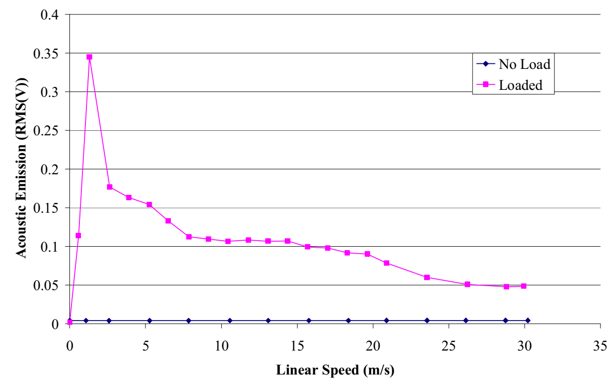

Figure 6: 4” Disk Baseline Data – Acoustic Emission

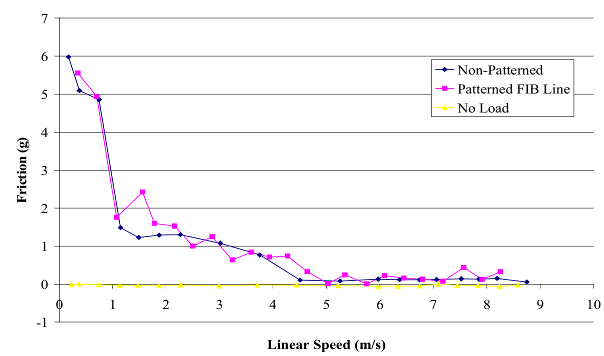

Figure 7: FIB High Density Results – Friction

In Figure 9, high density FIB regional acoustic emission results, deviation from the non-patterned AE data starts at 1.8 m/s and continues until apparent lift off at 4.6 m/s, which is delayed slightly compared to the non-patterned media.

Figure 10 and Figure 11 present thin film pattern data. Half-load patterned data is plotted against full-load non-patterned data and no-load data. Full-load data does not indicate lift off. Yet friction, in Figure 10, for the slider at half design load appears to have a lift-off profile. The significant drop in friction is complete by 16 m/s. The corresponding acoustic emission data, however, does not show the same trend.

One key difference between the FIB samples, that support stable flyability, and the thin film patterned sample, that does not clearly support flyability, is the difference in the fraction of non-etched media area. This can be termed the conserved surface area ratio (CSAR). If it is assumed that areas that are etched support little hydrodynamic pressure then the CSAR could be predictor of how well a particular patterned sample will allow a slider head to fly.

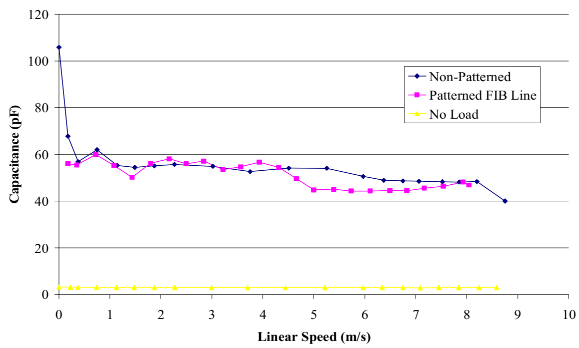

Figure 8: FIB High Density Results – Capacitance

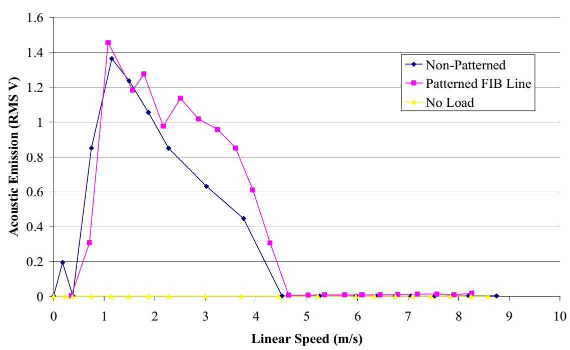

Figure 9: FIB High Density Results – Acoustic Emission

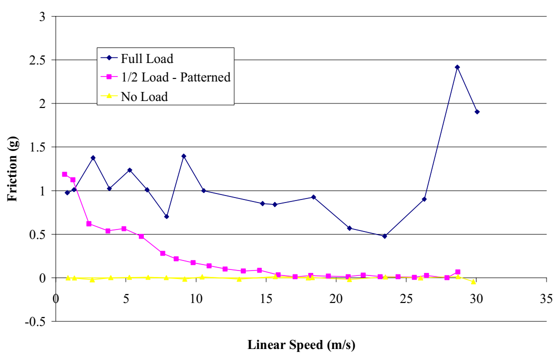

Figure 10: Thin Film Self Assembly Results – Friction

Considering CSARs for the three types of samples, it is more easily understood why the FIB samples provide better support for hydrodynamic lubrication. The conserved area ratios for the three types of patterned samples are 0.69, 0.5 and 0.15 for the FIB low density, FIB high density, and thin film pattern media, respectively.

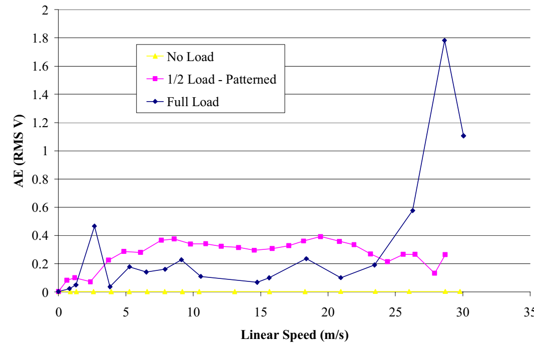

Figure 11: Thin Film Self Assembly Results – Acoustic Emission

SUMMARY

The ability to achieve lift off was not affected by the patterned area on either FIB sample. However, the thin film self assembled sample was not able to achieve lift off with full slider design load. However, at half design load the friction sensor appears to lift off by 16 m/s, which is higher than what was found with the baseline data a full load. A general predictor of a patterned media's ability to support hydrodynamic pressure is introduced as conserved surface area ratio (CSAR). High density patterned media look promising but may require a lower slider load.

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