Writing and Reading 7.5 Gbits/in^2 Longitudinal Quantized Magnetic Disk Using Magnetic Force Microscope Tips

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Abstract **— Quantized magnetic disks (QMDs) consisting of longitudinal single-domain Ni bars with densities from 3 Gbits/in^2 to 10 Gbits/in^2 were fabricated using nanoimprint lithography and a lift-off process. Two different types of MFM tips were used in the writing and reading process, one for erasing and writing, another for reading; both were magnetically 'hard'. The QMDs were first erased by aligning all bars with the write-tip scanning the entire sample, then written using lithography software in NanoScope III. Error-free results were obtained up to 7.5 Gbits/in^2 despite the poorly-defined magnetic field from the write-tip and despite not having a feedback control for the write-tip position.**

I. INTRODUCTION

Quantized Magnetic Disks (QMDs) based on single-domain patterned magnetic nanostrcutures have shown the potential to become the magnetic recording media with a density far beyond the fundamental limits of conventional thin film media [1, 2]. Previously, a QMD with 65 Gbits/in^2 density has been fabricated [1] and so has been the nanodot array with 400 Gdots/in^2 density using nanoimprint lithography--a low-cost, high throughput manufacturing technology [3]. In this paper, we present the experimental study of writing longitudinal QMDs with a density up to 10 Gbits/in^2. We report that despite a poorly-defined magnetic field from a magnetic force mircoscope (MFM) tip, and despite not having a feedback control for the write-tip position, QMDs with densities up to 7.5 Gbits/in^2 have been successfully written. The density is much higher than the 1.6 Gbits/in^2 that we demonstrated earlier in our preliminary experiment[4].

II. FABRICATION AND CHARACTERISTICS OF Ni BARS IN THE QMD

Longitudinal QMDs, consisting of rectangular Ni bars, with densities of 3, 5, 7.5 and 10 Gbits/in^2, were fabricated using nanoimprint lithography and a lift-off process. Nanoimprint lithography used a mold to physically deform a resist, followed by reactive ion etching to remove the residual resist in the compressed area. The details of the process have been published elsewhere [3]. The fabricated Ni bars on a silicon substrate have a thickness of 35 nm, sizes varying from 400 nm × 100 nm to 200 nm × 60 nm, and spacings varying from 240 nm to 130 nm. Figure 1 shows a scanning electron micrograph of the Ni bars with a density of 7.5 Gbits/in^2.

Two types of MFM tips were used in the experiment. One is the "image-tip", which is a silicon atomic force microscope (AFM) tip with 30 nm-thick Ni film deposited by sputtering. This type of tip images the QMD without flipping the Ni bars. The other is the "write-tip", which is a silicon AFM tip with 65 nm-thick Co film deposited by sputtering for writing the QMDs. The image-tip and write-tip were magnetized along tip axis in the same direction. Using a micron-current loop, we found that the MFM tip primarily behaved like a dipole with the moment along the tip axis, whose contribution is at least two orders of magnitude larger than those from the dipole moments transverse to the tip axis and monopole [5].

The coercivities for various MFM tips have been studied in Ref. [6]. We also found that the coercivities of both our write-tip and image-tip are high enough so that imaging QMD samples could not change the magnetization direction of the tips.

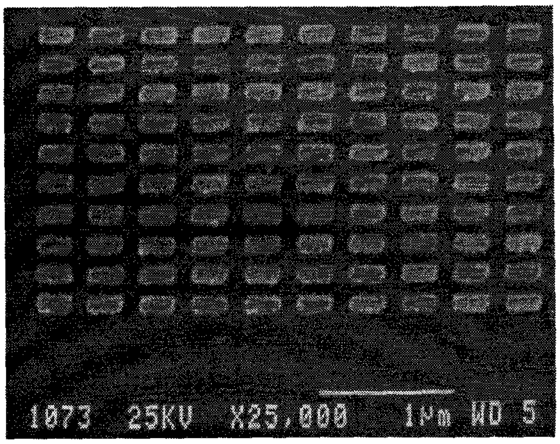

Fig. 1 SEM micrograph of Ni bars in a QMD with density of 7.5 Gbits/in^2, bar size of 240 nm × 70 nm and spacing of 150 nm.

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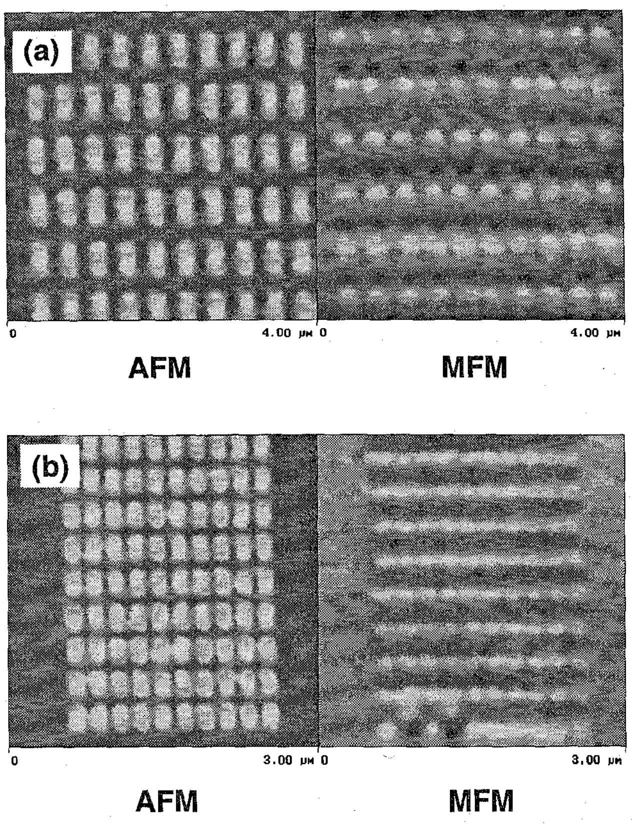

Fig. 2 AFM and MFM images of QMDs with a density of (a) 3 Gbits/in^2 (bar size of 400 nm × 100 nm and spacing of 240 nm) and (b) 10 Gbits/in^2 (bar size of 200 nm × 60 nm and spacing of 130 nm).

In testing the image-tip, we found that indeed the MFM image of Ni bars stayed the same, regardless of the scan direction and the scan height. This suggests that neither the bars being read nor the tip were magnetically disturbed or reversed. In testing the write-tip, we used the image-tip to observe the sample right after scanning the write-tip over the sample. We found that the magnetization direction of all the bars were aligned in the direction that was consistent with the scanning direction and the magnetic polarization of the tip. This indicates that the magnetic field of the write-tip was strong enough to flip every Ni bar.

MFM images read with the image-tip indicate that the Ni bars for all as-fabricated QMDs are single domain. Figures 2 (a) and (b) show the AFM and MFM images of QMDs with densities of 3 Gbits/in^2 and 10 Gbits/in^2 respectively. Each single domain bar has a pair of poles: one dark pole standing for the attractive tip-sample interaction, and one light pole standing for the repulsive interaction. The switching fields of Ni bars with different sizes were studied in our earlier work [2]. They vary from 100 Oe to 740 Oe.

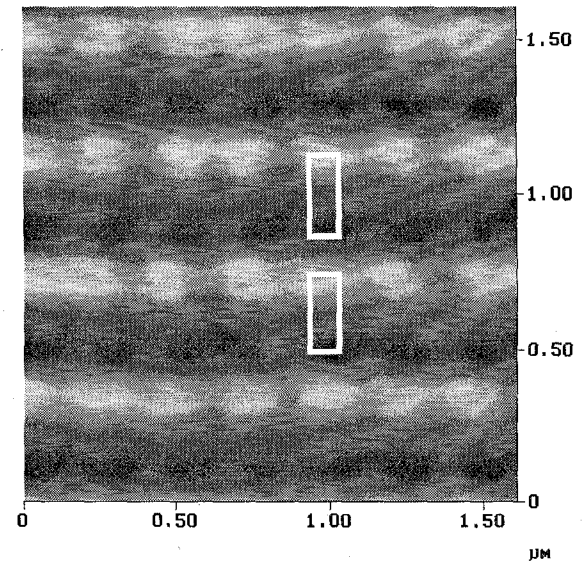

Fig. 3 MFM image of the same bars shown in Fig. 1. Each single-domain bar has two poles, which are located at the diagonal corners of the bar. The white frames indicate the shape and position of the bars.

In Fig. 2, it can be seen that the MFM signal becomes weaker as the density increases, due to reduction of the bar width and hence magnetic moment. To achieve stronger signals at higher bar densities, cobalt and permalloy bars with a higher magnetization should be used.

Moreover, as the density increases, the two poles of each Ni bar appear to not exactly be located at the end of the bar as in the case for lower density (for example, 1.6 Gbits/in^2). Instead they appear to be located at the diagonal corners, as shown in Fig. 3. If the deviation of pole position results from lowering the magnetostatic energy, the deviation can be reduced by fabricating the bars with a narrower width or with a rhombahedral shape.

III. WRITING PROCESS

Before writing, the write tip was scanned over the entire sample, thereby aligning all the bars in the same direction. The surface topography image during this process was captured using the program "Capture Plane", and was used as the map for later writing. A lithography software in NanoScope III was used to control the movement of the write tip. The lithography script was run in Tapping Mode, and the feedback was turned off in order to control the tip-sample separation through the script.

During writing, the write tip, controlled by the lithography program, was first lifted up and moved to one end of a bar. The magnetic pole at that bar end was initially

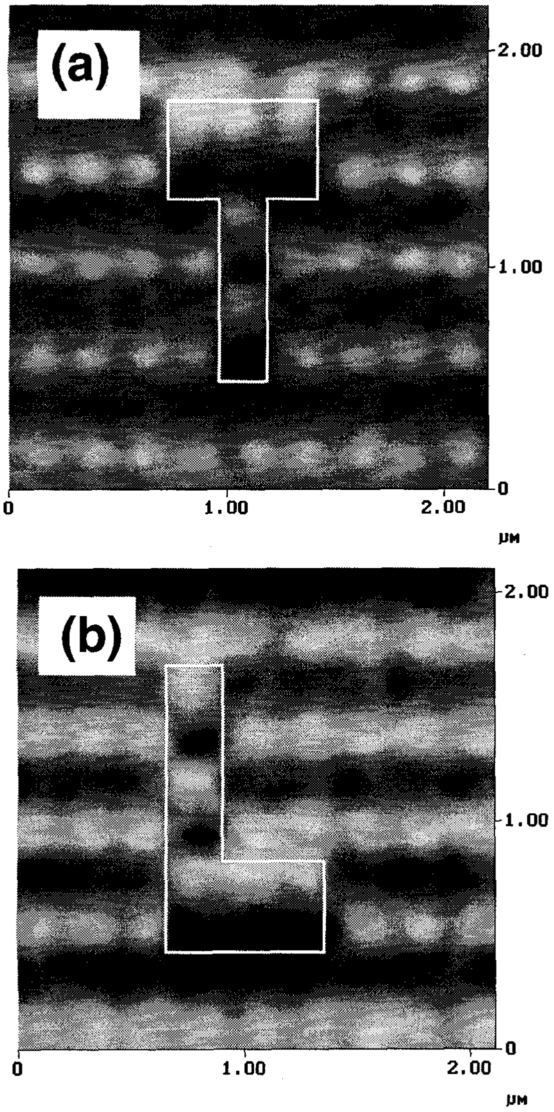

Fig. 4 MFM images of written patterns in QMD: (a) capitol letter "T" and (b) capitol letter "L".

opposite to that of the write tip. Without scanning, the tip was lowered until the tip-bar separation was 5 nm; writing occurred as the tip was close to the bar selected. After writing, the tip was raised up and moved to the location of the next bar. This process was continued until all the desired bars were written. Finally, the image-tip was used to nondestructively image the written pattern.

IV. RESULTS AND DISCUSSION

The "T" and "L" patterns written in 7.5 Gbits/in^2 longitudinal QMD are shown in Fig. 4. This pattern, written exactly according to the script inputted in the computer, shows that the MFM tip can write precisely and perfectly each desired bit without flipping neighboring bits. Our experimental results suggest that the accuracy of the write-tip positioning in the writing should be about 5% or better of the distance of tip's movement.

It should be noted that the error-free writing was achievable despite a number of detrimental factors. First, unlike a conventional write head, an MFM tip has a very poorly defined writing field. Second, the switching field of each bar is not the same due to variation in the bar's shape and due to the bar's mutual interaction. Third, during the writing process the MFM does not have any feedback to track the actual tip movement. Therefore the tip positioning is not very accurate. And fourth, the magnetic poles of the bars did not appear to be exactly at the end of the bar. The ability to achieve an error-free writing under all these detrimental conditions is attributed to the quantized writing nature of the QMD, namely quantized magnetization and quantized switching. This also implies that QMD can have not only very high intrinsic storage densities but also greatly relax the requirements on the design of the writing head. With a better write-tip and a write-tip position feedback, writing of longitudinal QMDs with a density higher than 7.5 Gbits/in^2 or vertical QMDs with a density higher than 15 Gbits/in^2 should be achieved.

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