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Fabrication, Writing, and Reading of 10 Gbits/in^2 Longitudinal Quantized Magnetic Disks with a Switching Field over 1000 Oe

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Quantized magnetic disks (QMDs) with a density of 10 Gbits/in^2 were fabricated using nanoimprint lithography and a lift-off process. Each bit in the QMD consists of a patterned single domain Co bar with a length of 200 nm, a width of 60 nm, and a bar spacing of 130 nm. Magnetic force microscope (MFM) was used to write and read the QMD. In 2.5 μm$\times$2.5μm MFM window, error-free MFM writing has been achieved, even though there is no feedback control of the writing tip position and the Co bars switching field was as high as 1020 Oe.

KEYWORDS: magnetic force microscope, quantized magnetic disk, nanoimprint lithography, single domain, switching field

1. Introduction

Quantized magnetic disk (QMD) is a very attractive approach to increasing the data storage density beyond the fundamental limits of continuous magnetic thin film media.[1–3] The invention of nanoimprint lithography, a high-throughput and low-cost manufacturing technology, makes the fabrication of QMD economically viable.[4] Previously, nanodot array with 400 Gdots/in^2 density was fabricated using nanoimprint lithography,[5,6] and the magnetic force microscope's (MFM) writing and reading of Ni based QMD with a storage density up to 7.5 Gbits/in^2 and a switching field of about 300 Oe were reported.[7] In this paper, we present our investigation on design and fabrication of QMDs with Co bars using a nanoimprint technique and, most importantly, a demonstration of MFM writing of 10 Gbits/in^2-density Cr/Co/Cr longitudinal QMD that has a switching field of over 1000 Oe.

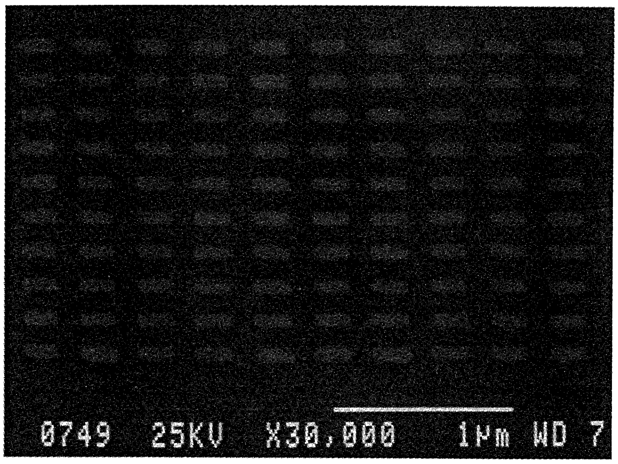

Fig. 1. SEM image of bars in a QMD with density of 10 Gbits/in^2, a bar thickness of 2 nm(Cr)/10 nm(Co)/5 nm(Cr), a bar size of 200 nm by 60 nm, and a bar spacing of 130 nm.

2. Experiments

In fabrication of longitudinal QMDs, which consist of Co or Cr/Co/Cr bars on a silicon substrate with a density of 10 Gbits/in^2, nanoimprint lithography (NIL) and a lift-off process were used. In nanoimprint lithography, a mold was pressed into and deformed the shape of a 200-nm-thick polymethyl methacrylate (PMMA) film spun on the silicon substrate, then anisotropic etching was used to etch away the residue PMMA at the compressed areas. Typical Si substrate size is 1 cm by 1 cm. Details of NIL have been published elsewhere.[4–6] After NIL, Co or Cr/Co/Cr was e-beam evaporated and lifted off. The Co bars have a size of 200 nm by 60 nm, a bar spacing of 130 nm and thickness varying from 35 nm to 10 nm. The patterned area achieved by imprint can have an excellent uniformity over 3 cm by 3 cm. However, for clearly demonstrating the MFM writing and an easy tracking, we fabricated arrays of longitudinal QMDs with small area on the same substrate. Each array has about one hundred magnetic bars. The bar size and spacing vary from one array to another. The scanning electron micrograph (SEM) of the fabricated bars in such QMD is shown in Fig. 1.

The writing tip was coated with 90-nm-thick Co by sputtering. The reading tip, which can image the QMD without altering the magnetization state of Co bars, was coated with Cr(5 nm)/Co(20 nm)/Cr(5 nm) by e-beam evaporation.

3. Results and Discussion

Although all unpatterned films have coercivities between 30 Oe and 50 Oe, measured by vibrating sample magnetometer, the patterned film can have a significantly larger coercivity or switching field due to a submicron size and a large shape anisotropy. The domain structure of Co and Ni bars and the switching field dependence on bar width and bar length have been reported elsewhere.[8]

MFM observations indicated that all Co bars in the 10 Gbits/in^2-density QMDs were single domain. Each bar has two opposite magnetic poles: one dark pole representing the attractive tip-bar interaction and one bright pole represent the repulsive interaction, as shown in Fig. 2(a).

When the Co bars were 35 nm and 25 nm thick, the switching field was found to be too large to flip the magnetization of the bars by the MFM writing tip. The shape anisotropy (therefore the switching field) of Co bars decreases with decreasing bar thickness.[9] To reduce bar switching field, less than the magnetic field near the MFM writing-tip end while maintaining an acceptable reading signal, we deposited Cr/Co/Cr bar and decreased the Co thickness to 10 nm. It was found that the QMD with a bar thickness of 2 nm(Cr)/10 nm(Co)/5 nm(Cr) was good enough for MFM reading and writing. The top Cr layer was used to protect Co from oxidation. The Cr underlayer might be helpful for improving the magnetic properties of Co bars, although the Cr layer was too thin (2 nm) to completely control the crystalline orientation of Cr bars.

The switching field of Co bars in the optimized QMD

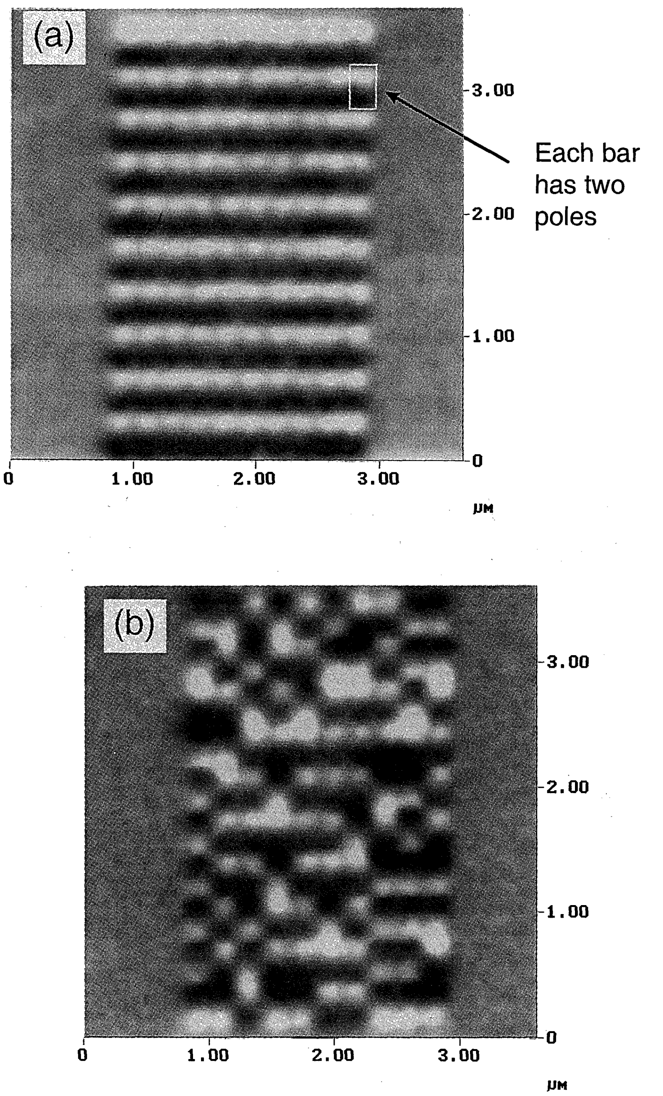

Fig. 2. MFM images of the optimum QMD (a) after being placed in a magnetic field of 5000 Oe and (b) after being placed first in a magnetic field of 5000 Oe then a reversed field of 1020 Oe.

was determined using MFM and an external magnetic field. A magnetic field, which was large enough (for example, 5000 Oe) to align all the bars in the field direction, was first applied to the sample. Then the reversed magnetic field but with a smaller amplitude was applied. MFM was used to observe the magnetization state of bars after taking the sample out the reversed field. Figure 2 shows the MFM images after the QMD sample was placed in the magnetic fields. It was found that, as shown in Fig. 2(b), when the reversed field was 1020 Oe, half of Co bars were flipped. This field is called the switching field.

Next, the writing tip was used to write the bar arrays and was able to flip every Co bar. This suggests that the magnetic field near the tip end should be larger than 1020 Oe.

During the writing, the writing tip, controlled by the lithography software in an MFM, was simply positioned at one end of the desired bar and then lowered until the tip-to-bar separation was reduced to 5 nm. The desired bar switched perfectly due to the quantized nature of a single domain bar, which can be switched by a field which covers only part of the bar.[2,11) The details of the writing process have been described else-

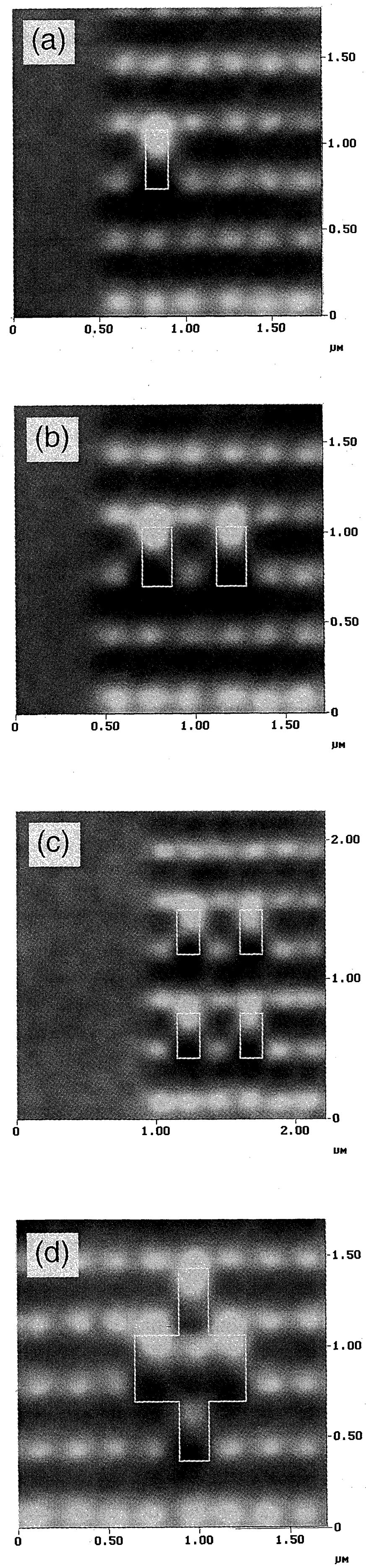

Fig. 3. MFM images of written patterns in the optimum QMD.

where.[7] Figure 3 shows respectively the written patterns, (a) one bit, (b) two separated bits, (c) four separated bits and (d) a plus sign, in 10 Gbits/in^2 Cr/Co/Cr longitudinal QMD. These written patterns clearly indicate that the MFM tip can write each desired bit of QMD without flipping the neighboring bits. Actually, it is also possible to read and write Co QMD without Cr underlayer using MFM as long as the switching field of Co bars is controlled to be around 1000 Oe by adjusting the thickness of Co bars.

Three facts should be noted in Fig. 3. First, the switching field of Co bars in the QMD is as high as 1020 Oe. Second, the spacing between the neighboring bars is as small as 130 nm. Both the higher switching field and the smaller spacing are very desirable for increasing the storage density and bits stability. But they impose more stringent requirements on the writing field and position accuracy of a writing head. Third, there is no feedback for the writing-tip position during the writing process. Nonetheless, 10 Gbits/in^2 Co QMD with a switching field over 1000 Oe was successfully written using an MFM tip. This suggests that QMDs may relax the requirements in the design and position of a writing head for ultra-high density magnetic recording.

4. Conclusions

We fabricated 10 Gbits/in^2 Co longitudinal QMD using nanoimprint lithography and a lift-off process. The QMD was optimized for MFM writing and reading, and the switching field was determined to be 1020 Oe. In 2.5 μm$\times$2.5 μm MFM window, error-free MFM writing has been achieved despite the lack of feedback control of the tip position. Based on our experiments, we feel that the MFM writing for 20 Gbits/in^2 longitudinal Co QMD or 40 Gbits/in^2 vertical Co QMD are achievable.

Acknowledgements

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