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Pinning magnetic domain via patterning artificial lattice under amorphous magnetic layer

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Abstract

A novel method for pinning magnetic domains on pre-formatted pinning sites has been developed for perpendicular magnetic anisotropy magneto-optical (MO) thin film media. The pinning sites were artificial lattices made by patterning a layer of gold grid on the substrate using electron beam lithography. Compared with the work proposed using photo-lithography, our method showed the ability of making smaller pinning domains. Moreover, compared with our previous work using the same electron beam lithography method and creating hole arrays on polymethyl methacrylate, this new method could stand higher film deposition temperatures and avoid the MO films rapid deterioration on a PMMA substrate. In order to investigate the domain pinning behavior we did several different procedures and observed their corresponding domain pinning layouts. Magnetic domains were found to be pinned inside the lattice and resembled the geometric shapes of the lattice. The pinned domains acquired the shape of the lattice. In this article, the star-shaped type of geometry of grid arrays is presented. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Pinned magnetic domain; E-beam lithography; Patterned substrate; Magneto-optical

1. Introduction

In magnetic recording technology, studies of domain characteristics such as shape, size, stability, jaggedness, and wall width are important for the optimization of the media. Higher storage densities demand smaller stable domains and a reduced media noise. Observations have indicated that some of the media noise arises from domain irregularity, the rough magnetization transition regions, and a non-uniform distribution of magnetization within recorded domains [1–3]. Consequently, a written domain with fixed shape and free from jaggedness could help reduce the media noise. One way to achieve this goal is by patterning of the disk substrates as proposed in Ref. [4]. Our previous works [5,6] have also shown that confining a magnetic domain is feasible by patterning the substrate using hole arrays on polymethyl methacrylate (PMMA). PMMA, however, has the following deficiencies: (1) it cannot stand high temperature film depositions; (2) it cracks rapidly in the surface of MO samples; (3) it is not sticky enough to attach on the sample substrate. Therefore, we have developed another method for pinning magnetic domains. This method employs a patterned substrate by laying a gold grid on the top of the substrate before the MO film deposition. Compared with the work proposed in Ref. [4] (using photo lithography), our method showed the ability of making smaller pinning domains; while compared to our previous work [5,6], this new method could stand higher film deposition temperatures and avoid the MO films rapid deterioration on a PMMA substrate. In this paper, we present this novel method for pinning the magnetic domains via patterning

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an artificial lattice under a magnetic layer and discuss the relationships between the pattern geometry and the domain structure.

2. The experimental

The fabrication procedures of artificial lattices which serves as pinning sites for the confinement of magnetic domains are described as follows: an electron resist, polymethyl methacrylate, was spun onto a SiN-coated Si-wafer and was baked at 140°C overnight, and electron beam lithography was used to delineate a variety of designed sub-micrometer pinning patterns such as square-, rectangle-, donut-, and star-shaped arrays[1]. Following resist development, 30 nm of gold was thermally deposited and the patterns were transferred onto the substrate by a lift-off procedure. The MO active layer $Dy_x(FeCo)_{1-x}$ with a thickness of 50 nm was DC magnetron co-sputtered onto the pre-formatted pinning patterns, and a 30 nm thick layer of silicon nitride was subsequently deposited to protect the MO layer. The layer structure is silicon/SiN(200 nm)//Au(30 nm)/DyFeCo(50 nm)/SiN(30 nm), as shown in Fig. 1.

The sample's morphology and magnetic domain structure were observed by employing a magnetic force microscope (MFM). A Digital Instruments Nanoscope IIIa MFM, equipped with a phase extender [7] was used in this study. The magnetic tip with a CoCr-coated Si tip magnetized along the tip axis was used to scan the magnetic domain structures in the tapping-lift mode and it was shown that MFM contrast could be associated with up- and down-magnetized domains [8]. Before the MFM measurements, the samples were either magnetized or demagnetized in magnetic fields perpendicular or parallel to the film plane [9]. For perpendicular magnetization and in-plane demagnetization, a 26 kOe magnetic field was used to saturate or to demagnetize the sample, respectively.

3. Results and discussion

Magnetic domains were found to be pinned by the grid arrays and resembled the geometric shapes of the grid. In order to investigate the domain pinning behavior, we followed several procedures and observed their corresponding domain pinning layouts. The procedures were (1) as deposited; (2) applying a 26 kOe magnetic field perpendicular to the film plane; (3) applying a −26 kOe magnetic field perpendicular to the film plane; (4) applying a 26 kOe magnetic field parallel to the film plane. Furthermore, we saturated the image tip along the tip axis and kept it at the same magnetization configuration during all the MFM image scans. The results of the MFM scans are shown in Fig. 2. Fig. 2a–Fig. 2e are scanning images of patterned grid substrate and magnetic domains in various conditions for a $Dy_{23.5}(Fe_{80}Co_{20})_{76.5}$ sample. Fig. 2a is a three-dimensional view of patterned star-shaped (with diameter of 2 μm) array morphology. Fig. 2b–Fig. 2e are the corresponding magnetic domain images of the aforementioned experimental procedures of (1), (2), (3), and (4), respectively. At the absence of any applying field, the magnetic domains were randomly distributed, as shown in Fig. 2b. Fig. 2c and Fig. 2d revealed the opposite magnetic moment signal as the applied magnetic field was reversed. When the applied field was parallel to the film plane, the magnetic domains displayed a totally different contour, as shown in Fig. 2e. Compared to Fig. 2c and Fig. 2d, the magnetic moment in Fig. 2e was decreased, as could be seen from the reduced strength of frequency signal of the y-axis. The above results led us conclude that the magnetic domains could be confined within a pre-formatted grid substrate and that the presence of magnetic domains could be explained by the frequency shift.

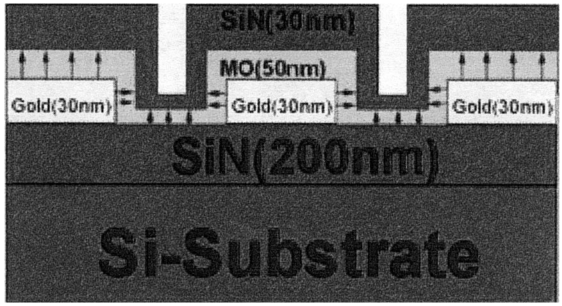

Fig. 1. Cross-sectional view of the fabricated layer structure: Silicon/SiN(200 nm)/Au(30 nm)/DyFeCo(50 nm)/SiN(30 nm).

4. Concluding remarks

We have developed a technique to compensate the deficiencies of the PMMA method [5,6] in studying magnetic domain pinning behavior. Although we showed only star-shaped grid arrays in this article, we found that magnetic domains could be pinned within the lattice arrays with different types of geometry, such as square-,

[1] A 30 kV of Hitachi S2460N SEM equipped with a versatile pattern generator is used for the structure fabrication in this study. The writing software, Nanopattern Generator Systems (NPGS), is produced by JC Nabity Lithography Systems, Bozeman, MT59717.

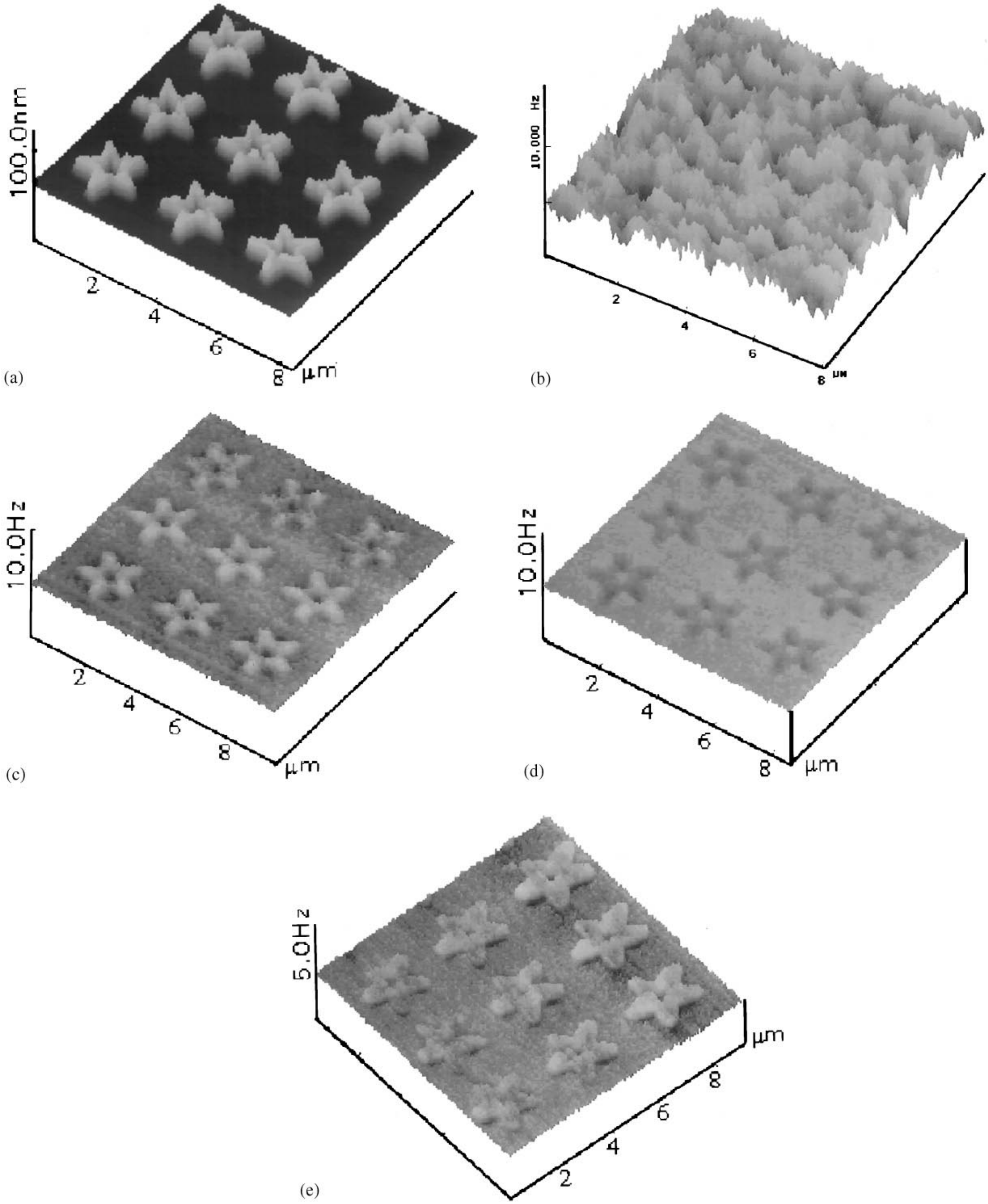

Fig. 2. (a) is a three-dimensional view of patterned star-shaped array morphology. (b)–(e) are the corresponding magnetic domain images of the experimental procedures of the as-deposited state, +26 kOe applied field perpendicular to the film plane, − 26 kOe applied field perpendicular to the film plane, and 26 kOe applied field parallel to the film plane, respectively.

rectangle-, circle-, donut-, and star-shape, and so on. In principle, it is possible to fabricate any desired domain geometry with this technique. In order to interpret and verify that the observed MFM images certainly reveal the pinned domains, we have applied different orientations of a magnetic field relative to the film plane to change the magnetization conditions of the sample. For opposite applied fields, we found that the domain images show the opposite contrast from up-side-down ones. Since we had saturated the image tip along the tip axis and kept it at the same magnetization configuration during all the MFM image scans, we could conclude that the contrast of image actually disclosed the pinning domains. In addition, we found that the coercivity of the film is higher within the range of lattice than in the rest of the film. However, for pinning smaller domains, the present results indicate that the ratio of grid diameter to depth is critical. It was observed that the stability of the pinned domain is also affected by the sample's magnetization. Further investigation is necessary to understand the effect of changing the ratio of lattice diameter to depth and the sample's magnetization on the stability of domains and definite shape in thin film MO materials.

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