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Enhanced Magnetic Properties of Bit Patterned Magnetic Recording Media by Trench-Filled Nanostructure

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Abstract

The structure and properties of nanoscale magnetic island arrays for bit patterned media (BPM) have been studied. A periodic Si nano-island array was fabricated by nano-imprint-lithography (NIL), with the trench-filling and flattening achieved by resist spin coating followed by reactive ion back-etching. A [Co 0.3nm\Pd 0.8nm]$_8$ multilayer magnetic media with a perpendicular anisotropy was then sputtered and lifted-off so that the processed nanostructure array now has the magnetic material only on the top of the pillars. This process significantly improved the magnetic characteristics of the bit patterned media. A planarization by hydrogen silsesquioxane filling can reduce the tribological interference of the protruding nanoisland heights in the bit patterned media.

I. Introduction

For hard disk magnetic recording media with substantially improved recording capacity of 1 Tbit/in^2 or higher recording density, a reduction in the feature size is one of the key requirements[1]. Bit patterned magnetic recording media (BPM) have attracted much attention due to the projected increase in magnetic recording density. Some of the important intrinsic parameters that affect the recording media performance are the thermal stability factor (K_uV/k_BT), proper anisotropy (K_u) and magnetization values with a narrow K_u distribution.[2, 3]. Important extrinsic parameters include the uniformity of the nano geometry in the processed patterned media.

Two major nano-fabrication methods exist for deposition of magnetic material for the patterned media[4, 5, 6]. The first approach is the substrate patterning, followed by magnetic layer deposition. The substrate is pre-patterned into islands using e-beam or nano-imprint lithography before the magnetic material is deposited. The main advantages of this method are that (i) no chemical or reactive ion etching process is required for metallic magnetic layer once the substrate island array structure is prepared, (ii) and hence the possible damage of the magnetic material associated with ion etching process is minimized, (iii) and a high throughput process is possible. However, the magnetic material is also deposited in the trenches (between the protruding Si or other substrate islands), which introduce undesirable noises during the read/write process and can cause magnetic interactions between the media material deposited in the trench or island sidewall and that on the top of the islands[5]. The second approach of placing the magnetic layer is to first deposit the high coercivity magnetic thin film material on a flat substrate, then followed by direct patterning of the media layer into discrete magnetic island bits by ion beam etching or focused ion beam milling (FIB). The main advantage of this method is that the magnetic material left between the neighboring bits is minimized to reduce interfering magnetic signals. However, this method has a low throughput with slow etching process for magnetic metal patterning by ion milling, with possible complications of magnetic material re-deposition during the ion-etching process. Also, the magnetic material can more easily be damaged by the ion bombardment required for metal etching.[6]

We have demonstrated significantly improved magnetic bit patterned media properties by a simple, convenient, and reliable trench-filled nanostructure to ensure the magnetic material deposition only on the patterned media islands. A two-step planarization process of using the PMMA filler first to block the trenches during magnetic layer deposition, followed by hydrogen silsesquioxane (HSQ) filler to planarize and obtain nano-topographically flat recording media was employed. Both polymers can easily be spin-coated to fill the etched areas [7].

II. Experimental Procedures

Figure 1 schematically illustrates the process used for bit patterned media nanostructure fabrication, trench filler additions and planarization. A Si wafer was spin-coated with an approximately 250 nm thick layer of poly-methylmethacrylate (PMMA) (Micro Resist Technology, mr-I 35k PMMA 300). A Si nanoimprint stamp (mould) having a nano-hole array (~100 nm diameter) is then imprinted onto PMMA layer on Si wafer at using an ANT-2 nano imprinter (step (a) in Fig. 1). The nano imprint lithography (NIL) stamp (mould) was created on (100) silicon wafers by deep ultraviolet (DUV) lithography patterning, reactive ion etch (RIE), and surface oxidation [8]. The NIL patterned PMMA was slightly RIE etched (Oxford Plasmalab-80) in a gas mixture of CF_4 and O_2 to form a through hole (Fig. 1(c)). The hole-patterned PMMA was then used as an etching mask for Si etching to faithfully transfer the patterns into Si wafer using a mixture of SF_6 and C_4F_8 for RIE (Oxford Plasmalab-100) as illustrated in Fig. 1(d), followed by removal of PMMA by O_2 plasma to produce an array of protruding Si nanoisland columns (~100 nm diameter and ~100 nm tall) Fig. 1(e).

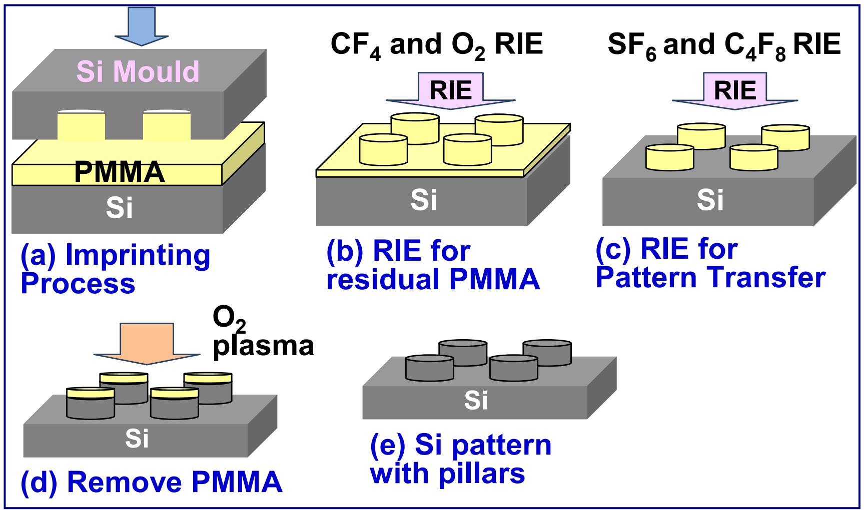

Fig. 1 Schematic illustration of the fabrication processes for bit patterned media (BPM) using trench-filling process.

In order to place the magnetic bit layer only on top of pillars, we utilized a nanoscale filling and manipulation of the Fig. 1(e) nanostructured substrate as illustrated by the insets in Fig. 2(c). A thin PMMA layer was first spin coated to fill the valley and subsequently re-etched by a CF4 and O2 mixture RIE to remove the overfilled regions on the substrate for planarization. A magnetically hard Co/Pd multilayer film, having a [Ta 3nm\Pd 3nm\[Co 0.3nm\Pd 0.8nm]8 structure with desirable perpendicular magnetic anisotropy was sputtered on the pre-patterned and planarized substrate.

After magnetic layer deposition, the filling processed BPM was lifted-off by acetone and sonication. A HSQ (hydrogen silsesquioxane) resist film was spun on the BPM to fill the trenches and subsequently back-etched by RIE to remove the “overfilled” extra HSQ material. The surface roughness of the nanostructured BPM before vs after trench filling was monitored by atomic force microscopy (AFM) and scanning electron microscopy (SEM). The magnetic properties of the BPM media material were evaluated by magnetic force microscopy (MFM) and superconducting quantum interference device (SQUID) with vs. without the trench-filled nanostructure.

III. Results and discussion

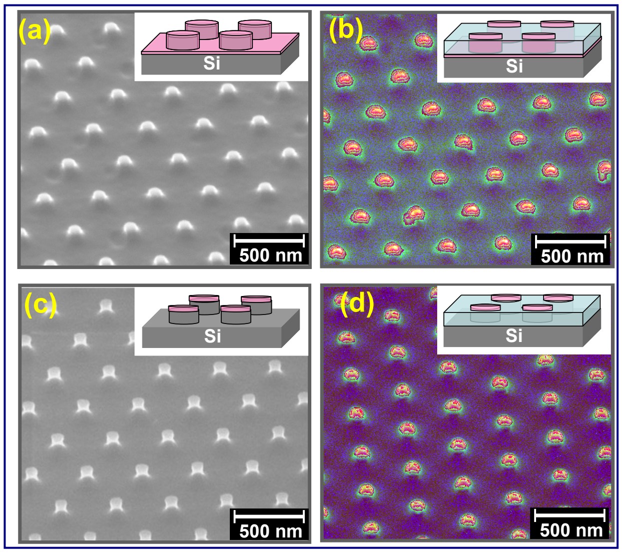

Fig. 2. SEM images showing topographical features of bit patterned media. (a) magnetic media deposited without trench filling, (b) the structure of (a) + additional geometry planarization, (c) magnetic media deposited with trench filling for isolated magnetic islands, and (d) the structure of (c) + additional geometry planarization. The insets show the schematic description of the BPM nanostructures.

As a demonstration of principle, we fabricated a ~100 nm diameter periodic array of Si nano pillars using nano imprint lithography (NIL). Each of the samples contained ~100 million Si nanopillars over a relatively large area of 0.6 cm x 0.6 cm. The oblique angle SEM image of the bit patterned media consisting of high-coercivity magnetic multilayer stacks of [Ta 3 nm\Pd 3 nm\[Co 0.3 nm\Pd 0.8 nm]8] deposited on top of Si islands as well as in the valleys (trenches) is shown in Fig. 2 (a). Our patterned Si islands have a dimension of ~100 nm diameter, ~ 100 nm height and a periodicity of 400 nm. It is notable that the Si island nanofeature dimension is undesirably altered during the magnetic multilayer deposition, with the magnetic materials deposited in the trench, on the top, as well as on the sidewall of the pillars. Also shown in Fig. 2(b) is the SEM image of the Fig. 2(a) nanopillar structure subjected to an additional process of geometrical planarization using HSQ (hydrogen silsesquioxane) spin coating, back etch and conversion of the trench HSQ into SiO2 by annealing. The trenches are completely filled by HSQ. The planarization process has reduced the bit height from ~ 100 nm to ~ flat, 15 nm layer. Only the magnetic bit islands are exposed.

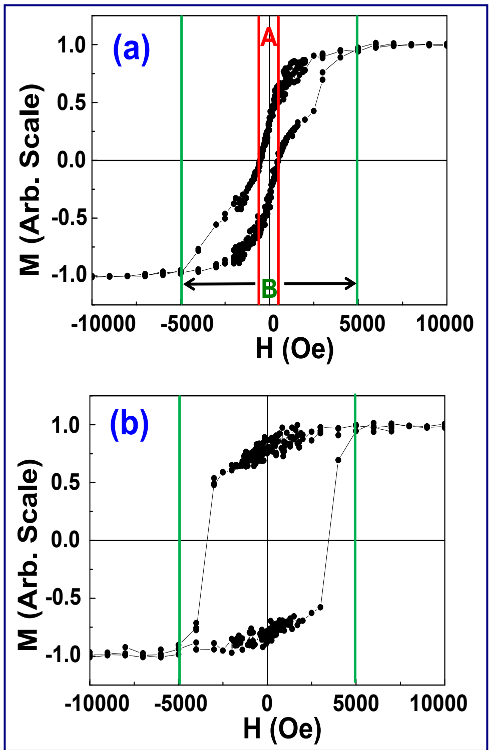

Fig. 3. M-H loop of bit patterned media by SQUID measurements for (a) BPM with unremoved magnetic materials in the trenches, (b) BPM with trench filling process for isolated magnetic islands.

In order to restrict the presence of magnetic materials only on the pillar top, not in the unwanted places such as sidewall and valley, the samples were pre-covered by PMMA (poly-methylmethacrylate) using spin coating before magnetic layer deposition so as to exclude the magnetic materials on these unwanted locations. After spin coating, the superfluous PMMA is back-etched by RIE to reveal the top of the Si islands. The required RIE time depends on the thickness of PMMA, the height of the Si pillars, and the etching rate. A SEM image of a BPM with the magnetic recording media material restricted to the Si pillar top area via the trench-filling process is shown in Fig. 2(c). It is apparent that the trench filled nanostructure controls the location of magnetic material in a well-defined manner and prevents the unwanted deposition of magnetic material outside the pillar tip region.

To evaluate how such nanostructural manipulations influence the magnetic behavior of BPM media, the magnetic properties of BPM were measured and analyzed. Figure 3(a) shows the M-H magnetization loop of the patterned media measured by SQUID (super-conducting quantum interference device), without the trench filling process. This M-H loop appears to have two distinctly different regions. The Region A (marked in Fig. 3(a)) represents the magnetic signal from the relatively continuous CoPd multilayer film in the valley, which exhibits a low coercivity of only about 600 Oe as anticipated for non-nanosize Co-Pd layer materials. The Region B, on the other hand, shows the magnetic signal from the ~100 nm diameter size-confined CoPd multilayer islands on top of the Si pillars, which exhibits a much higher coercivity of about 5000 Oe. It is known that the smaller CoPd multilayer islands produce much higher coercivity. The M-H loop clearly shows that not only was the magnetic multi layer present on top of pillars, but on sidewall and valley. Shown in Figure 3 (b) is the M-H loop measured from BPM with magnetic material confined to the Si pillar top only, accomplished by using the trench-filling process. Contrary to the M-H loop of Fig. 3(a) for the BPM without filling process, the Fig. 3(b) exhibits a much better defined M-H loop indicative of a more uniform material, namely only the pillar top island magnetic material.

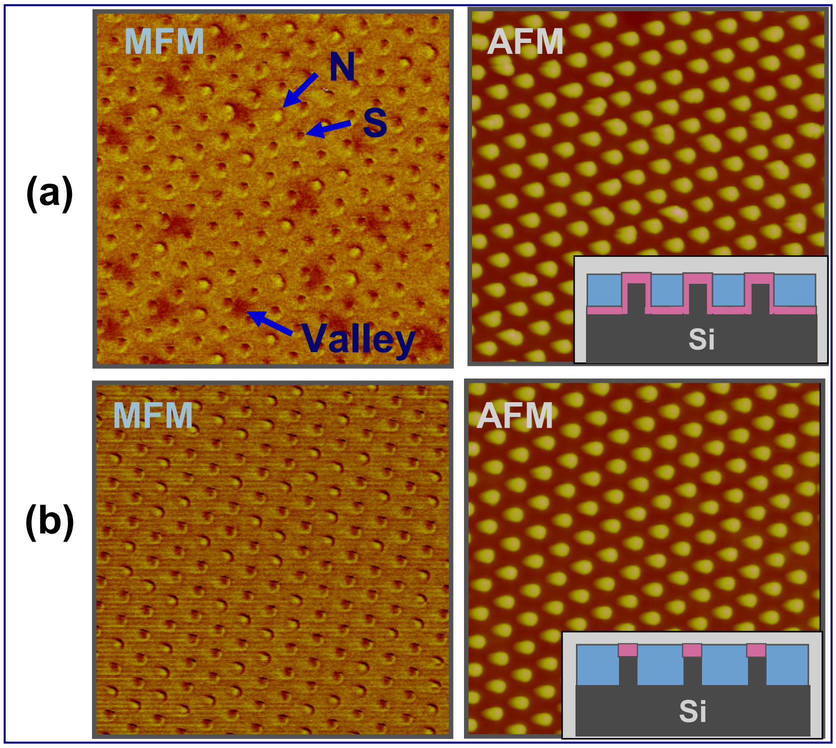

Fig. 4. MFM data (left) and AFM data (right) of BPM (a) without trench filling process vs. (b) with trench filling process.

Shown in Figure 4(a) are typical magnetic force microscopy (MFM) and atomic force microscopy (AFM) images of the BPM without the filling process. The schematics in the insets illustrate the cross-sectional geometry of the magnetic recording media in relation to the substrate and the HSQ filler material. The AFM data, Fig. 4(a) (rightside image, representing ~5 mm square area) indicates a relatively uniform pillar array. The MFM image (leftside image) shows a somewhat smaller island images, which is possibly related to the larger measurement distance between MFM probe tip and magnetic multilayer surface as compared to the AFM imaging. The light phase vs. dark phase contrast represents opposite magnetization directions in the MFM imaging. It is seen that the valley regions also show some response to the MFM imaging (darker and blurry contrast regions) indicating the presence of magnetic materials in the valley. In the BPM processed with the trench-filling step (thus having the magnetic material only on the island top), the MFM image of Fig. 4(b) leftside is much more uniform than the case of Fig. 4(a) MFM imaging, and exhibits no dark contrast regions from the valley seen in Fig. 4(a).

Higher resolution MFM image of the BPM with the filling process (magnetic material only on the pillar top), Fig. 5, indicates further details of the domain structure. Because of the somewhat larger island diameter of ~ 100 nm, the magnetic island is not a single domain in this particular case, and a two-domain structure is therefore observed. It is anticipated that single domain structure in a periodic arrangement will be obtained if the island diameter is reduced to ~50 nm or smaller, which is one of our current research topics.

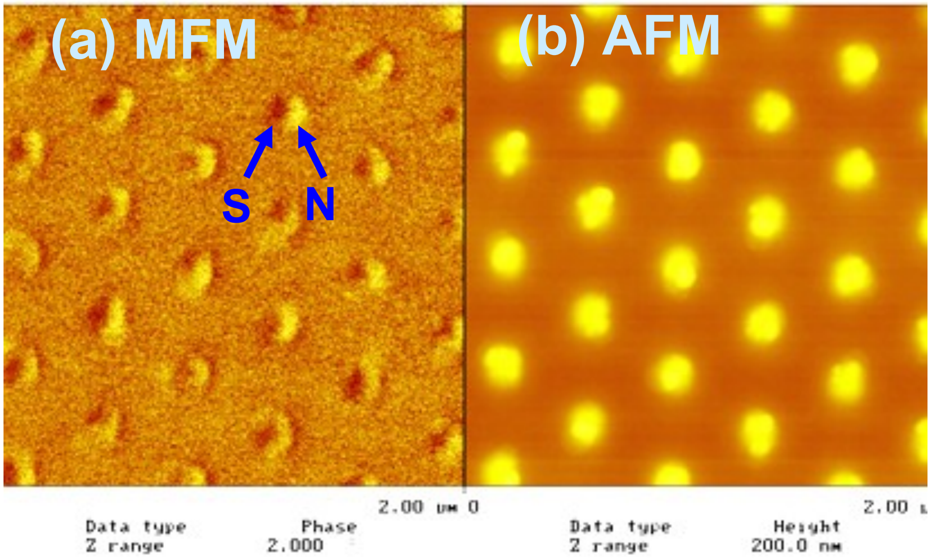

Fig. 5. Higher resolution images of (a) MFM and (b) AFM for the BPM with trench filled nanostructure.

In summary, the structure and properties of nanoscale magnetic island arrays for bit patterned media (BPM) have been studied, in which the deposition of unwanted magnetic materials outside the island region was prevented by trench-filling. A Co-Pd multilayer magnetic media placed on nano-imprint-lithography-processed, periodic Si nano-island array using such trench-filled configurations exhibited significantly improved magnetic characteristics of the bit patterned media.

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