Fabrication of Metallic Nano-stamper and Replication of Nano-patterned Substrate for Patterned Media

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ABSTRACT

With increasing demand for ultra high-density information storages, patterned media has received much attention as a solution to overcome the limits of conventional continuous magnetic media. Current methods to fabricate the patterned media are to use direct patterning and etching. However, those procedures are very costly and are not suitable for mass production. In this study, we investigate the possibility of mass production of patterned media by molding technology with the metallic nano-stapmer. The metallic nano-stamper was fabricated using an electroforming process, and then the nano-patterned substrate was replicated using a nano-molding process. To evaluate the replication quality of the nano-patterned substrate, the surface profile and the roughness of the patterns on the molded substrate were measured and analyzed. The magnetic layer was deposited on the nano-patterned substrate, and a single magnetic domain state was observed on the nano-patterned substrate.

Keywords: nano-molding, metallc-nano stamper, nano-patterned substrate, patterned media

1 INTRODUCTION

As the need for information storage with high storage density increases, patterned media has received much attention as a solution to overcome limits of conventional continuous magnetic media, such as superparamagnetic effect and medium noise. Patterned media is regarded as a forefront candidate to achieve high storage density up to a few Tbits/in^2. Data can be stored in a bit on the discrete nanoscale patterns of single magnetic domains on the media.

Patterned media with nanoscale patterns can be produced using various micro-electro-mechanical system (MEMS) and nano-electro-mechanical system (NEMS) technologies. Aoyama and Hao et al. fabricated the patterned media using electron beam (e-beam) and holographic lithography, and etching [1-2]. Also, a focused ion beam (FIB) was proposed to directly fabricate discrete magnetic patterns [3]. However, those procedures are high-costed and low-throughput techniques. Chou et al. has proposed a nano-imprint lithography to produce nanoscale patterns at low-cost [4]. In a nano-imprint lithography process, a mold containing initial patterns is required, silicon or quartz is used as a mold due to its ease of fabrication [5-6]. However, the silicon or quartz mold has a short lifetime, because they are too brittle to be used for nano-imprint lithography, which requires the process under repeated pressure and temperature. McClelland et al. applied the nano-imprint lithography to fabricate the patterned media, and a photopolymer was used as a mold material [7]. However, the polymer mold is not suitable to use a mold repeatedly for mass production in imprint process because of its flexibility. A metallic nano-mold can solve this problem, and Heydermann et al. made metallic nano-structures using numerous steps; deposition of the seed-layer on the substrate using a evaporation or sputtering, fabrication of patterns using lithography processes, fabrication of metallic structures using a electroplating, and reactive ion etching (RIE) [8]. However, when a metallic mold was fabricated, RIE is applied to each cycle to these processes.

This paper describes the methodology of fabricating a nano-patterned substrate for patterned media using a molding process, and application of this methodology. The metallic nano-stamper was fabricated using a electroforming, and then the nano-patterned substrate was replicated using a nano-molding with the metallic nano-stamper as illustrated in Figure 1.

As a first step, the master nano-patterns were fabricated by e-beam and holographic lithography. After the seed-layer was deposited on the master by e-beam evaporation and sputterning, the electroforming process followed to

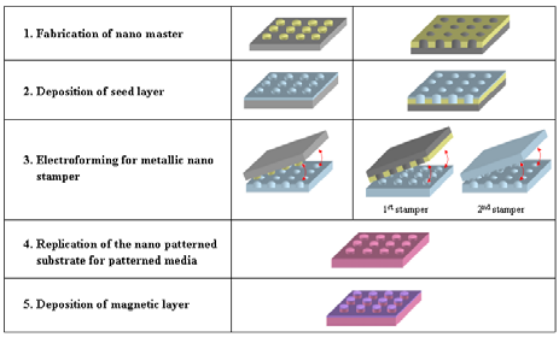


Figure 1: Fabrication procedures for patterned media using the present method

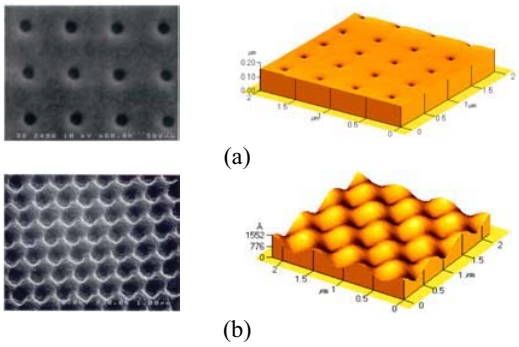


Figure 2: SEM and AFM images of the master nano-patterns by (a) e-beam lithography and (b) holographic lithography, respectively.

make the nickel nano-stamper. And then, the polymeric nano-patterned substrate was replicated by nano-molding. The surface profile and the roughness of the patterns on the polymeric substrate were measured and analyzed. Finally, the Cr underlayer and the Co magnetic layer were deposited on the patterned polymeric substrate, and a single magnetic domain state was observed on the nano-patterned substrate.

2 EXPERIMENTS AND RESULTS

2.1 Fabrication of Master Nano-patterns

To replicate patterns of nanoscale sizes and pitches by a nano-molding process, we fabricated the master nano-patterns using e-beam and holographic lithography.

E-beam lithography can fabricate the arbitrary patterns with various hole and pillar patterns in nanoscale diameters, pitches and depths. Also, holographic lithography can generate the periodically repeated nano-structures in large area. Figure 2 shows scanning electron microscope (SEM) images and atomic force microscope (AFM) images of the master nano-patterns by e-beam and holographic lithography, respectively. Hole patterns with a diameter of 200 nm, a pitch of 500 nm and a depth of 100 nm, were fabricated by e-beam lithography. To produce two-dimensional crossed gratings with a period of 500 nm and a depth of 60 nm on 4-inch wafer, double exposures with half

Parameters		Range of values
Temperature (°C)		43-45
pH		4-4.2
Current density (mA/cm^2)		10-20
Concentration of Electrolytes (g/l)	$Ni{\cdot}(NH_2SO_3)_2$ $4H_2O$	300-450
	$Ni{\cdot}Cl_26H_2O$	15
	H_3BO_3	45

Table 1: Processing parameters for nickel electroforming

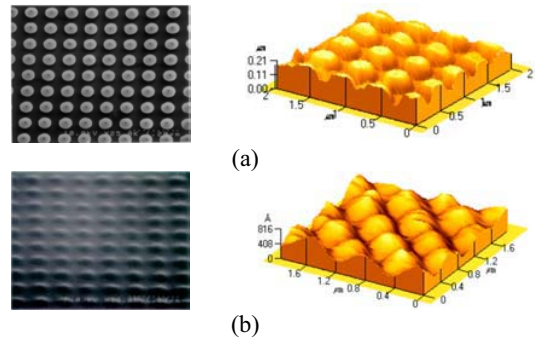


Figure 3: SEM and AFM images of the electroformed metallic nano-stampers using (a) the e-beam patterned master and (b) the holographic patterned master, respectively.

of exposure energy along different directions by 90° rotating the sample, were performed.

2.2 Fabrication of Metallic Nano-stamper

The seed-layer was deposited on the master by e-beam evaporation and sputtering to enhance the coverage and to uniformize the deposition states of metallic particles. Because the seed-layer functions as not only nano-patterns on the metallic nano-stamper but also as a conduction layer in the electroforming process, control of the deposition process and selection of the material for the seed-layer are important. The nickel was chosen as the seed-layer because it can satisfy desirable requirements, such as high hardness and thermal stability [9]. Also, processing conditions should be properly controlled during the process not to separate the metallic layer from the patterned resist-layer on the master.

After the seed-layer was deposited, the electroforming process using a nickel sulfamate solution was peformed to make the nickel nano-stamper with a thickness of 0.5 mm [10]. As shown in Table 1, we controlled an electroforming process to suppress the separation of seed-layer and the development of residual stress in the electroformed layer. In particular, an electric current was maintained at low value to slow the electroforming rate until the metallic layer was stable. After the electroforming, the silicon wafer and residue resist were removed. The nanoscale pillar and hole shapes of the metallic nano-patterns, which were transferred from the shapes of master nano-patterns, were formed. Figure 3 shows SEM and AFM images of the electroformed metallic nano-stampers.

2.3 Replication of Polymeric Nano-patterns

Metallic nano-stamper was used for the nano-molding process, such as compression molding, ultra-violet (UV) molding and injection molding. Nano-molding process can be regarded as a suitable mass production process for replicating nano-patterns. The present molding system is modified from the micro-compression molding system [11].

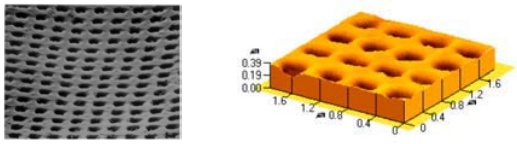


Figure 4: SEM and AFM images of the polymeric nano-patterns with a diameter of 200 nm, a pitch of 500 nm and a depth of 100 nm

A polymethyl methacrylate (PMMA) powder was used as the molding material. In nano-molding process, the molding temperature and compression pressure are the most dominant governing processing conditions that affect the replication quality of the molded parts. If the molding temperature and compression pressure are too low, molded patterns can not be made because PMMA powder particles can not bond, and the polymeric nano-patterns can not fill the metallic nano-stamper. Also, if the molding temperature and compression pressure excessively increased, they can deteriorate the replication quality because of the sticking effect. Therefore, it is important to control the molding temperature and compression pressure conditions to improve the quality of replication in the molded parts.

After the proper processing conditions were determined from experiments, the molding process was carried out at a molding temperature from 210-220 °C and compression pressure 2-4 MPa. To evaluate the replication quality of the polymeric nano-patterns, the surface profile and the surface roughness of the molded parts were measured and analyzed by SEM and AFM. Figure 4 shows SEM and AFM images of hole patterns with a diameter of 200 nm, a pitch of 500 nm and a depth of 100 nm in the molded parts. And Table 2 shows the surface roughness of the patterns in the master, the stamper and the molded part. As shown in Figure 4 and Table 2, the pillar shapes in the metallic stamper were properly transferred to the polymeric patterns. Also, the surface roughness of molded patterns was less than 10 Å.

These experimental results show that our replication method with the metallic nano-stamper can be applied to fabricate the nano-patterned substrate for patterned media.

2.4 Application to Patterned Media

To apply our replication method to patterned media, the nano-patterned substrate with pillar patterns should be replicated. After the metallic nano-stamper with hole

	Ra (Å)
Master nano-patterns	3.29
Metallic nano-stamper	6.42
Polymeric nano-patterns	7.55

Table 2: Surface roughness of the master nano-patterns, the metallic nano-stamper and the polymeric nano-patterns

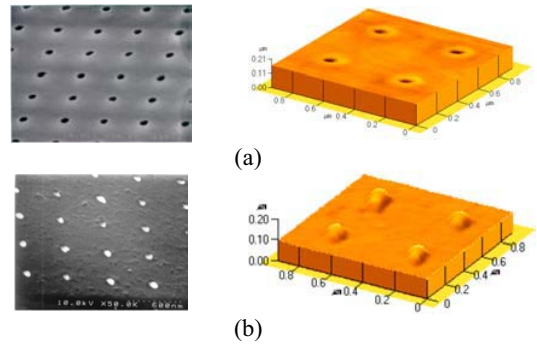


Figure 5: SEM and AFM images of (a) the metallic nano-stampers and (b) the corresponding nano-patterned substrate with a diameter of 200 nm and a pitch of 500 nm

patterns was fabricated using e-beam evaporation and electroforming, the corresponding nano-patterned substrate with pillar patterns was replicated. The nano-patterned substrate had pillar patterns with a diameter of 200 nm and a pitch of 500 nm, and a diameter of 100 nm and a pitch of 250 nm, respectively. Figure 5 and Figure 6 show SEM and AFM images of the metallic nano-stamper and nano-patterned substrate for patterned media. Comparing with the molded substrate with hole patterns, it was observed that molded patterns were not stable for the case of pillar shape. In particular, when the pillar diameter was 100 nm, some defects were founded in the substrate, and patterns in shape and size were not uniformly distributed as desired. From these results, we believe that the replication of pillar patterns is more difficult than that of hole patterns, because non-filling and sticking problems can occur. To solve these problems, it is necessary that more precise processing condition is optimized and the releasing method is developed in the nano-molding process.

Finally, the magnetic layer was deposited on the molded patterns for patterned media. The magnetic material and

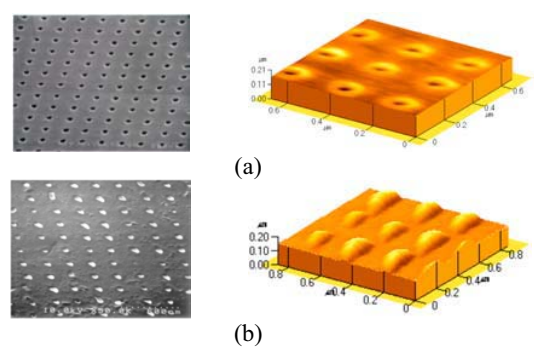
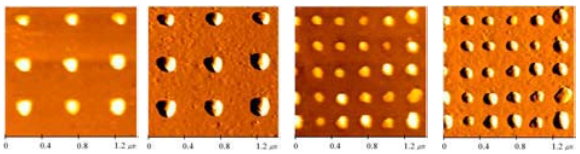


Figure 6: SEM and AFM images of (a) the metallic nano-stampers and (b) the corresponding nano-patterned substrate with a diameter of 100 nm and a pitch of 250 nm



(a) (b)

Figure 7: AFM and MFM images of the magnetic layer with (a) a diameter of 200 nm and a pitch of 500 nm, and (b) a diameter of 100 nm and a pitch of 250 nm on the nano-patterned substrate

thickness were designed for the polymeric nano-patterns with diameters of 200 nm and 100 nm. The Cr underlayer was first deposited on the molded patterns with a thickness of 100 Å, and then the Co magnetic layer was deposited on it with a thickness of 200 Å in an ultra-high vacuum (UHV) system. To evaluate the magnetic characteristics, the Co magnetic layer was saturated along the longitudinal direction of the patterns. The magnetic domain structure was analyzed by magnetic force microscope (MFM). Figure 6 shows AFM and MFM images of the magnetic layer with a diameter of 200 nm and a diameter of 100 nm. Single magnetic domain states were observed on the nano-patterned substrate with a diameter of 200 nm. On the other hand, the pillars with a diameter of 100 nm show multi-domain states, probably due to non-uniform distributions of shapes and sizes of the nano-patterned magnetic pillars.

3 CONCLUSION

In this study, it was showed that our molding process with the metallic nano-stamper could be applied to mass production of patterned media. The master nano-patterns, which contain nanoscale hole and pillar patterns, were fabricated by e-beam and holographic lithography. Electroforming process was followed to make the nickel nano-stapmer, and then the nano-molding was performed to replicate the polymeric nano-patterns. The replication quality of the molded parts was analyzed by SEM and AFM, and these results showed that our replication method could be applied to fabricate the nano-patterned substrate for patterned media. Finally, the magnetic layer was deposited on the nano-patterned substrate; results showed that a single magnetic domain was established on the nano-patterned substrate. However, the molded and magnetic domain states have non-uniform distributions when the pillar diameter is 100 nm. Research on the improvement of replication quality and uniformity of the molded patterns, and on the development of injection molding and UV molding with the metallic nano-stamper are ongoing.

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