Fabrication of Magnetic Nanodots Array Using UV Nanoimprint Lithography and Electrodeposition for High Density Patterned Media

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A Magnetic nanodots array fabrication method using ultraviolet nanoimprint lithography (UV-NIL) and electrodeposition was developed. Since the photocurable resin patterned by UV-NIL was directly used for electrodeposition mask, simple and high throughput fabrication process was realized. The CoPt nanodots (diameter: 120 nm) array was formed after the electrodeposition. After chemical mechanical polishing (CMP), the arithmetic mean roughness ($R_a$) of the track area was smaller than 1 nm.

Keywords: UV nanoimprint lithography, electrodeposition, chemical mechanical polishing, magnetic nanodots array

1. Introduction

For portable electronic devices, compact and large capacity hard disc drives are indispensable. Patterned media is attracting considerable attention as a next-generation magnetic recording media [1-3]. As single magnetic nanodot domain has magnetic anisotropy of opposite direction, which produce 1 bit of data. The patterned media can decrease read/write error compared to conventional multi-crystal magnetic film type media. On the other hand, perpendicular magnetic recording can increase the memory density [3-5]. Some examples of fabrication methods of the magnetic nanodots have been reported including etching of magnetic layer [6], lift-off [6,7], embedding magnetic layer after substrate etching [8,9], and electrodeposition [6,10]. In many cases, these methods have many process steps, because multistep mask patterning/removing processes were requested.

Ultraviolet nanoimprint lithography (UV-NIL) has attracted attention in a nanopattern fabrication technology. This method is expected to replace in some process steps by the conventional nanostructure fabrication method, electron beam lithography and photolithography. For mass production of wafer-level nanostructures, UV-NIL is most cost-effective fabrication methods [11-14]. We developed a UV-NIL technique applied for fabrication of cobalt alloy nanodots array and nanostructures of GaN for high-intensity light-emitting diode [15-17].

In this paper, a fabrication method of a magnetic nanodots array using UV-NIL and electrodeposition is demonstrated. Since the photocurable resin patterned by UV-NIL was directly used for electrodeposition mask, simple and high throughput fabrication process was realized.
2. Experimental

2.1. Device design

The layout of our prototype device is shown in Fig. 1. A CoPt nanodots array is integrated on a track area (diameter: 20.0 mm, width: 150 µm). The track is patterned on a SiO₂ disk substrate (internal diameter: 7.0 mm, external diameter: 27.4 mm, thickness: 0.38 mm). The nanodots array is located in the resin film, and each dot is separated with resin. The diameter of one dot is 100 nm and the pitch is 160 nm.

2.2. Fabrication process

Figure 2 shows the fabrication process of the prototype device. First, Cr/Cu film which becomes a seed layer of electrodeposition was coated by DC sputtering on the SiO₂ substrate (Figure 2(a)). Thicknesses of the Cr and Cu film were 25 nm and 100 nm, respectively. Next, a photocurable resin (TR-21 from Toyo Gosei Co., Ltd.) was spin-coated on the substrate (Figure 2(b)). Thickness of the resin was 90 nm. The UV-cured resin has high durability against the electrodeposition and oxygen dry etching [16]. Then, the nanohole pattern was formed by UV imprinting equipment (ST-50 from Toshiba Machine Co., Ltd.) (Figure 2(c)). The quartz mold fabricated by electron beam lithography was used. The force applied to the mold was 3 kN. UV was irradiated at the wavelength of 365 nm to solidify the resin. In order to remove micro/nano air bubbles, the imprint process was carried out under reduced pressure (30 hPa) [16]. After the mold was released, the residual layer was removed by oxygen reactive ion etching (Figure 2(d)). The etching condition was optimized to reduce the side etching. CoPt was electrodeposited at a constant potential onto the surface of the seed layer (Figure 2(e)), using a rotating disk electrode (RDE) apparatus. Table 1 and Table 2 show the electrodeposition bath composition and the RDE speed, pH, temperature, etc. conditions,
Table 1. Electrodeposition bath composition

<table>
<thead>
<tr>
<th>Composition</th>
<th>Relative proportion (mmol/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diammonium hydrogen citrate</td>
<td>1</td>
</tr>
<tr>
<td>Sodium dodecylsulfate</td>
<td>100</td>
</tr>
<tr>
<td>Cobalt (II) sulfate heptahydrate</td>
<td>100</td>
</tr>
<tr>
<td>Diaminodinitro platinum</td>
<td>100</td>
</tr>
<tr>
<td>Sodium phosphinate monohydrate</td>
<td>0.035</td>
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Table 2. Electrodeposition condition

<table>
<thead>
<tr>
<th>Opposite electrode</th>
<th>Co</th>
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</thead>
<tbody>
<tr>
<td>Reference electrode</td>
<td>Ag/AgCl</td>
</tr>
<tr>
<td>RDE rotation speed</td>
<td>200 rpm</td>
</tr>
<tr>
<td>pH</td>
<td>8</td>
</tr>
<tr>
<td>Bath temperature</td>
<td>30 °C</td>
</tr>
<tr>
<td>Deposition time</td>
<td>1 min</td>
</tr>
<tr>
<td>Deposition potential</td>
<td>-1050 mV (see section 2.3.1)</td>
</tr>
</tbody>
</table>

Table 3. Optimized CMP condition

<table>
<thead>
<tr>
<th>Polishing agent</th>
<th>Glanzox SP-15 : H₂O₂ : H₂O = 1 : 2 : 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.8</td>
</tr>
<tr>
<td>Slurry drip rate</td>
<td>1050 ml/h</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>Table: 75 rpm; Head: 50 rpm</td>
</tr>
<tr>
<td>Applied pressure</td>
<td>610 gf/cm²</td>
</tr>
<tr>
<td>Polishing area</td>
<td>3.36 cm²</td>
</tr>
<tr>
<td>Polishing time</td>
<td>1 min</td>
</tr>
</tbody>
</table>

respectively [18]. Finally, the CoPt nanodots array and the resin surface were planarized by chemical mechanical polishing (CMP) equipment (MA-400D from Musashino Denshi Co., Ltd.). The optimized CMP condition is shown in Table 3. In order to keep properties of the CoPt nanodots, or to prevent from over-polishing the resin, the pH of the polishing agent including slurry (Glanzox SP-15 from Fujimi Inc.) was kept in mild alkaline.

2.3. Characterization of magnetic properties

2.3.1. Coercivity and squareness ratio

In order to optimize the electrodeposition potential, the perpendicular coercivity ($H_c$) and the squareness ratio (SR) of the CoPt were measured by a vibrating sample magnetometer (VSM). In this case, CoPt layer was directly electrodeposited for 5 min on the seed layer without any patterning. The electrodeposition potential was changed from -900 mV to -1500 mV.

2.3.2. MFM observation

The fabricated nanodots array device was magnetized by a VSM. The applied external magnetic field was 15 kOe. The magnetic domains were observed by a magnetic force microscopy (MFM). For the reference, the geometry was also observed by an atomic force microscopy (AFM). In order to observe by AFM, the resin around the nanodots was over-polished.

3. Results and Discussion

3.1. Result of UV nanoimprint

The whole view and the SEM images of the fabricated sample after UV nanoimprint were shown in Figure 3. The mold pattern was successfully replicated over the whole substrate. The failures such as non-filling patterns or collapse patterns after the demolding process were negligible.

3.2. Measurement results of coercivity and squareness ratio

The variation of the perpendicular $H_c$ and the SR with deposition potential was shown in Figure 4. The largest $H_c$ and SR were 2000 Oe and 0.21 at the deposition potential of -1100 mV. It was difficult to obtain large perpendicular SR in the CoPt membrane. It is expected that larger SR can be obtained if the high-aspect CoPt dots are formed.

Figure 5 shows the result of the electrodeposition onto the actual hole pattern under the deposition potential of -1050 mV for 1 min (Table 2). The CoPt nanodots measured from SEM images were 120 nm diameter and 120 nm height.

3.3 Results of the CMP

The whole view and the SEM images of the sample after the CMP process were shown in
Figure 3. Result of UV nanoimprint: (a) whole view, (b) SEM image at the track area, (c) magnified SEM image

Figure 4. Variation of perpendicular coercivity ($H_c$) and squareness ratio (SR) with deposition potential

Figure 5. Result of electrodeposition: (a) whole view, (b) SEM image at the track area, (c) magnified SEM image

Figure 6. The height of the CoPt nanodots measured from the SEM image was 60 nm. Figure 7 shows an AFM image and the profiles as shown in the image (C-D and E-F). The arithmetic mean roughness ($R_a$) and the ten-point average roughness ($R_z$) calculated from the AFM image were shown in Table 4. The whole $R_a$ and $R_z$ were 0.9 nm and 13.5 nm. Both the height of the convex (Figure 7(b)) and the concave (Figure 7(c)) were lower than 10 nm. These results indicate that the track area including the CoPt nanodots array and the resin was successfully planarized.

3.4 Results of the MFM observation

Figure 8 shows an AFM image in the track area and the corresponding MFM image. These figures indicate that the magnetic domains corresponded in position to the nanodots array were formed. However, the correspondence was not perfectly one to one because there were some internal polarizations in the nanodots. Small perpendicular SR causes unstable vertical magnetic flux behavior. The small $SR$ is attributed to the low aspect ratio of the nanodots (~0.5). These horizontally long
nanodots were difficult to be magnetized vertically compared to the in-plane direction. This problem is expected to be overcome by fabricating high aspect ratio (higher than 1) nanodots.

4. Conclusion
This paper describes a novel magnetic nanodots array fabrication method combined UV-NIL with electrodeposition. The CoPt nanodots (diameter: 120 nm) array was successfully fabricated. After CMP, the $R_a$ of the track area was realized within 1 nm. The MFM image indicates that the magnetic domains corresponded in position to the UV-imprinted nanodots array were formed. The method has remarkable advantages in fabrication of the high density patterned media.

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Table 4. Surface roughness from Figure 7

<table>
<thead>
<tr>
<th>Roughness</th>
<th>Whole area</th>
<th>Area 1</th>
<th>Area 2</th>
</tr>
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<tbody>
<tr>
<td>$R_a$ (nm)</td>
<td>0.9</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>$R_z$ (nm)</td>
<td>13.5</td>
<td>7.2</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Figure 7. (a) AFM image in the track area after CMP, (b) a convex profile (C-D), and (c) a concave profile (E-F)

Figure 8. (a) AFM image and (b) the corresponding MFM image of the nanodots array after magnetization
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References