Amorphous Magnetic Film Patterned Media with Columnar Structure

*Advanced Technology Research Laboratories, SHARP CORPORATION, 2613-1 Ichinomoto-cho, Tenri, Nara, 632-8567, Japan
**Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University, 2-1 Yamadagaoka, Suita, Osaka, 565-0871, Japan

Magnetic properties of amorphous TbFeCo magnetic film on periodic nanodot pattern were examined. Cross sectional TEM image revealed the magnetic film deposited on a nanodot pattern with two dimensional periodicity of around 28 nm had columnar structure on the convexity portion. Measured magnetic properties and magnetic force microscope images indicated miniaturization of the magnetic domain attributed to the reduction of magnetic exchange coupling between the columns.

Key words: amorphous magnetic film, patterned media, near-field assisted magnetic recording

1. Introduction

Near-field assisted magnetic recording (NAMR) is proposed to overcome the limitation of magnetic recording density. Magnetic recording media utilized for the NAMR are required to have enough recording resolution, and the patterned media technology which is eagerly examined in the field of magnetic recording is a powerful candidate. When we consider utilizing the patterned media for the NAMR, rare earth-transition metal (RE-TM) ferrimagnetic materials have advantages of high coercive forces ($H_C$) at room temperature, relative low Curie temperatures and ease of magnetic property adjustment by tuning their compositions. However, the difficulty in the RE-TM media is to form minute magnetic domains because of their strong exchange coupling although some investigations revealed that adoption of Al or Pt as a metal under-layer works as pinning site. In this paper, we investigated TbFeCo continuous film with columnar structure fabricated on a periodic nanodot pattern which is easily fabricated by using conventional vacuum equipments. The purpose is to reduce the exchange coupling and to clarify the capability of RE-TM patterned media with area density beyond 1 Tbits/inch².

2. Experiments

Figure 1 shows the sample fabrication procedure of our TbFeCo continuous film patterned media. A nanodot pattern as under-layer for the TbFeCo magnetic film was fabricated on a Si(100) substrate by using reverse sputtering and subsequent reactive ion etching. Before the reverse sputtering, a Ta film was deposited on the substrate holder and the chamber wall, followed by the attachment of the Si(100) substrate. Subsequently, the reverse sputtering was executed in Ar gas atmosphere. Atomic force microscope (AFM) image of the substrate surface after the reverse sputtering showed two dimensional periodic pattern with the

![Fig. 1] Fabrication procedure for the continuous magnetic film patterned media utilizing TbFeCo amorphous magnetic film.

![Fig. 2] AFM image of the fabricated pattern after the reactive ion etching process.
height of 3 to 5 nm and the periodicity around 25 nm.

We consider the nanodot pattern generation is caused by re-deposition and cohesion of the Ta (possibly in the form of Ta silicide) on the Si substrate during the reverse sputtering. Figure 2 shows an example of the AFM image after the reactive ion etching (after the second procedure in Fig. 1). Two dimensional periodicity of around 28 nm was observed from the image and the maximum height of the convexity was 15 nm. Such periodic patterns shown in the Fig. 2 were observed at plural arbitrary points in the 3-inch Si(100) substrate. After the reactive ion etching, a TbFeCo magnetic film with 20 nm-thick (TM-rich composition at room temperature) and a Ta protective film with 80 nm-thick were deposited on the pattern by sputter deposition. Sputtering targets for the TbFeCo and the substrate were located so that the sputtered TbFeCo grains include low incident angle to the substrate plane. This alignment enabled the columnar structure formation only by the sputter deposition onto the nanodot pattern.

3. Results and discussions

Figure 3(a) and 3(b) show cross-sectional transmission electron microscope (TEM) images with low and high magnification, respectively, for the fabricated sample on the pattern. For the TEM sample, AlN protective layer was employed to enhance the contrast of the boundary between the TbFeCo and the protective film. We can see wide range uniformity and high density formation of columnar structure in the Fig. 3(a), and good separation of each TbFeCo in the upper portion of the columns in Fig. 3 (b). The columns were connected each other at the bottom portion with local constrictions. The height of the TbFeCo on the convexity portion, i.e., TbFeCo column was 20 nm and it corresponds to the thickness when the film was deposited on a flat substrate. Diameters of the columns were about 20 nm at the widest position. The TbFeCo thicknesses at the constrictions were 3 to 5 nm.

Figure 4 shows magnetic hysteresis loops for the samples fabricated on the nanodot pattern and on a flat Si(100) substrate (comparative sample), respectively. Both hysteresis loops were measured in the direction perpendicular to the substrate plane. The TbFeCo films and the Ta protective films of both samples were fabricated at a time in the sputtering chamber. The magnetizations of both hysteresis loops were standardized by the M_s of the sample on the flat Si(100) substrate to compare the difference of the values. As shown in Fig. 4, clear two-tier hysteresis loop indicating superposition of two loops with low and high H_c was observed about the sample on the nanodot pattern (black line), and the H_c of the higher one was up to 12 kOe. The squareness ratio (M_r/M_s) was high of 0.91. Compared with the sample on the flat Si(100) substrate (gray line), the M_r was almost the same value. M_r-T measurement for both samples indicated almost the same Curie temperatures of 220 degrees Celsius. These results indicate the increase of H_c by adoption of the nanodot pattern is mainly derived from the reduction of exchange coupling between the columns attributed to the reduction of the contact area, not from the elemental composition difference, oxidization of the
TbFeCo, or change of easy axis direction. The low $H_c$ part of the hysteresis loop is supposed to be mainly derived from the TbFeCo on the concavity and high $H_c$ part is from the TbFeCo columns on the convexity because the TbFeCo on the concavity is widely linked in the space between the columns and magnetic reversal of the local area with relative low $H_c$ induces magnetic reversal of all over the film on the concave. The gradual change of magnetization under high magnetic field more than 5 kOe can be attributed to dispersion of the pattern size and resultant dispersion of $H_c$ of the TbFeCo columns. From these considerations, the results shown in Fig. 4 suggest the possibility of individual magnetic reversal of each TbFeCo column.

Figure 5 shows the magnetic force microscope (MFM) images for the sample on the nanodot pattern after various magnitudes of magnetic filed exposures in the perpendicular direction to the substrate plane. The sample was once magnetically saturated by negative magnetic field of -20 kOe (to the left side of the hysteresis loop in the Fig. 4) and exposed to various positive fields $H_{ext}$ (to the right side of the hysteresis loop in the Fig. 4). The MFM images shown in Fig. 5 were observed after removing the positive magnetic fields. Figure 5(f) shows topographic image for the MFM image shown in Fig. 5(d). The MFM images in the Fig. 5(a) to (e) were not from the exactly same positions on the sample. The Ta protection layer of the sample for the MFM observation was thinned to the thickness of about 20 nm to magnify the signal. Figures 5(a) and 5(b) show the results after magnetic field exposure of $H_{ext}=2$ and 3 kOe, respectively. These magnetic fields are in the hysteresis loop with low $H_c$ as shown in the Fig. 4. After the exposure of 3 kOe (Fig. 5(b)), which is corresponds to the switching field of the sample on the flat Si(100) substrate, we could see considerable degree of magnetic domains remained without reversal (dark region in the image). Figures 5(c) and 5(d) show the results after magnetic field exposure of $H_{ext}=12$ and 16 kOe, respectively. These magnetic fields are in the hysteresis loop with high $H_c$. After the exposure of 12 kOe (Fig. 5(c)), domains with high switching fields more than the $H_{ext}$ (dark regions in the image) were observed. The domains were isolated and some domains had the diameters of less than 60 nm. Even after the exposure of 16 kOe (Fig. 5(d)), some small domains still existed. Small domains observed in the Fig. 5(c) and 5(d) are supposed to be magnetically well separated from surrounding lower $H_c$ region (TbFeCo on the concavity), and the domains are supposed to correspond to the TbFeCo on the convexity portion because the positions of the domains shown in the Fig. 5(d) agree with those of the convexity portions of the topographic image (Fig. 5(f)). Although the observed domain sizes were larger
than those of the columns shown in the Fig. 3(b), we consider the MFM tip radius of 50 nm and the spread of magnetic field in the protective layer can explain the reason. After the exposure of 20 kOe (Fig. 5(e)), the small domains have disappeared and this agrees with the hysteresis loop shown in Fig. 4.

Figure 6 shows the value of magnetic field where hysteresis disappears when the applied field is increased (defined as $H_{\text{sw}}$ in this paper) as a function of applied field angle ($\theta$) from perpendicular direction to the substrate plane. Considering the results shown in the Fig. 5, the value $H_{\text{sw}}$ corresponds to the switching field of a magnetic domain whose switching field is the highest in the sample. Open rhombic marks in the Fig. 6 are the values for the sample on a flat Si(100) substrate, and closed square marks are those for the sample on the nanodot pattern. All the marks are plotted without demagnetizing field correction. Dotted line in the Fig. 6 indicates theoretical domain wall displacement (DW), and solid line indicates that of Stoner-Wohlfarth mode (S-W). The TbFeCo on the flat Si(100) substrate indicated well known domain wall mode like behavior, in contrast, that on the nanodot pattern indicated similar behavior to the Stoner-Wohlfarth mode. This result indicates the well separated small TbFeCo magnetic domains can behave as single domain particle and their switching fields are large enough even when the TbFeCo columnar diameter is less than 25 nm.

4. Conclusions

We confirmed the possibility of high density patterned media using TbFeCo amorphous magnetic film with columnar structure which can be fabricated only by sputter deposition onto the periodic nanodot pattern. Fabricated sample showed wide range uniformity and clear separation of dense columnar structure. Measured magnetic properties indicated the structure enables to hold minute magnetic domain which shows the magnetic reversal mode similar to the Stoner-Wohlfarth mode as well as sufficiently high switching field.

In this paper, we utilized easily fabricable nanodot pattern as under-layer of TbFeCo film as a patterned medium. When we intend to fabricate practical patterned media by using the method we mentioned here, it is required to reduce the size and spacing dispension of the pattern and to align the nanodots along the recording track precisely. We consider a possible way to meet these demands is to introduce physical or chemical template as nucleation site for the nanodot generation.

References


Received May 14, 2009; Revised July 28, 2009; Accepted Aug. 11, 2009