Micromagnetic simulation of wall motion for MAMMOS and DWDD

Yoshinobu Nakatani and Nobuo Hayashi

Department of Computer Science, University of Electro-Communications

1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan

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Abstract- The process of domain transcription and wall motion in magneto-optical recording media for MAMMOS and DWDD is investigated by micromagnetic computer simulation. The result of calculation agrees with experiment semiquantitatively, which shows the effectiveness of the micromagnetic simulation in the development of these devices.

Key Words: magneto-optical recording, MAMMOS, DWDD, micromagnetic simulation

1. Introduction

Recently novel methods such as MAMMOS and DWDD have been proposed for next-generation magneto-optical recording device.^{1,2} In these methods a readout layer is placed on top of the recording layer and fine magnetic domains written in the recording layer are transcribed to the readout layer and expanded. It is necessary to investigate mechanisms of the transcription and expansion of a magnetic domain and the time required for these operations in order to develop these methods. In the present paper mechanisms of domain transcription, motion of domain wall in MAMMOS and DWDD and time necessary for these operations were investigated by micromagnetic simulation.

2. Calculation Model

The MAMMOS simulation was modeled as follows: A readout layer consisting of a 300 Å thick perpendicular anisotropic GdFeCo film was placed above the recording layer with a 250 Å thick spacer placed between them. To make the simulation close to the experiment, experimental values were used for the temperature dependent M_s and K_u , and the coercivity of the readout layer was realized by introducing dispersion into K_u among the computing cells. Detailed time evolution of micromagnetic configurations showing the domain transcription in the readout layer was obtained by solving the Landau-Lifshitz-Gilbert (LLG) equation.³

The simulation of DWDD was modeled as follows. Although the recording medium was composed of three layers, memory, switching and displacement layers, the simulation was performed for the displacement layer

only to investigate the wall displacement mechanism in this layer.

The saturation magnetization was measured between the liquid nitrogen temperature and the Curie point. The anisotropy field was measured at a room temperature, and its temperature dependence was calculated based on molecular-field approximation [4]. The exchange constant was also calculated using molecular-field approximation [4]. The coercive field was measured at 200°C. The dissipation constant α was obtained as $\alpha = 10/M_s$, which was derived from a relation $\alpha = \lambda/\gamma M_s$ on the assumption that λ is independent of temperature and that α is 0.1 at $M_s = 100 \text{ emu/cm}^3$. The gyromagnetic ratio was assumed to be $\gamma = -1.76 \times 10^7 \text{ rad/(s·Oe)}$, independent of temperature. The motion of magnetic moments in the displacement layer was solved by the LLG equation to investigate the wall motion in this layer.

In both simulations the anisotropy constant was dispersed among the calculation points according to the Gaussian distribution in order to realize coercivity of several ten to several hundred Oe.

3. Calculation Results

1. MAMMOS

The thickness of the readout layer was chosen to be 200 Å. The recording layer was 2000 Å thick. The spacing between these layers was 250 Å. The shape of the recorded domain was a crescent defined by two circles of the same size with their centers shifted to each other. The diameter of a circle and the distance between the neighboring centers stand for the size and the width of the domain in the present paper. The calculation region was composed of 128×128 cubes of which size was 100 Å. The temperature distribution calculated separately was taken into account, and the material constants at each calculation cell were determined from the temperature distribution.

Figure 1 shows the change in the size of the transcribed domain with time obtained from calculation using a recorded domain whose size and width are 0.7 μm and 0.15 μm, respectively. The figure shows that domain transcription occurs when the laser beam power is larger than 1.6 mW. The time necessary for transcription decreases as the laser power is increased. It is about 1.5 ns at 2.0 mW laser power. The figure

Fig. 1. Change in transcribed area with time.

also shows the cases when a bias field of 200 Oe was applied. It can be seen that the transcription time is decreased and the transcribed area is increased by the application of a bias field.

Fig. 2 shows the change in the transcribed domain in the readout layer when laser power is 1.8 mW. The crescent shaped region in Fig. 2(a) represents the recorded domain. The white area is the transcribed domain. We see from the figure that the domain transcription starts in the region above the concave side of the crescent (Fig. 2(b)). This is due to the inplane component of the stray field from the recorded domain which reaches a maximum in this region. The torque acting the magnetic moment becomes maximum in this region. It can also be seen that the transcription does not occur coherently but starts at several regions. In the present calculation the anisotropy constant is made to vary cell by cell in order to realize coercivity. The domain transcription starts at regions with smaller anisotropy constant. The transcribed domain spreads toward the edges of the crescent and then expands to a region a little wider than the recorded domain area. The transcribed domain finally expands to a region where there is not a recorded domain. This is due to the effective field by thermal gradient which pushes the wall of the transcribed domain in the wane portion of the crescent toward the center of the heated region.

Fig. 3 shows the transcription process when a bias field of 200 Oe was applied. By comparing with Fig. 2 showing the case with no bias field, we see the followings: There are more nucleation sites. The transcribed domain expands much faster. The final size of the transcribed domain is larger than that of the recorded domain, which is because the transcribed domain expands mainly toward the wane portion of the crescent.

Fig. 4 shows the effect of laser power on the area of the transcribed domain. The result obtained using a bias field of 200 Oe is also shown. It can be seen from the figure that the domain transcription occurs abruptly when the laser power exceeds a threshold from which the area increases almost linearly with respect

Fig. 2. Change in transcribed domain in readout layer with 1.8 mW laser power (center portion).

to the laser power increment.

Fig. 3. Change in transcribed domain in readout layer with 1.8 mW laser power and 200 Oe of bias field(center portion).

The velocity of the wall of the transcribed domain

Fig. 4. Dependence of laser beam power on copied domain area.

Fig. 5. Wall velocity of expanding domain.

was derived from the change in the domain area with time. The minimum size of a domain necessary for read out was assumed to be about 60 % of the spot of the laser beam, and the wall velocity was obtained from the time taken by the transcribed domain to reach that size. The result is shown in Fig. 5. The figure shows that the wall velocity increases with increasing laser power and that it is in a range from 100 to 280 m/s.

Fig. 6. Effect of off-centered laser beam on domain transcription (converged state).

Fig. 7. Transcribed domain in case with off-centered laser beam.

Calculation was also made to investigate the change in the area of the transcribed domain when the laser beam center was shifted from the center of the circle defining the outer curve of the crescent. Fig. 6 shows the results obtained for three cases of laser power, 1.6, 1.8 and 2.0 mW. The figure shows that the area of the transcribed domain increases gradually as the laser beam center approaches the area center from the left side and that the domain transcription is suppressed when the beam center moves to the right side of the area center.

Fig. 7 shows the transcription process with laser

Fig. 8. Displacement of wall center at every 2 ns.

power of 1.8 mW when the laser-beam center was shifted from the center of the circle which defines the left side curve of the crescent. When the laser beam is shifted to the left largely, the transcription occurs only in the region above the central portion of the crescent, and the domain fails to reach the edges of the crescent. This is due to the high-temperature state which is limited to the central portion of the domain. Thus transcription takes place in this region only. The figure also shows that the area of the transcribed domain increases as the laser beam is shifted toward the recorded domain, but that transcription ceases to take place when the beam is shifted 1500 Å to the right of the circle center.

2. DWDD

The thickness of the medium was chosen to be 300 Å, the width of the calculation region in the direction parallel to the track was 1.28 μm, and the region parallel to the track width was 0.45 μm. The size of a calculation cell was 100 × 100 × 300 Å. A Bloch wall was placed at the center of the displacement layer. The domain displacement caused by temperature distribution by laser beam was investigated. The speed of the medium was chosen to be 1.5 m/s, and the maximum temperature in the medium due to the laser beam was assumed to be 225°. In the wall displacement detection scheme the wall was considered to begin to displace at a position where the switching layer reached the Curie temperature (150°). Therefore the center of the laser beam was placed 4300 Å ahead of the wall so that the medium temperature became 150° at the initial wall position. As the peak temperature point is about 1000 Å behind the center of the laser beam, the wall is to stop after displacing about 5300 Å.

Fig. 8 shows the change in the locus of wall center with time. We see that the shape of the moving wall is not a straight line but curved in the track direction. This is considered to be due to the temperature gradient which is largest at the track center decreasing gradually toward the track edges. Thus the effec-

Fig. 9. Change in wall center position with time.

Fig. 10. Effect of track width on wall velocity (The peak temperature in the medium is varied).

tive driving field acting at the wall becomes smaller at the track edges than at the track center, which is considered to be the reason for the simulated uneven displacement of the wall.

Because this effect is expected to be enhanced as the track width is increased, wall motion was simulated while varying the track width. The result is shown in Fig. 9 for the cases with track width of 150, 300, 450 and 600 nm. We see from the figure that it takes more time, and hence wall velocity decreases, as the track width is increased.

Fig. 10 shows the average wall velocity obtained from the amount of wall displacement and the time taken for the wall to displace. The figure also shows the average wall velocity when the maximum temperature in the medium was varied. The velocity is seen to increase almost linearly as the track width is decreased. It is also seen that the wall velocity increases with increasing maximum medium temperature, independent of track width.

Fig. 11 shows the wall velocity calculated while varying the moving speed of the medium. It is seen from the figure that the wall velocity increases as the speed of the medium is increased. The wall velocity is the more accelerated with decreasing track width.

Fig. 11. Effect of track width on wall velocity (The moving speed of the medium was varied).

Fig. 12. Wall displacement in case with laser beam detracking (200 nm detracking and 600 nm trackwidth).

If the temperature gradient across the track affects the wall velocity, detracking of the laser beam should also affect the wall motion through the temperature gradient along the track width. Thus we investigated the change in the wall velocity when the laser beam becomes off the track. Fig. 12 shows the result of the calculation. The figure shows that the wall moves with a large curvature.

Fig. 13 shows the change in wall velocity affected by detracking. We see from the figure that detracking decreases wall velocity. The velocity decreases more when the track width is narrow. When the amount of detracking is within 50 nm, the decrease in the wall velocity is less than 3 % in the worst case, and hence laser beam detracking is almost effectless.

Finally we investigated the effect of ruggedness which might appear in the track edge at the time of track formation. The result of calculation concerning the relation between track width and wall velocity showed that wall moved faster when track width was narrow. The effect of the ruggedness in the track edge, however, is expected to increase when track width is decreased. Thus calculation was carried out with both ruggedness and width of the track taken into consid-

Fig. 13. Wall velocity vs track width (effect of detracking).

Fig. 14. Wall velocity vs track width (effect of rugged edge).

eration. The ruggedness in the track edge was represented by the absence of a square region with a side of 10 nm or 20 nm. The result of calculation is shown in Fig. 14.

The figure shows that the wall velocity decreases slightly with ruggedness of 10 nm and that the wall is pinned down when ruggedness is 20 nm. This can be explained as follows. The surface wall energy σ exerts a driving force

$$\frac{\partial \sigma}{\partial x}$$

to the wall whereas the increase dw in the track width w yields an effective force

$$\frac{\sigma}{w} \frac{\partial w}{\partial x}$$

which tends to hinder wall motion. dw means the increase in the wall area and hence extra wall energy, which prevents a wall from displacing. Even when $\partial w / \partial x$ is the same, σ / w increases with decreasing w , and hence the wall-hindering force is increased. Thus the effect of rugged edge increases as the track width is decreased.

4. Conclusion

Micromagnetic simulation was performed to investigate the expansion of a transcribed domain and the motion of domain wall for MAMMOS and DWDD which had been proposed as candidates for next-generation magneto-optical recording schemes.

In the MAMMOS simulation, the effect of laser beam power on the area of the transcribed domain, and the wall velocity associated with domain transcription were investigated. It was found that the domain transcription completed in several nano second and that the wall velocity was in the range from 200 to 300 m/s. The change in the transcribed domain area was also investigated when the laser beam was shifted.

It was found in the simulation of DWDD that the wall velocity was affected by the temperature distribution in the track width direction. The velocity was shown to increase with the decrease in the track width. Although the wall velocity was seen to be affected by the detracking of the laser beam, the velocity hardly decreased when the amount of detracking was less than 500 Å. The wall velocity in DWDD was found to be in the order of several ten m/s under the condition of the calculation performed presently.

The results of these calculations agree with experiment semiquantitatively. It is believed that micromagnetic simulation is useful for developing these magneto-optical recording devices.

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