Magnetization Process of Heat Assisted Magnetic Recording by Micro-magnetic Simulation

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Abstract. Magnetization reversal in a uniform magnetic field and one bit recording process by a thin film head in the heat assisted magnetic recording system of TbFeCo medium are studied by using the micro-magnetic simulation and the heat equation. The Landau-Lifsitz-Gilbert equation is solved for magnetic parameters at temperatures as the time goes by. It is found that magnetization proceeds as a progressive wave, although this behaviour may not limit the recording speed. The recording bit is expanded by the thermal fluctuation. The expansion can be suppressed as the medium thickness increases, because the thermal fluctuation is small in the thick medium. So the control of the medium thickness is important very much to achieve a high-density heat-assisted recording.

1. Introduction
The heat-assisted magnetic recording (HAMR) has been expected as a next generation magnetic recording systems capable of high density and high speed. When the recording density becomes high and the bit size becomes small, thermal fluctuation degrades the recorded bit even at the room temperature. Although high coercive media may solve this problem, it is difficult to record a small bit by a conventional magnetic head. HAMR has been proposed to solve this problem [1]. However, the feasibility of the HAMR is not clear yet. A thermal process may limit the recording speed. And there is an effect of the thermal fluctuation on the recorded bit because of high temperature and low coercive force during the recording process.

In this paper, the magnetization process is studied by using the micro-magnetic simulation in order to study a feasibility of the HAMR system.

2. Calculation method
Magnetization processes are simulated by solving the Landau-Lifshitz-Gilbert (LLG) equation in the recording medium, as given by

\[ \frac{dM}{dt} = -\gamma [M \times H_{\text{eff}}] + \alpha [M \times (dM / dt)] / M_s \]

where \( M \) is the magnetization, \( \gamma \) is the gyro-magnetic ratio, \( H_{\text{eff}} \) is the effective field, and \( M_s \) is the saturation magnetization. \( H_{\text{ex}}, H_k \) and \( H_d \) are the exchange field, anisotropic field, and demagnetization field of the medium, respectively. \( H_{\text{out}} \) is the external uniform reversal magnetic field and the recording field at a frequency of 400 MHz calculated by the 3D dynamic magnetic moment (DMM) method for a thin film head [2] according as the study on magnetization reversal and one bit recording process. The thermal fluctuation is considered by introducing the thermal field that is based on the
fluctuation dissipation theorem of Langevin [3].

The amorphous TbFeCo medium has dimensions of 900 nm x 800 nm x 10 nm, which is divided into 10nm³ cubic cells. The damping constant, $\alpha$, is set to be 0.03.

A near field laser of gaussian beam was supposed in the HAMR simulation as the irradiated devise. A laser beam pulse of 100 nm is irradiated for 100 ps at a moment when the external magnetic field is applied. The temperature of the beam center is set to be 120 – 170 C. Temperature of each cell at that instance is calculated by the heat equation. The density, the heat capacity and the thermal conductivity of the medium are set to be 8.1 g/cm³, 0.37 Jg⁻¹deg⁻¹ and 0.2 Jcm⁻¹deg⁻¹s⁻¹, respectively. The ambient temperature is 25 C and the heat transfer coefficient is $2.5 \times 10^{-3}$ Jcm⁻²deg⁻¹s⁻¹. Medium properties and their temperature dependences of experimental results [4] are used for the micro-magnetic simulation. Anisotropic magnetic field $H_k$, exchange stiffness $A$ and saturation magnetization $M_s$ are $4.4 \times 10^4$ Oe, $1 \times 10^7$ erg/cm and 35 G, respectively at room temperature. After assigning the values to Landau-Lifshitz-Gilbert (LLG) equation, the magnetization of the medium is calculated.

3. Results and discussion
3.1 Magnetization reversal in uniform magnetic field

Figures 1 and 2 show the process of magnetization reversal in a uniform magnetic field of 10 kOe. In these cases, the damping factor, $\alpha$, of the medium is supposed to be 0.03. At first, magnetization reversal starts at a center of the spot irradiated by the laser beam where the temperature is high and the coercive force is low. The reversal region gradually increases within about 80 ps after start of the laser irradiation. The reversal region spreads outwards monotonically. However, the magnetization swings back at some rings. The magnetization reverses with a distribution such as a progressive wave, which

![Fig.1 Magnetization reversal during the laser beam irradiation (\(\alpha = 0.03\)).](image1)

![Fig.2 Magnetization reversal after the laser beam irradiation (\(\alpha = 0.03\)).](image2)
proceeds less than about 200 ps, although the laser beam stops at 100 ps.

Although the magnetic recording speed may be restricted by the oscillation, the recording process is completed in several hundreds pico-seconds, which corresponds to the recording frequency of several GHz. It can be understood that this anomalous behavior is caused by the natural resonance. Figures 3 and 4 show magnetization reversal process for medium of a damping factor, $\alpha$, 0.30 and 0.00, respectively. When the damping parameter is high enough, the wave does not appear.

3.2 One bit recording process
The one bit recording processes are simulated for various temperatures of the laser beam. Figure 5 shows the recording processes (a) without thermal fluctuation and (b) with thermal fluctuation at 140 C. The color bar shows the perpendicular component of the magnetization value. After irradiation, the magnetization goes on rapidly and reaches the final state. At any time of the magnetization process, the bit size is expanded by the thermal fluctuation, although only two stages of the magnetization states (at 150 ps and final) are typically shown in the figure.

Figure 6 shows that the final size of the recorded bit is expanded about 1.1 - 1.6 times large by the thermal fluctuation. Here, the magnifying factor is defined as area ratio. The tendency is independent on the beam diameter $D$, although $D$ is 200 nm in this case. The magnifying power depends on the random number used for the calculation of the thermal field. As the temperature increases, the power becomes small.

Figure 7 shows magnetization processes around the beam center. The magnetization begins to rotate in the opposite magnetic field as the temperature is increased by an irradiation. If the temperature rise is not sufficient to reverse, the magnetization returns back to the original direction. However, the thermal fluctuation increases a chance to reverse the magnetization. So the magnetization size becomes large by the thermal fluctuation.

It can be understood that the fluctuation increases the bit size. It is known that the thermal fluctuation is small in the thick medium. Figure 8 shows the thickness dependence of the magnifying
power. The expansion is suppressed about 10% as the medium thickness increases from 10 to 39 nm. So the thickness control is important very much, to achieve a high-density recording.

References
[1] H. Saga, H. Nemoto, H. Sukeda and M. Takahashi, *J. Appl. Phys.*, 38 (1999) 1839.
[2] K. Shiiki, *Journal of Magnetism and Magnetic Materials*, 316 (2007) 195.
[3] H. N. Bertram and Q. Peng, *IEEE Trans. Magn.*, 34 (1998) 349.
[4] M. Hasegawa, Meeting of the Magnetics Society of Japan *MAG91-26*, (1991) 49.