Journal of Magnetism and Magnetic Materials 320 (2008) 2917–2920

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

3-D FEM analysis of thermal degradation in writing and reading characteristics of a perpendicular magnetic head

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ARTICLE INFO

Available online 3 August 2008

PACS:
75.50.Ss
02.70.Dc
85.70.Kh

Keywords:
Perpendicular magnetic recording
Stoner–Wohlfarth particle
Thermal degradation
Finite element method

ABSTRACT

In order to achieve high-density recording, the detailed behavior of thermal degradation should be investigated. In this paper, the degradation of magnetization of high-density recording medium is examined using the 3-D finite element method (FEM) combined with the modeling of Stoner–Wohlfarth (SW) particles and Neel–Arrhenius switching probability. It is shown that the anisotropy field H_k suppressed the thermal degradation and the saturation magnetization M_s enhances it. The thermal degradation is also changed by the amplitude of magnetization.

1. Introduction

Thermal degradation is a problem for the high-density recording medium. Although the simulation of writing and reading characteristics using the 3-D finite element method (FEM) combined with the modeling of Stoner–Wohlfarth (SW) particles has been carried out [1,2], the analysis of thermal degradation of recorded magnetization seems rare.

In this paper, we introduce the Neel–Arrhenius switching probability in the 3-D simulation system, and applied it to the analysis of writing and reading characteristics of a cusp-field-single-pole-type (CF-SPT) head considering its thermal degradation. The effect of recording density and medium parameters on thermal degradation is examined.

2. Simulation of writing and reading characteristics using the 3-D FEM combined with the modeling of SW particles

We use the following fundamental equation to carry out the writing and reading simulation, in which the unknown variable is vector potential A:

$$\mathrm{rot}\,(\nu\,\mathrm{rot}\,\boldsymbol{A} =)\boldsymbol{J}_0 + \nu_0\,\mathrm{rot}\,\boldsymbol{M} \tag{1}$$

where $\boldsymbol{J}_0$ is the current density, ν is the reluctivity and $\boldsymbol{M}$ is the magnetization. $\boldsymbol{M}$ is calculated by the model of SW particles [1].

In the writing process, the current in the coil is substituted for $\boldsymbol{J}_0$ of Eq. (1) to calculate the magnetization of medium [1]. In the reading process, the magnetization pattern that is calculated in the writing process is substituted for $\boldsymbol{M}$ to calculate the output at each position of the medium.

When the magnetic field $\boldsymbol{H}$ is applied, all the energy of SW particles at absolute zero is denoted by the following equation:

$$E = K_u V\{\sin^2\theta - 2h\cos(\alpha - \theta)\} \tag{2}$$

where K_u is the anisotropic energy constant, V is the volume of a magnetic grain, θ is the angle from the magnetic easy axis of the magnetic moment, α is the angle between the applied magnetic field and the magnetic easy axis and h is the magnetic field that is normalized by the anisotropic magnetic field H_k ($h \equiv H/H_k$). If the energy is equal to minimum values E_1 or E_2, the magnetization direction becomes stable.

3. Extension of the SW particle model to the finite temperature

At absolute zero, the magnetization direction of an SW particle does not reverse. However, at a finite temperature, the magnetization can be reversed by the thermal energy. The probability that the energy of an SW particle climbs over the energy barrier E_b and the magnetization direction reverses is calculated by the Neel–Arrhenius switching probability. The possibility of the existence of $P_1(t)$ and $P_2(t)$ at an assigned instant t is shown by the following

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doi:10.1016/j.jmmm.2008.08.001

equation:

$$P_1(t) = P_1(\mathrm{eq}) + \{P_1(0) - P_1(\mathrm{eq})\}\exp\left(-\frac{t}{\tau}\right) \quad (3)$$

$$P_2(t) = P_2(\mathrm{eq}) + \{P_2(0) - P_2(\mathrm{eq})\}\exp\left(-\frac{t}{\tau}\right) \quad (4)$$

where $P_1(\mathrm{eq})$ and $P_2(\mathrm{eq})$ are the possibilities of the existence at a thermally equilibrium state, $P_1(0)$ and $P_2(0)$ are the possibilities at $t = 0$ (initial value), and τ is the relaxation time shown by the following equation:

$$\frac{1}{\tau} = w_{1\to 2} + w_{2\to 1} \quad (5)$$

$$w_{1\to 2} = f_0 \exp\left\{-\frac{(E_\mathrm{b} - E_1)}{k_\mathrm{B}T}\right\} \quad (6)$$

$$w_{2\to 1} = f_0 \exp\left\{-\frac{(E_\mathrm{b} - E_2)}{k_\mathrm{B}T}\right\} \quad (7)$$

where k_B is the Boltzmann constant, T is the temperature of the medium and f_0 is the attempt frequency. E_1 and E_2 are the minimum values, and E_b is the maximum value of Eq. (2).

Using these possibilities as a record of SW particles, we can analyze the thermal degradation of magnetization.

4. Analysis model

Fig. 1 shows a $\frac{1}{2}$ region of the CF-SPT head [3] model. Fig. 2 shows a $\frac{1}{2}$ region of the magnetoresistive (MR) head model. The write current is DC 0.1AT.

The saturation flux densities of the main pole, shield and soft underlayer are 2.4 T. The recording density of the medium is 200 or 600 Gbit/in^2. The characteristic of each medium is shown in Table 1. H_c, H_k, M_s, V and $K_\mathrm{u}V/k_\mathrm{B}T$ are the switching field, anisotropic field, saturation magnetization, volume of a magnetic particle and thermal coefficient, respectively. The discrete track medium is used. The track width is 70 nm and the groove width is 15 nm. In this paper, the effect of medium parameter on thermal degradation is examined. Therefore, the track pitch was assumed as 85 nm for the 200 and 600 Gbit/in^2. The attempt frequency f_0 of the Neel–Arrhenius switching probability is assumed as 1 GHz.

Fig. 3 shows the M–H loops of the media. The black loop indicates the relation of the external field and magnetization in the medium. The gray loop indicates the relationship between the magnetic field in the medium and magnetization. These figures denote that the external field and the magnetic field in the medium are different. In the FEM analysis, such a magnetic field in the medium (gray loop) can be taken into account. The maximum write field at the medium is 1.3 T.

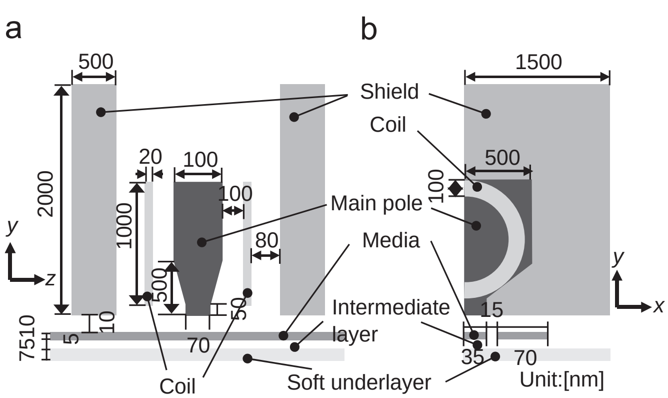

Fig. 1. CF-SPT head model that is used for writing the medium: (a) front view (z–y); (b) side view (x–y).

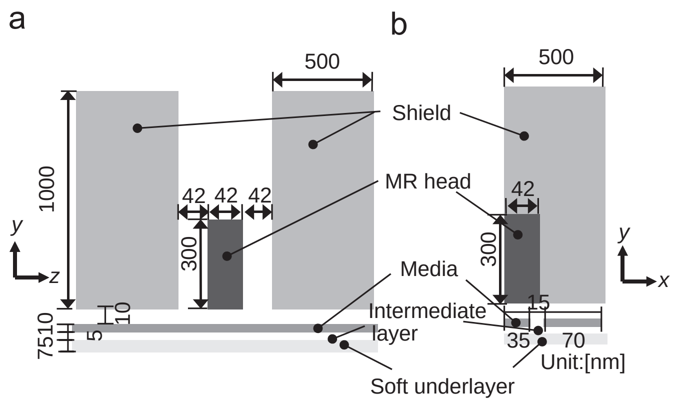

Fig. 2. MR head model that is used for reading: (a) front view (z–y); (b) side view (x–y).

Table 1
Characteristics of media

	200 Gbit/in^2	600 Gbit/in^2
H_c (Oe)	8200	8000
H_k (Oe)	14,700	17,500
M_s (emu/cm^3)	300	600
V (m^3)	1.56×10^{-24}	4.70×10^{-25}
$K_\mathrm{u}V/k_\mathrm{B}T$ (298.15(K))	83.7	60

The data are shown by storage research consortium (SRC) 14th Meeting, R/W Division (2002) and SRC 20th Meeting (2005).

5. Results and discussion

5.1. Effect of recording density

Fig. 4 shows the change of output (the summation of the y-component of flux on the ABS of MR sensor) with time. Fig. 5 shows the degradation of magnetization. The initial state of the medium is AC demagnetized. The energies of the 200 and the 600 Gbit/in^2 are different ($T = 298.15$ K constant). The figure shows that the thermal degradation of the 600 Gbit/in^2 medium is more remarkable than that of the 200 Gbit/in^2 one. This means that smaller grains are more susceptible to thermal degradation.

5.2. Effect of volume of magnetic particle

Even if the medium energy $K_\mathrm{u}V/k_\mathrm{B}T$ is the same, the degradation speed will be affected by the parameters of the medium.

Fig. 6 shows the change of output with time at the same medium energy ($K_\mathrm{u}V/k_\mathrm{B}T = 60$). The temperature T of the medium is changed to fit the same $K_\mathrm{u}V/k_\mathrm{B}T$. The volume V of 200 Gbit/in^2 is 1.12×10^{-24} m^3 and that of 600 Gbit/in^2 is 4.70×10^{-25} m^3. The reason for the slower thermal degradation of the medium for 200 Gbit/in^2 at the time range between 1E−2 and 1E4 s is that the magnetization at this time range is larger than that for between 1E4 and 1E10 s. The figure denotes that the parameters, such as V of the medium, affect the degradation. M_s and H_k are different in the two media, and this is responsible for the difference in degradation speed. This fact suggests that the degradation speed is not decided by only the thermal coefficient $K_\mathrm{u}V/k_\mathrm{B}T$.