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Heating Mode Effect on Perpendicular Magnetic Recording

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ABSTRACT: Micromagnetic simulation study has been conducted on the perpendicular material ferromagnetic $Pt_xMn_ySb_z$ by completing Landau-Lifshift Gilbert equation. Choosen ferromagnetic material has some parameters such as anisotropy constant as large as 4.5×10^5 erg/cm^3, magnetic saturation of 2100 G, Curie temperature of 373 K, and finite-dimension of $50\times50\times10$ nm^3. The use of perpendicular anisotropy media with appropriate properties value are intended to increase the storage capacity of the hard disk without ignoring its thermal stabilty. At writing information, ferromagnetic material is induced by magnetic field for reversing the direction of magnetization and all at once also heated by thermal pulse which was designed matches closely the reality. To examine thermal fluctuation effects, twenty random number for magnetization was adopted in calculation and probability of magnetization reversal was introduced for determining the theshold field. Evaluation of reversal mechanism has been done for the variations of temperature of 299.0-372.9 K. Heating exceeds 368.0 K capable to lowering the threshold field up to 90 % through the declining of energy barrier. Investigation also has done for some heating interval i.e. 62.5-1000.0 ps on the temperature which approaches to Curie temperature. As a result, in a span of heating were yielded that reversal field required for reversing the direction of magnetization is only about 250-300 Oe.

KEYWORDS: HAMR, perpendicular magnetic anisotropy, magnetization, threshold field, reversal probability, threshold field.

1 INTRODUCTION

Before 20th Century, the Magnetic Recording (LMR) technology has dominated the storage technology on Hard Disk Drive (HDD) [1]. LMR uses Longitudinal Magnetic Anisotropy (LMA). Although once dominated, but since 2005 to 2009 there had been decreasing consumers of HDD with LMR technology. Just as shown in Figure 1, the reason is that it has limited storage capacity [2].

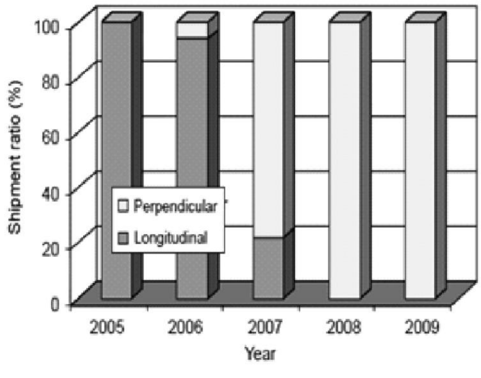

Fig. 1. The comparison of shipping ratio changes for HDD per year between perpendicular and longitudinal technology

The storage capacity is determined from how small unit cell needed to store a bit of information. It means that the size of storage media should be reduced to nano size to realize a hard disk with a bigger capacity. But when the size of memory cell units are reduced into nano order, it result problem on thermal stability [3], that is the magnetization tendency to change direction spontaneously even in room temperature, thus hindering the data recording process. To tackle this problem, it needs Perpendicular Magnetic Anisotropy (PMA) that has a large magnetic anisotropy so that the magnetization bearing will be more stable even though in room temperature [4]. As it grows, 2006 has become a new era for industry of Perpendicular Magnetic Recording (PMR) that using PMA as storage media [5]. The use of this technology gives hope to bring in the storage media with capacity in Tbit/in^2 level [6], [7].

However, the use of PMA as a recording media with PMR technology still remains a critical issue, namely the need for a large current field in an attempt of PMA magnetization reversal as a result of the strong magnetic anisotropy materials [8]. One promising solution to solve the problem is by adding heat in the process of reversal magnetization then cooled rapidly to "freeze" the written information or called as Heat Assisted Magnetization Reversal (HAMR) [9], [10]. The process of writing data on TAMR technology uses laser to help raise the temperature of the media to a certain temperature [11].

In order to study the mechanism of heat-assisted reversal magnetization, a quantitative study is needed to understand the relationship between microstructure with magnetic properties in nano-sized materials with the help of numerical and computational techniques [6]. This technique, in a lot of thought, has received many praises as one of the foremost experimental tools in order to understand the mechanism of magnetization reversal which defines the performance of nano-sized materials in accordance with the fact [6]. The purpose of this research is to study numerically the influence of thermal field, both high temperature and duration of the heating towards the required field reversal with micromagnetic simulator.

2 METHODOLOGY

Magnetization reversal behavior on the perpendicular anisotropy nano-dot magnetic materials is investigated by solving the equation of Landau-Lifshiftz Gilbert [12]:

$$\frac{d\mathbf{M}}{dt} = -\frac{\gamma}{1+\alpha^2}\mathbf{M}\times\mathbf{H}_{eff} - \frac{\alpha\lambda}{(1+\alpha^2)M_s}\mathbf{M}\times\left(\mathbf{M}\times\mathbf{H}_{eff}\right) \tag{1}$$

With M as the magnetization vector, M_s as the saturation of magnetization, α is the constant of gilbert muffle (0.3), γ is the gyromagnetic ratio as much as 1,76×10^7 oe^{-1}.s^{-1} and $\mathbf{H}_{eff}$ is the effective field. On Equation (2), $\mathbf{H}_{eff}$ is the vector resultant of anisotropy field ($\mathbf{H}_k$), magneto-static field ($\mathbf{H}_M$), interaction exchange field ($\mathbf{H}_{ex}$), external field ($\mathbf{H}_{ext}$), and stochastic random field ($\mathbf{H}_T$) [13].

$$\mathbf{H}_{eff} = \mathbf{H}_k + \mathbf{H}_M + \mathbf{H}_{ex} + \mathbf{H}_{ext} + \mathbf{H}_T \tag{2}$$

The influence of temperature towards the constant behavior can be formulated in Equation (3) [14].

$$A(T) = A(0)\left(\frac{M_s(T)}{M_s(0)}\right)^2 \tag{3}$$

Consecutively, the dependency of magnetization and anisotropy constant on temperature related to magnetization changes is expressed as follows [15]:

$$M_s(T) = M_s(0)\sqrt{\left(1-\frac{T}{T_c}\right)} \tag{4}$$

$$K_\perp(T) = K_\perp(0)\left(\frac{M_s(\mathrm{T})}{M_s(0)}\right)^2 \tag{5}$$

With is the $K_\perp$perpendicular anisotropy constant and T_c is the Curie temperature. The total fluctuation field with zero temperature and assumed in Gaussian distribution with amplitude expressed through dissipation-fluctuation theorem just as seen on Equation (6-8) [15].

$$\left\langle H_T^i(t)\right\rangle = 0 \tag{6}$$

$$\left\langle H_T^i(t)H_T^j(t)\right\rangle = \delta_{ij}\delta\left(t-t'\right)\sigma^2 \tag{7}$$

$$\sigma = \sqrt{\frac{2k_B T\alpha}{\gamma V M_s \Delta t}} \quad (8)$$

With $\delta(t)$ is the dirac delta function, δ_{ij} is the Kronecker delta, indexes i and j are component vectors, k_B is the Bolltzman constant, Δt is the time difference (0.25×10^{-12}s),and V is the volume of nano-dot.

Perpendicular anisotropy material used as model in this research is $Pt_xMn_ySb_z$ with magnetic parameter $K_\perp = (3,0-4,8)\times10^5$ erg/cm^{3}and $4\pi M_s$=2100 G [16]. Dimension nano-dot from $Pt_xMn_ySb_z$ is a square field with 50×50 nm^2 size and has thickness of 10 cm with Curie temperature is 373 K.

In the framework of understanding the influence of heat, either the temperature level of writing (T_w) towards the extent of reversal field, simulation scheme designed to approach the heat pulse shape and the external magnetic field exactly as shown in Figure 2.

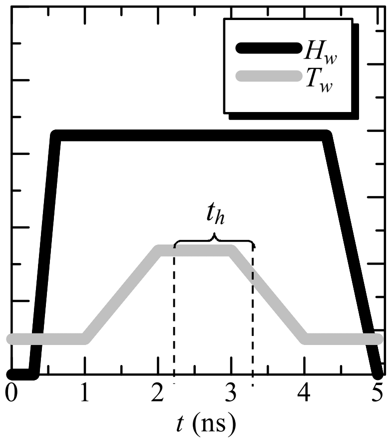

Fig. 2. Magnetization of heat-assisted reversal micromagnetic simulation scheme

As for evaluating the influence of fluctuations due to temperature, the inverter field was calculated for 20 different series of random numbers. The minimum so that the inverter field reversal of opportunities to 20 the number of 1 are known as threshold field (H_{th}), which can be associated with the reversal field.

3 RESULT AND DISCUSSION

3.1 REVERSAL MAGNETIZATION ON HIGH TEMPERATURE

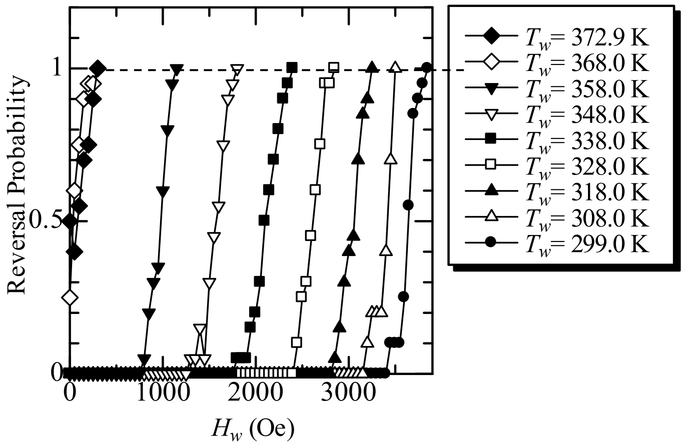

Fig. 3. The likelihood of magnetization reversal against the inductive field on $K_{\perp}$= 4.5×10^5 erg/cm^3, 4πM$_s$=2100 G with several variances of temperature of writing (T_w)

Figure 3 shows the nano-dot magnetization reversal probability from $Pt_xMn_ySb_z$. The increasing of temperature level of writing will add the nano-dot magnetization reversal probability. When the temperature at below 385 K where the field of writing has not been given, there are no likelihood of nano-dot magnetization reversal and this probability appears when the temperature of writing approaches curie temperature. This indicates an increase in writing temperature also affects on the increasing of magnetization reversal probability even with no help from external field.

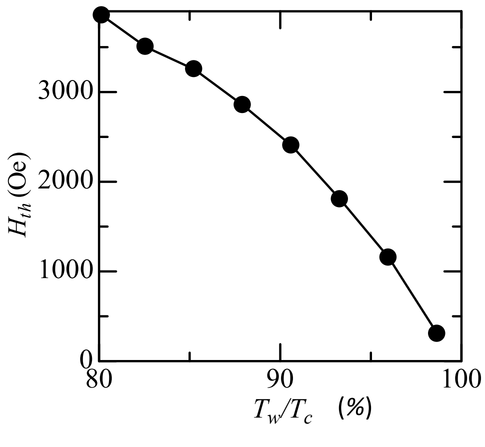

Fig. 4. The profile of threshold field towards the temperature on $K_{\perp}$= 4.5×10^5 erg/cm^3, 4πM$_s$=2100 G , and T_w=298.0–372.9 K

Figure 4 shows the influence of temperature against threshold field. The increasing of writing temperature can decrease threshold field extremely up to 90% and start saturating when writing temperature approaching its curie temperature. This can be understood from Figure 5 that illustrates the decrease in the amount of barrier energy when added temperature. As the barrier energy decreases caused by the increasing of reversal field, the needed writing field becomes so small so that it is as the solution for the limited writing field on harddisk head of which technically the resulted maximum field as much as 17 kOe [17].

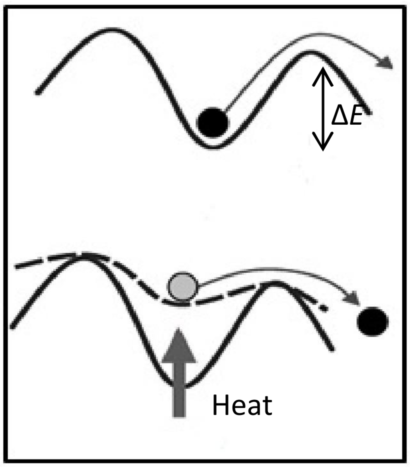

Fig. 5. The mechanism of barrier energy barrier decreases caused by the effect of heat addition (a). barrier energy without the help of heat, (b) barrier energy during heating process

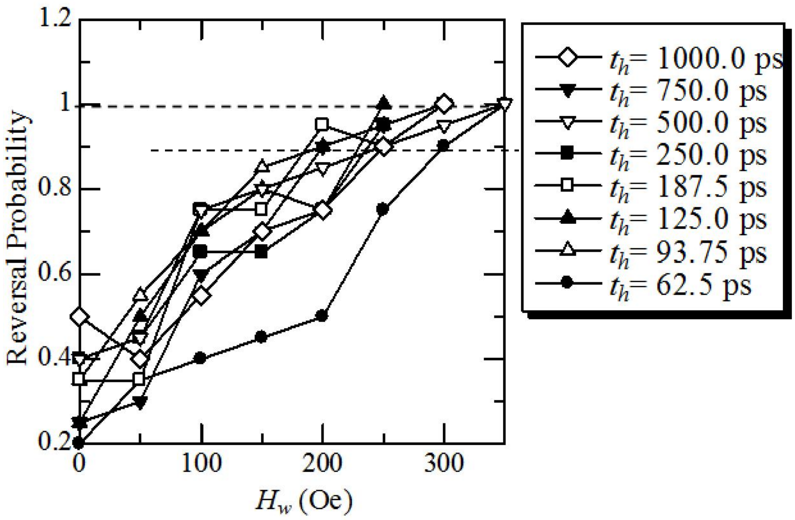

Fig. 6. Profile of H_w against the likelihood of reversal towards $K_{\perp}$= 4.5×10^5 erg/cm^3, 4πM_s =2100 G on variances of heating time (t_h)

In numeric study of heat-influencing mechanism on materials with several variances of perpendicular anisotropy ferromagnetic heating, simulation has been conducted with of heating time (t_h). Figure 6 shows the probability of nano-dot magnetization reversal on some diversity of heating time. It can be seen that the length of heating influences the probability of nano-dot magnetization reversal when there is no reversal field. The increasing of writing field has affected on the probability of nano-dot magnetization reversal. The extent of effective reversal field to make probability of reversal into 1 is around 250–300 Oe. When the heating time is more than 97.3 ps and has not been given a reversal field, there has been a chance of reversal.

Figure 7 represents the relationship between the size of threshold field needed for some heating time. Variant of heating time does not affect much on the threshold field. This information can be seen on the curve that tends to be constant more or less 300 Oe threshold field.

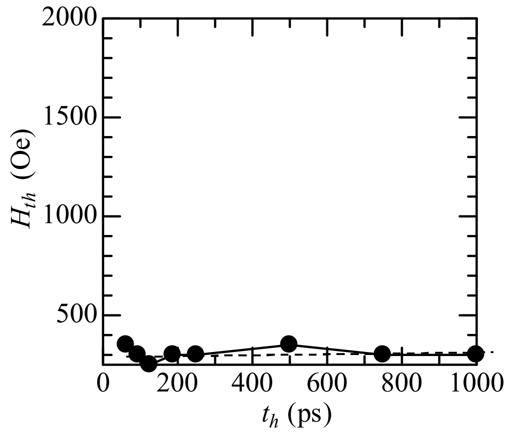

Fig. 7. Profile of $t_{heating}$ towards H_{tw} in a temperature variant for $K_{\perp}$= 4.5×10^5 erg/cm^3 and 4πM_s =2100 G value

4 CONCLUSION

Has done a micromagnetic simulation of thermal field effect, both high temperature and duration of warming of the necessary reversal of field. This can be concluded from the micromagnetic simulation of heat assisted magnetization reversal in ferromagnetic materials with perpendicular anisotropy for the value of $K_{\perp}$= 4.5×10^5 erg/cm^3 and 4πM_s =2100 G on curie temperature heat-up to range of heating 62.5−1000.0 ps effectively capable of lowering the field author until the range 300 Oe or 500% under the maximum field which is capable of being produced by the hard disk head writer at this time.

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