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Contributed Paper

Characteristic of Nano-barium-ferrite as Recording Media Using HAMR Technology

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ABSTRACT

Micromagnetic study using Barium-ferrite has been performed with the magnetic parameters such as saturated magnetization 4800 Gauss, Gilbert damping 0.8, and exchange constant 6.3×10^{-7} erg/cm^3. This research is performed to investigate the characteristics of optimum magnetic anisotropy of Barium-ferrite as HDD media using HAMR technology. Barium-ferrite is chosen to be evaluated because of its strong magnetic anisotropy which potentially used as high-density storage media. The researched magnetic anisotropy of the material has a range of $(1.0\text{-}4.5)\times10^6$ erg/cm^3 which performed using two schemes, which are RBW and MRDP schemes. RBW scheme is used to investigate the appropriate anisotropy material to be used as HDD media. The feasibility of anisotropy to use is observed from the thermal stability level, shown by the value of energy barrier which is higher than 70 k_BT. On the other hand, MRDP scheme is used to estimate the required magnitude of the writing magnetic field to reverse the magnetization of the material when being stimulated with the thermal field. It is found that Barium-ferrite with magnetic anisotropy ranging from $(1.00\text{-}3.75)\times10^6$ erg/cm^3 has excellent thermal stability, suitable to be used as HDD media. Moreover, hundreds Oersted of magnetic field induction can be used to reverse the bit magnetization.

Keywords: micromagnetic, magnetic anisotropy, HAMR, nano-dot, Barium-ferrite

1. INTRODUCTION

Hard Disk Drive (HDD) storage media will have wide storage capacity if 1 bit of information is able to be stored in a tiny area in nanometer level. However, usage of the tiny area in storing the bit causes thermal stability problem. Magnetic polarization would be unstable in the tiny region. To overcome this instability, usage of materials with high magnetic anisotropy is needed to ensure that the magnetic orientation lies on preferred direction. Bit storage in the tiny unit is able to realize if magnetic media has strong magnetic anisotropy [1]. This characteristic is a property of a magnetic material with perpendicular anisotropy. Magnetic recording technology which uses perpendicular magnetic anisotropy media is known as Perpendicular Magnetic Recording (PMR) technology. PMR technology has tiny storage unit compared to Longitudinal Magnetic Recording (LMR) technology [2]. The arising problem in PMR technology is the high magnetic anisotropy of the used media and that it has a direct impact on the high writing magnetic field-a field used to control the magnetic polarization [3]. A suggested method to reduce the magnitude of this writing magnetic field is by applying thermal stimulus. Technology which utilizes thermal field in stimulating magnetization process is known as Heat Assisted Magnetic Recording (HAMR). HAMR technology uses two kinds of field pulses in data writing, which are magnetic field and thermal field pulse [4]. A number of previous researchers have proved that applying thermal field has successfully decreased the writing field [5]. Using HAMR technology, HDD recording media with a capacity larger than 1 Tb/in^2 is able to realize [6].

In this study, material characteristic investigated is Barium-ferrite. Barium-ferrite is chosen because of its potential as HDD media material with high capacity. The advantage of Barium-ferrite is its high magnetic anisotropy [7, 8]. With high anisotropy, Barium-ferrite will have good thermal stability despite being formed in tiny and compact size; therefore, it will be appropriate as HDD material. Moreover, this material also has strong mechanic structure and stable chemical structure [9]. Barium-ferrite compound is not easily corroded; therefore, it will ensure its durability in long term use.

Characteristics of Barium-ferrite in HDD application are being further researched using micromagnetic simulation study. This simulation study is performed to examine the characteristics of Barium-ferrite with optimum anisotropy to be applied in HAMR technology.

2. MATERIALS AND METHODS

In this simulation [10], Barium-ferrite is being modeled in the form of a block with an area of 50×50 nm^2 and thickness of 20 nm. This model is called as nano-dot and used one-bit information storage. This nano-dot consists of 15×15 unit cells which each dimension is $3.3 \times 3.3 \times 20$ nm^3. Each unit cell has one magnetic moment which the direction is perpendicular to its surface. This nano-dot size is chosen to realize HDD with areal density ~ 250 $Gbit/inch^2$.

Magnetization reversal behavior of nano-Barium-ferrite is examined by solving Equation (1) which is known as Landau-Lifshiftz-Gilbert equation [11].

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma \mathbf{M} \times \mathbf{H}_{eff} + \frac{\alpha}{M} \mathbf{M} \times \frac{\partial \mathbf{M}}{\partial t} \quad (1)$$

with $\mathbf{M}$ is magnetization vector, $\mathbf{H}_{eff}$ is an effective field, α is Gilbert damping constant, γ is a gyromagnetic ratio, that is 1.76×10^7 $oe^{-1}.s^{-1}$, and M is saturated magnetization. $\mathbf{H}_{eff}$ is vector resultant of anisotropy field ($\mathbf{H}_k$), magnetostatic field ($\mathbf{H}_M$), exchange field ($\mathbf{H}_{ex}$), and external magnetic field ($\mathbf{H}_{ext}$) as shown in Equation (2) [11].

$$\mathbf{H}_{eff} = \mathbf{H}_k + \mathbf{H}_M + \mathbf{H}_{ex} + \mathbf{H}_{ext} \quad (2)$$

The chosen magnetic parameters to represent Barium-ferrite characteristics are saturated magnetization ($4\pi M_s$) = 4800 Gauss, Gilbert damping (α) = 0.8, and exchange constant (A_{ex} = 6.3×10^{-7} erg/cm^3) with various magnetic anisotropy constants (K_u) in the range of (1.0-4.5) $\times 10^6$ erg/cm^3 [12].

Two schemes are used in this simulation which are Reduced Barrier Writing (RBW) and Magnetization Reversal using Double Pulses (MRDP), as what has been performed previously by Nur Aji Wibowo, *et al.* [13]. In the RBW scheme, nano-dot is conditioned at ambient temperature, 298 K and being induced by a magnetic field which magnitude increases linearly from 0 to 2 Tesla in the time range of 2.5 ns. Simulation using MRDP scheme utilizes magnetic field pulse of the inducer (H_w) and thermal pulse (T_w) in controlling the direction of magnetization. These two pulses increase linearly from 0 Tesla and 298 K for H_w and T_w consecutively until it reaches a particular value, is constant in that value for a moment, and then decreases linearly to its initial value. The entire process lasts for 5 ns with integrated steps 0.25 ps. To accommodate thermal contribution in the micromagnetic system, the thermal field is calculated as a random field vector, $\mathbf{H}_T$, which added to the $\mathbf{H}_{eff}$ in Equation (2) as a complement for four previously mentioned field terms. The zero mean value was calculated for thermal field contribution during magnetic switching, $\langle H_T^i(t) = 0 \rangle$. Gaussian model which was assumed to represent the thermal field distribution as followed $\langle H_T^i(t) H_T^j(t') \rangle = \delta_{ij}\delta(t - t')A^2$, where A given by the fluctuation-dissipation theorem $A = \sqrt{2k_B T\alpha/\gamma V M_s \Delta t}$, with k_B for Boltzmann constant. The distribution of thermal field contributes to the decrease of the energy barrier, ΔE, which is the minimum energy required by field inducer for nano-dot inducing process [14]. For MRDP scheme, nano-dot was locally heated which the heat distribution is uniform over its region. 373 K temperature was set up as its Curie point. Heating process has been assumed that temperature of nano-dot increase linearly from ambient temperature to 372.9 K (just below its Curie point) for 1 ns. Then the nano-dot was temporarily heated for 0.25 ps at 372.9 K before its temperature downgraded linearly to ambient temperature for 0.75 ps.

3. RESULT AND DISCUSSION

3.1 Reduced Barrier Writing (RBW)

Figure 1 shows the dependence of the energy barrier to the magnetic anisotropy of the material. It can be seen that the stronger the magnetic anisotropy, the higher energy barrier should be overcome to reverse the direction of nano-dot's magnetization. Magnetic anisotropy of material refers to the bond of magnetic orientation with crystal lattice structure of a material [11]. Therefore, the result achieved is in line with hypothesis stating that for high magnetic anisotropy, magnetic orientation is actually preferred to the specific orientation that depends on the crystal structure. This strong tendency effect on the magnitude of energy required to release the bond and redirect the magnetic orientation to be in line with the induced magnetic field. When $K_\perp$ as large as 4.0×10^6 erg/cm^3 and 4.5×10^6 erg/cm^3, Barium-ferrite has not yet responded to magnetic field exposure by forming energy barrier. This indicates that the induced magnetic field configuration gave has not yet been able to release the magnetic bond from the crystal lattice.

An HDD can be said to have good thermal stability and be able to last for 10 years if the energy barrier magnitude is larger than 70 k_BT. From Figure 1, it can be seen that the energy barrier formed in Barium-ferrite material is larger than 70 k_BT. This indicates that Barium-ferrite has good thermal stability; therefore, it is feasible for HDD media.

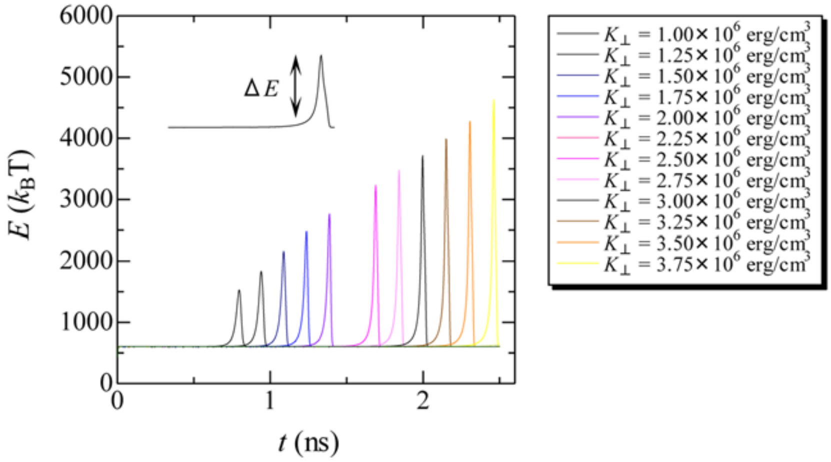

Figure 1. Energy profile of Barium-ferrite while being induced by the magnetic field in RBW scheme for several magnetic anisotropy.

However, the high energy barrier which appears inside Barium-ferrite causes consequences on the magnitude of coercive field, H_c. Coercive field is an induced magnetic field required to reverse half of the total magnetization of the material to be parallel with its orientation [15]. As shown by Figure 2, coercive field increases along with the amplification of the magnetic anisotropy. In the magnetic anisotropy values range taken, the coercive field is in the range of 6000-19000 Oe. The material is not feasible for magnetic storage media if its coercivity larger than 10000 Oe. This large coercivity value is lacking for writing field application because the writing field that surpasses 17000 Oe is not projected [16]. Thus, to decrease the magnitude of this coercive field, magnetization reversal has to be stimulated with the thermal field. The use of the thermal field in this magnetization reversal will be studied using micromagnetic simulation with MRDP scheme.

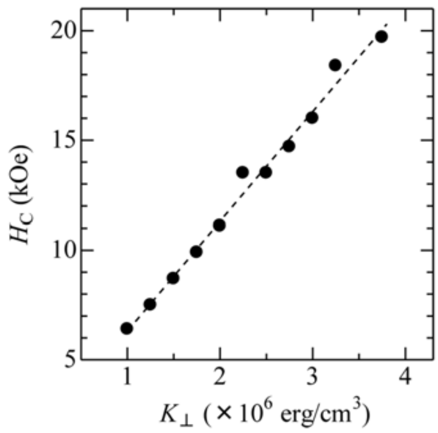

Figure 2. Profile of magnetic anisotropy dependence of coercive field.

3.2 Magnetization Reversal using Double Pulses (MRDP)

Magnetic anisotropy from the chosen Barium-ferrite for simulation using MRDP scheme is 3.75×10^6 erg/cm^3. This value is chosen because of its high energy barrier with good thermal stability level. By locally heating Barium-ferrite nano-dot until its temperature increases near its Curie temperature, and in the same time, being induced by constant magnetic field, the probability of magnetization reversal as a function of magnetic field of the inducer is obtained. The dependence of the reversal probability to the magnetic field magnitude of the inducer is shown by Figure 3. This probability value increases along with the increasing induced magnetic field. The probability value will reach the value of one when nano-dot magnetization has been reversed in line with an induced magnetic field for over twenty taken random values. The magnetic field which perfectly reverses this magnetization is known as Threshold field (H_{th}). In HAMR application, the threshold field represents the writing magnetic field. To perfectly align the direction of the magnetization to the induced magnetic field, threshold field with the value of 450 Oe is required; a smaller number compared to a coercive field owned by the material in ambient temperature.

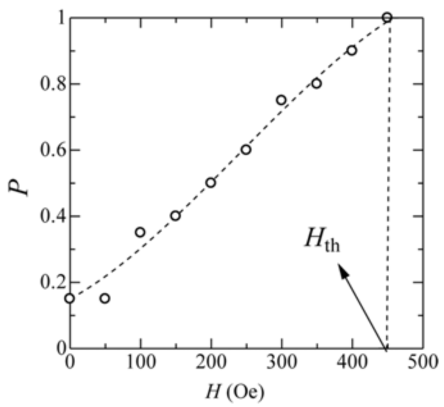

Figure 3. Increasing reversal probability as a function of the induced magnetic field in MRDP scheme.

Figure 4 shows the dynamics of magnetization reversal of Barium-ferrite with magnetic anisotropy value 3.75×10^6 erg/cm^3 under the influence of magnetic field pulse and thermal pulse in MRDP scheme. In the first 2 ns, the direction of the magnetization is stable and has not yet shown any response to the induced magnetic field. However, when the thermal pulse is given, that is after 2 ns, the magnetization direction of the material quickly changes and becomes random for a moment when the thermal pulse temperature reaches its peak. This randomness of the magnetization direction is shown by the value of M_x/M_{sat} which is around 0. After 2.4 ns, the temperature is being lowered into ambient temperature. In the process of cooling, material's magnetization starts to reverse its magnetization direction and is perfectly in line with the induced magnetic field when the temperature has reached the ambient temperature. At this time, information is being stored.

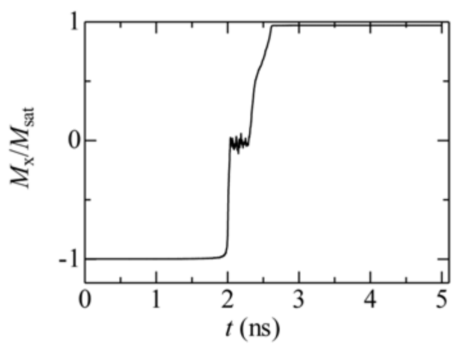

Figure 4. Normalization value of Barium-ferrite magnetization with magnetic anisotropy 3.75×10^6 erg/cm^3 under the influence of magnetic field and thermal pulse in MRDP scheme.

Figure 5 visualizes micromagnetic configuration of Barium-ferrite in RBW and MRDP scheme. Magnetization reversal pattern from both simulation schemes is significantly different. Magnetization reversal using RBW scheme starts with the domain wall forming in the center, then propagates into four corners. On the other hand, magnetization reversal using MRDP scheme starts with the forming of irregular multi-domain. This irregularity of the formed domain indicates the randomness of the magnetization direction of the material, which is caused by the distribution of thermal stimulus near its Curie temperature. Domain wall starts to nucleate when nano-dot starts to being cooled. This domain wall shifts into nano-dot corners and disappears when the material is in the thermal equilibrium condition with the environment.

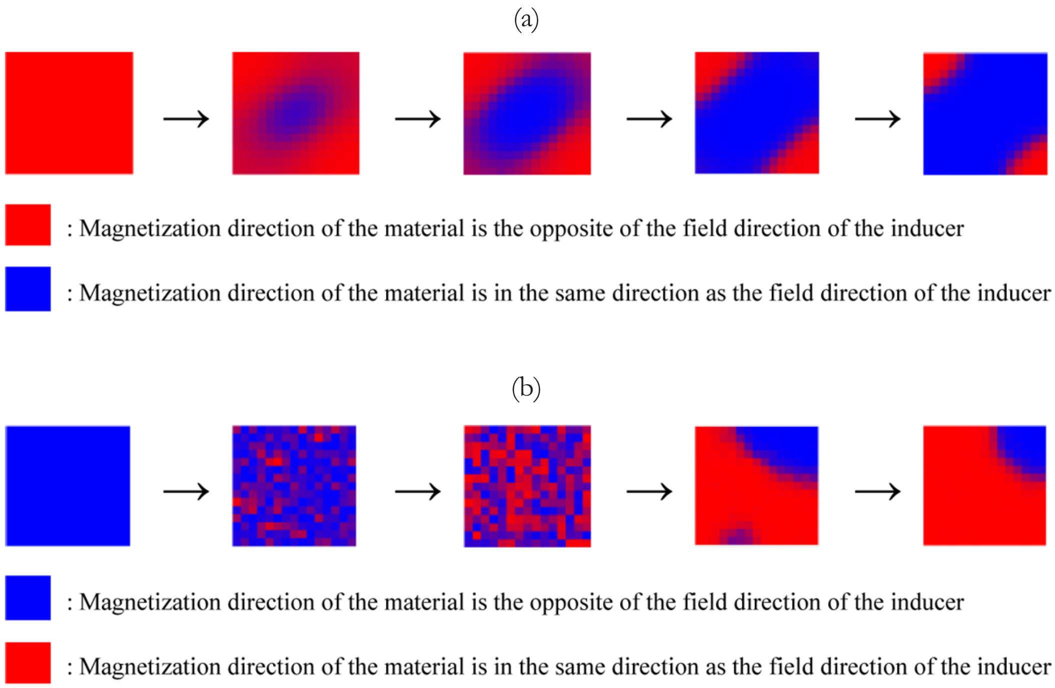

Figure 5. Visualization of magnetization reversal mechanism of Barium-ferrite material with magnetic anisotropy 3.75×10^{6} erg/cm^{3} (a) using RBW scheme, (b) using MRDP scheme.

4. Conclusion

Micromagnetic simulation study of Barium-ferrite has been performed using two simulation schemes which are RBW and MRDP for HDD application with HAMR technology. Has been found that Barium-ferrite ferromagnetic material with a range of magnetic anisotropy of $(1.00\text{-}3.75)\times10^{6}$ erg/cm^{3} is appropriate to use as HDD media with HAMR technology. In that range, Barium-ferrite had high thermal stability with the magnetic energy barrier for about 900-4000 k_BT. The value of the writing magnetic field was only in hundreds of Oersted for the highest magnetic anisotropy. This low writing magnetic field was significantly caused by the distribution of thermal pulse with the temperature near Currie temperature through the mechanism of random magnetization.

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