Magnetic Hysteresis Modeling in Perpendicular Toggle-MRAM System for Scalability Cell Technology

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Abstract — This paper presents a micromagnetic analysis of the new MRAM system for high Gb/Chip. Conventional MRAM has weak points to realize high capacity in the design structure of the cell, one of which is that using simple current injection system can generate only weak switching field. In order to solve the problem, we propose the new MRAM system that has two additional poles in this paper. Proposed MRAM has a strong switching field owing to two poles added on both sides of the free layer, just like perpendicular magnetic recording heads on the hard disk drive system. For stronger switching field, proposed MRAM is optimized by changing shape. In this paper, analysis of the switching field and useful designs for high GB/Chip are presented. This approach reduces computing time and gives more precise results because the result of 2 dimensional Preisach model becomes an initial values of 3 dimensional micromagnetics. And vectorial magnetization with time dependent magnetization could be also included in this model.

I. Introduction

Conventional (toggle) MRAM has unlimited read/write endurance but has a low capacity than flash technology. Partly because conventional MRAM has a faulty structure using a simple write current injection system.

A lot of work has been done for the commercialization of submicrometer MRAM in recent years. A low-power 1–Mb MRAM with copper interconnects and cladding layer, and about 35 ns access and cycle times tested in the previous work show the potential of this technology[2]. A new multibit MRAM cell of toggle switching type has been reported[3] and also, a heat interaction investigation in thermally assisted MRAM has been reported[4].

In this paper we presents a new technology that has advantages conventional MRAM on injected current and cell size. It is pole type perpendicular MRAM (PTP MRAM). PTP MRAM uses perpendicular magnetic field in order to change the state of the free layer in a perpendicular magnetic tunnel junction (pMTJ) [5]. PTP MRAM uses two high permeability poles on both sides of the free layer in order to enhance switching field. Switching field of conventional MRAM generated by injected current is equally distributed on the space but most of the filed in PTP MRAM has downsize scalability and is expected to be utilized usefully as a commercial memory with high capacity for having the enhanced switching field. Also PTP MRAM solves thermally assisted self-demagnetizing problem because this system is able to use high coercivity free layer.

We show results that are variation of a switching filed owing to two poles added on both sides of the free layer by thickness of the free layer and cell square size, injected current density. So we present an optimization design of PTP MRAM for high Gb/Chip. This research was done using three dimensional FEM with injected current density of $8\times10^{7}\,\mathrm{A}/cm^{2}$ ~ $6\times10^{8}\,\mathrm{A}/cm^{2}$. In this paper, new efficient algorithm to combine two models are presented and tested. This approach reduces computing time and gives more precise results because the result of 2 dimensional Preisach model becomes an initial values of 3 dimensional micromagnetics. And vectorial magnetization with time dependent magnetization could be also included in this model.

II. Switching Field on The PTP MRAM System

Partly because conventional MRAM has a faulty structure using a simple write current injection system, conventional MRAM has a weak switching field. Figure 3 shows switching field of MRAM and PTP MRAM with direct current. Fig 1 (a) shows uniform field distribution so that has a weak switching field but (b) shows saturated field distribution for high permeability poles. Therefore PTP MRAM has a very strong switching field in order to change magnetization of free layer.

For the analysis of a devices with magnetic material, it is necessary to include a magnetic hysteresis phenomena. According to the size of magnetic particles in the devices, a micromagnetics modeling or Preisach modeling has been adopted for the analysis of a magnetic hysteresis. In small size devices with sub-micro sized magnetic particles, a micromagnetics are composed with well defined equations. Although it gives a fine results, a real experimental results show a little discrepancy with measurement data because of inter-particle interactions in real size devices. Preisach

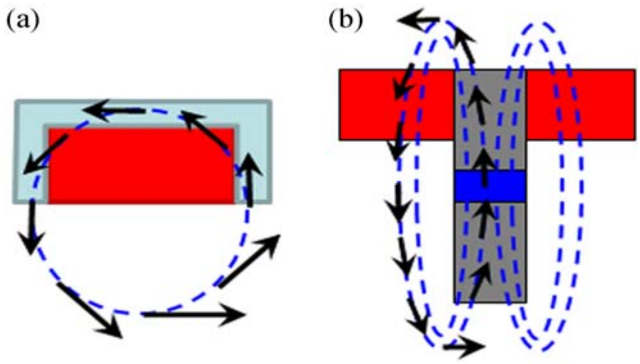


Fig. 1 Comparison of magnetic field intensity on the center of the free layer of PTP MRAM and conventional MRAM with direct current (a) Distribution of magnetic field intensity of conventional MRAM. (b) Distribution of magnetic field intensity of PTP MRAM.

model could include all thes interactions, but it is hard to express vector magnetization and timely dependent variations of magnetization. In this paper, new efficient algorithm to combine two models are presented and tested.

III. RESULTS AND DISCUSS

To gain the same results have to match the two material conditions for using combined method. We have used new method in order to match the two material properties. First, it is defined anisotropy constant and exchange constant, from which the major curve is calculated. Second, we calculated Preisach plane density for match the curve.

Preisach plane density is that has a gaussian distribution so simply using a gauss function to defined the material properties can be. Equation (1) ~(3) to defined the material properties will be used.

$$\begin{cases} \alpha = \max\left[f\left(x,y,s,\theta_{mi},\theta_c\right) = \dfrac{1}{2\pi\theta_{mi}\theta_c} e^{-\left(\frac{(x-s)^2}{2\theta_{mi}^2}+\frac{(y-s)^2}{2\theta_c^2}\right)} \right] \\ \beta = \max\left[f\left(x,y,s,\theta_{pi},\theta_c\right) = \dfrac{1}{2\pi\theta_{pi}\theta_c} e^{-\left(\frac{(x-s)^2}{2\theta_{pi}^2}+\frac{(y-s)^2}{2\theta_c^2}\right)} \right] \end{cases} \quad (1)$$

$$R_{\alpha\beta} = \alpha / \beta \quad (2)$$

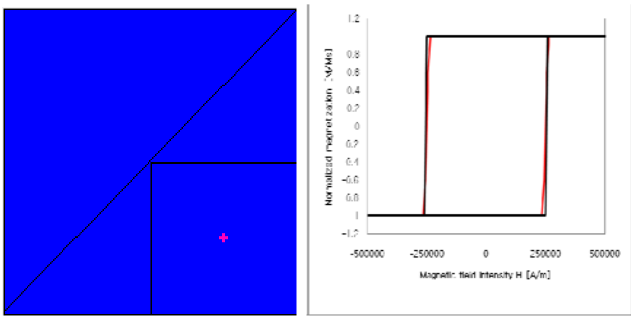
$$\begin{cases} f\left(x,y,s,\theta_{mi},\theta_c\right) = \dfrac{1}{2\pi\theta_{mi}\theta_c} e^{-\left(\frac{(x-s)^2}{2\theta_{mi}^2}+\frac{(y-s)^2}{2\theta_c^2}\right)} \\ f\left(x,y,s,\theta_{pi},\theta_c\right) = \dfrac{1}{2\pi\theta_{pi}\theta_c} e^{-\left(\frac{(x-s)^2}{2\theta_{pi}^2}+\frac{(y-s)^2}{2\theta_c^2}\right)} * R_{\alpha\beta} \end{cases} \quad (3)$$

Fig. 2 (a) shows Preisach plane with defined the ferromagnetic materials like the exchange constant 5e-13 [J/m] and anisotropy constant 2.33e4 [J/m^3]. Fig. 3 (b) is described that the two major curves can see the consistency of material properties. By the defined material properties, this paper is gained results shown in fig.3 could be obtained very consistent results with micromagnetics model and Preisach model.

Fig. 4 analysis of the two models is shown by the magnetization changes. As a result, the two values are very consistent, both models seem to conclude that the same results can be obtained. In addition, each element Preisach model to obtain the change in the magnetic hysteresis and micro-magnetic switch in accordance with the time change in magnetization can be obtained. As a result, two models are the interaction of this complete.

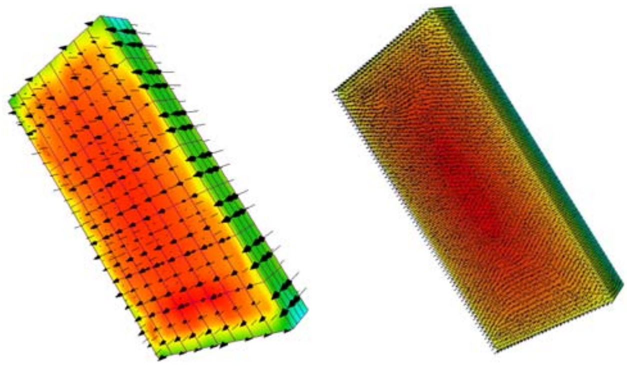
IV. CONCLUSION

This approach reduces computing time and gives more precise results because the result of 2 dimensional Preisach model becomes an initial values of 3 dimensional micromagnetics. And vectorial magnetization with the time dependent magnetization could be also included in this model.



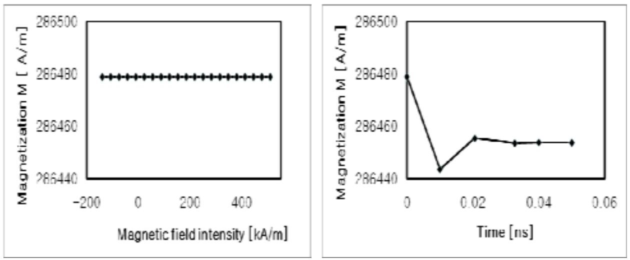
(a) (b)

Fig. 2 Distributed Preisach density and compared two model by M-H hysteresis curves. (a) Preisach plane density (b) compared M-H curves (exchange constant: 5e-13 [J/m], anisotropy constant: 2.33e4 [J/m^3])



(a) (b)

Fig. 3 Results of the two model analysis after magnetizing. (a) Preisach model. (b) micromagnetics model.



(a) (b)

Fig. 4 Change magnetization on the magnetizing process. . (a) Preisach model. (b) micromagnetics model.

V. REFERENCES

[1] Brad N. Engel, Nicholas D. Rizzo, Jason Janesky, Jon M. Slaughter, Renu Dave, Mark DeHerrera, Mark Durlam and Saied Tehrani, “The Science and Technology of Magnetoresistive Tunneling Memory”, IEEE Trans. Nonotech., Vol. 1, No. 1, March 2002.

[2] Kochan Ju, “A Novel Dual-Bit MRAM Cell”, IEEE Trans. Mag., Vol. 42, No. 10, October 2006.

[3] Kochan Ju and Oletta Allegranza, “Multibit Cells Schemes for Toggle MRAM Applications”, IEEE Trans. Mag., Vol. 42, No. 10, October 2006.

[4] Z. Y. Liu, G. C. Han and Y. K. Zheng, “A Heat Interaction Investigation in Thermally Assisted MRAM”, IEEE Trans. Mag., Vol. 42, No. 10, October 2006.

[5] Naoki Nishimura, Tadahiko Hirai, Akio Koganei, Takashi Ikeda, Kazuhisa Okano, Yoshinobu Sekiguchi, and Yoshiyuki Osada, “Magnetic tunnel junction device with perpendicular magnetization films for high-density magnetic random access memory”, J.Appl, Phys., vol.91, Apr. 2002.