International Journal of
Science and Engineering Investigations
vol. 2, issue 16, May 2013
ISSN: 2251-8843

Gilbert Damping Effect on Thermally Assisted Magnetization Reversal of Perpendicular Magnetized Nano-Dot

Wahyu Natalis Handayani[1], Andreas Setiawan[2], Nur Aji Wibowo[3]
[1,2,3]Faculty of Science and Mathematic, Satya Wacana Christian University, Indonesia
([1]192009014@student.uksw.edu, [2]andreas.setiawan@staff.uksw.edu, [3]nur.aji@staff.uksw.edu, [3]nurajiwibowo@gmail.com)

Abstract- Gilbert damping effect on thermally assisted magnetization reversal of perpendicular magnetized nano-dot has been investigated by completing Landau - Liftshitz Gilbert equation. Using of perpendicular magnetic anisotropy, as realization of sizable capacities necessity, has to be compensated with amount of magnetic field that required reversing nano-dot magnetization. Applying of heat has been suggested to reduce this switching field. Variation of Gilbert damping for different values of anisotropy constant with equal saturation magnetization at room temperature have impact to amount of energy barrier, reversal field as well as magnetization rate. Heating at Curie temperature which followed by cooling abruptly until it reaches room temperature has succeeded to lowering reversal magnetic field size up to ~ 90%. Other important conclusion that reversal field could be reduced by Gilbert damping increament.

Keywords- *nano-dot, Gilbert damping, thermally assisted, probability, reversal field.*

I. INTRODUCTION

Computerize technologies requirement is one of demands on this fast-paced era, but still considering for accuracy in workmanship and efficiency in data storage. So many specification of computer's today, one consideration is computer data storage capacity. It is addressed to answer the advance of technology in all fields that require a lot of data that must be stored. Read-write technology which based on magnetic recording media and promising a non-volatile memory with better capacity, speed and resistance were introduced. This technology utilizes Perpendicular Magnetic Recording (PMR) which using Perpendicular Magnetic Anisotropy (PMA) as its media. PMR compiling magnetic bits into vertical direction, this way distinguish it with conventional longitudinal recording which compiling magnetic bits into horizontal direction that requiring a wider surface area to store information [1][2]. However, the use of PMR should be compensated by a large of magnetic field that required reversing nano-dot magnetization [3]. Activating of heat on magnetization reversal is one of techniques that can be proposed to reduce the amount of magnetic field [4][5]. Except the magnetic field, there are many factors that related and affected each other in the development of PMR and one of them is Gilbert damping constant [6]. In this paper, magnetization reversal mode on perpendicular magnetic materials has been studied micro magnetic simulationly by investigating Gilbert damping effect. Based on the Landau Lifshitz Gilbert (LLG) equation, Gilbert damping affect on magnetization rate. This simulation performed on two schemes namely Reduced Barrier Writing (RBW) and Curie Point Writing (CPW).

II. NUMERICAL METHOD

Micro magnetic simulation of magnetization reversal of PMA in 50×50×20 nm^3 dimensions has been studied by solving LLG equation.

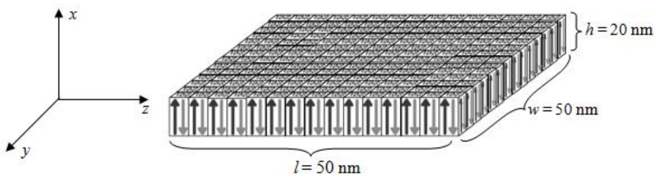


Figure 1. Perpendicular magnetized nano-dot model.

LLG equation explains the changing of magnetization direction when a bias field applied [7][8].

$$\frac{d\mathbf{M}}{dt} = -[\gamma]\mathbf{M}\times\mathbf{H}_{eff} + \frac{\alpha}{M_s}\mathbf{M}\times\frac{d\mathbf{M}}{dt} \qquad (1)$$

This simulation is performed by changing the value of Gilbert damping constant (α) which taken value are 0.26, 0.28, 0.3 and 0.32, γ is gyromagnetic ratio by which its value is 1.76×10^7 Oe^{-1}.s^{-1} and M_s is saturation magnetization. Effective magnetic field ($\mathbf{H}_{eff}$) are the sum of anisotropy field ($\mathbf{H}_k$), demagnetization field ($\mathbf{H}_d$), exchange field ($\mathbf{H}_{ex}$), eksternal field ($\mathbf{H}_{ext}$) and random field ($\mathbf{H}_T$) as in shown Eq. (2) [8] :

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

Relation between $\mathbf{H}_{ex}$ with exchange stiffness constant (A) and saturation magnetization can be seen at Eq. (3) [9] :

$$\mathbf{H}_{ex} = \frac{A}{\mu_0 M_s^2} \Delta \mathbf{M} \tag{3}$$

Where A as exchange stiffness constant (1×10^7 erg/cm), μ_0 as permeability of vacuum and function of $\Delta\mathbf{M}$ as shown in Eq. (4)[10] .

$$\Delta \mathbf{M} = \frac{\partial^2}{\partial x^2}\mathbf{M}_x + \frac{\partial^2}{\partial y^2}\mathbf{M}_y + \frac{\partial^2}{\partial z^2}\mathbf{M}_z \tag{4}$$

Whereas, $K_\perp$ and M_s are related to $\mathbf{H}_k$ as a function of the unitary vector $\mathbf{m}$ which is given by following equation :

$$\mathbf{H}_k = \frac{2K_\perp}{\mu_0 M_s}(\mathbf{u.m})\mathbf{u} \tag{5}$$

where $\mathbf{u}$ is the unit vector, along the direction of the uniaxial easy axis [11].

Temperature dependence of A, $K_\perp$ and M_s which are related to reduction of magnetization with respect to temperature also expressed in Eq. (6), (7) and (8) where $A^{(0)} = 1\times10^7$ erg/cm, T is temperature and T_c is curie temperature (373 K)[4].

$$A(T) = A^{(0)}\left(\frac{M_s(T)}{M_s(0)}\right)^2 \tag{6}$$

$$K_\perp(T) = K_\perp^{(0)}\left(\frac{M_s(T)}{M_s(0)}\right)^2 \tag{7}$$

$$M_s(T) = M_s^{(0)}\left(1 - T/T_c\right)^{0,5} \tag{8}$$

Strenght of random field due to thermal fluctuation is presented by following dissipation theorem [12].

$$\sigma = \sqrt{\frac{2k_B T\alpha}{\gamma V M_s \Delta t}} \tag{9}$$

where k_b = Boltzman constant, V = nano-dot models volume ($50\times50\times20$ nm^3) and Δt = time increment (2.5 ns).

III. Result and Discussion

A. *Reduce Barrier Writting (RBW)*

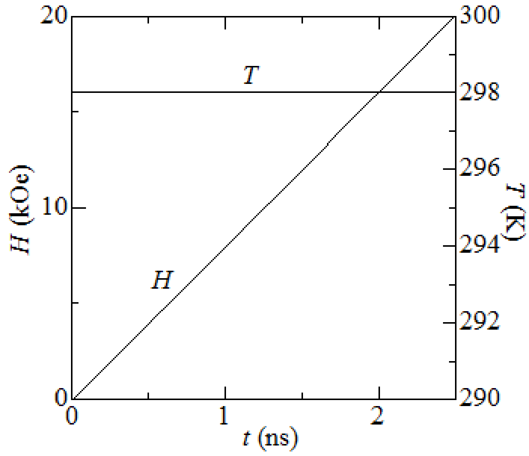


Figure 2. Micromagnetic Simulation Scheme of Reduce Barrier Writing.

Nano-dot ferromagnetic that analysed numerically in this research has magnetization toward $+x$ ($M_{sat}\uparrow$), then bias magnetic field toward $-x$ ($H\downarrow$) was applied which its magnitude linearly from 0 to 20 kOe at room temperature (298 K) as seen in Fig. 2.

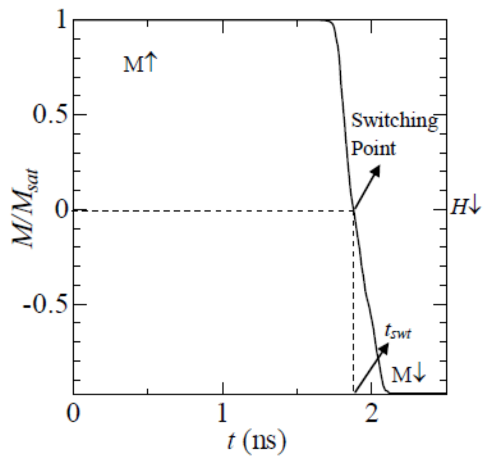


Figure 3. Magnetization reversal for $K_\perp = 3.51 \times 10^6$ erg/cm^3 and $4\pi M_s$ = 5697.5 G at room temperature (298 K) with coresponding value of $\alpha = 0.28$.

When nano-dot induced by bias magnetic field (H), it tends to reverse its direction parallel to H. This magnetization mechanism which represented by value of M/M_{sat} has shown in Fig. 3. The value of M/M_{sat} shows a comparison between the instantaneous magnetization (M) in the direction of the x axis to initial magnetization (M_{sat}). Value of M/M_{sat} = 1 indicates that both have the same magnitude and direction. Value of M/M_{sat} = 0 explains a state in which M has no component in the instantaneous direction of the x axis, in this case, nano-dot said to be in switching point. While value of M/M_{sat} = -1 refers that M and M_{sat} has the same magnitude moment but oppositely in direction.

www.IJSEI.com ISSN: 2251-8843 Paper ID: 21613-06

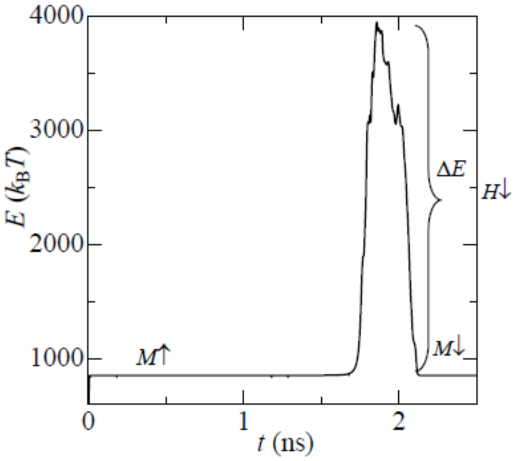
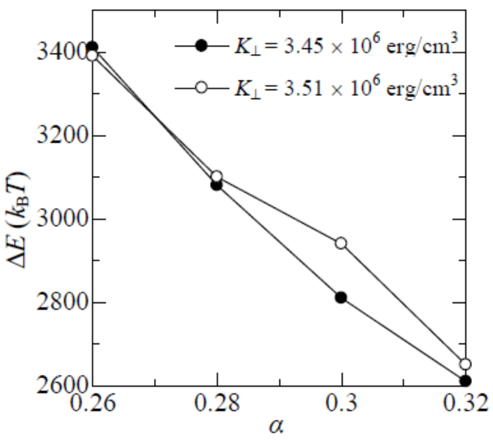
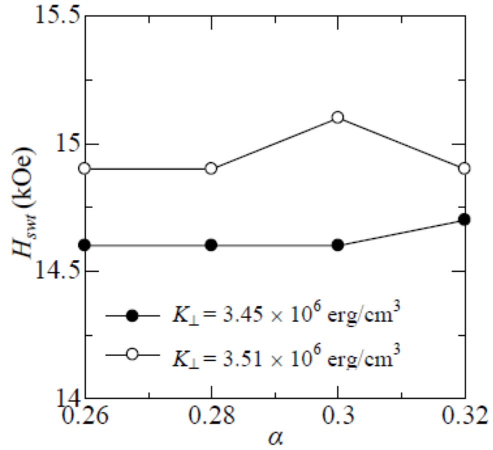


Figure 4. Energy barrier that occurs on nano-dot $K_\perp = 3.51 \times 10^6$ erg/cm^3 with coresponding value of $\alpha = 0.28$ for $4\pi M_s = 5697.5$ G at room temperature (298 K).

An important one in magnetization reversal mechanism investigating of perpendicular magnetized nano-dot is about energy barrier existence that separates two magnetized stable states. The first stable state is a condition that orientation of magnetization at x axis is opposite to bias magnetic field, while the second one is a condition that the magnetization orientation of material is parallel. The existence of energy barrier indicates that a threshold energy is needed to reverse the nano-dot magnetization point to bias magnetic field, which is related to the magnitude of applied magnetic field. Energy barrier for nano-dot with characteristics of $K_\perp = 3.51 \times 10^6$ erg/cm^3 and $4\pi M_s = 5697.5$ G at room temperature (298 K) with coresponding value of $\alpha = 0.28$ is shown in Fig. 4. Bias magnetic field and time are required to exactly reverse the nano-dot magnetization called as switching field (H_{swt}) and switching time (t_{swt}) respectively.



(a)



(b)

Figure 5. Influence of α towards ΔE (a) and H_{swt} (b) for $K_\perp = 3.45 \times 10^6$ erg/cm^3 and $K_\perp = 3.51 \times 10^6$ erg/cm^3 with corresponding value of $4\pi M_s = 5697.5$ G at room temperature (298 K).

Refers to Eq. 1, it can be seen that α is one of the important factor that gives influences to magnetization rate of nano-dot actually in motion precision. Fig. 5 shows the relation between ΔE and H_{swt} in variation of α. Dependence of ΔE values with respect to α can be seen in Fig. 5(a). It can be clearly seen that for two different value of $K_\perp$, increasing of α typically decrease ΔE value. Interesting part is the declining value of ΔE was not followed by a dropping value of H_{swt}, whose tends to fluctuated which shown in Fig. 5(b). Although both have identic changes, there is a difference of H_{swt} values due to differences of $K_\perp$. For equal value of α, larger H_{swt} are obtained for higher $K_\perp$. As an example, for $\alpha = 0.3$, H_{swt} as big as 14.6 kOe for $K_\perp = 3.45 \times 10^6$ erg/cm^3 and H_{swt} as big as 15.1 kOe for $K_\perp = 3.51 \times 10^6$ erg/cm^3.

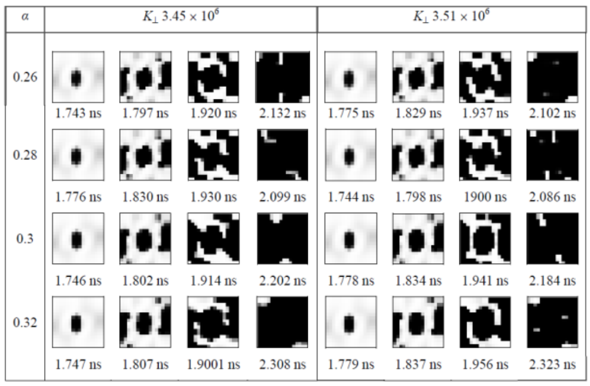


Figure 6. Visualization of reversal magnetization mechanism.

Fig. 6 is the micromagnetic visualization for two values of $K_\perp$ on four different values of α. Mechanism of reversal magnetization on both condition with four variations of α has an identical magnetization profile, either on domain wall nucleation and on its propagation which forming Z pattern until its magnetization saturated at direction of H. White color shows the direction of initial magnetization (at direction of $+x$

axis). Meanwhile, black color indicates the direction of magnetization that in line with H (at direction of $-x$ axis). Based on domain wall nucleation and on its propagation, could be indicated that the domain wall is most easily formed from central region of nano-dot then propagates to its edges. This is caused by the domination of exchanging energy at the center. This identical mechanism is a confirmation of previous yield about the identical changes of ΔE and H_{swt} with respect to α for two different $K_{\perp}$.

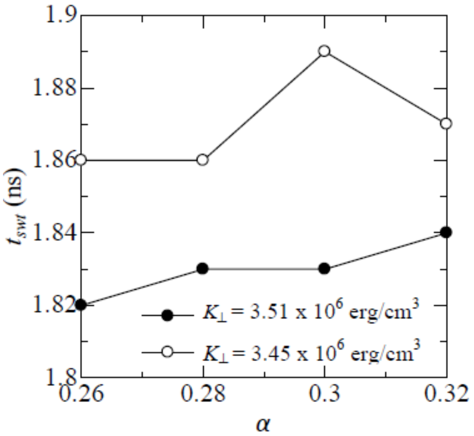


Figure 7. Comparison of t_{swc} for two different values of $K_{\perp}$ with α variation.

Fig. 7 represents the comparison of t_{swc} for two values of $K_{\perp}$ with variation of α. It is clearly seen that nano-dot with greater $K_{\perp}$ needs longer time to magnetized. This is related to the anisotropy energy of nano-dot that corresponding to $K_{\perp}$, which for nano-dot with greater $K_{\perp}$ shows a greater binding energy.

B. *Curie Point Writting (CPW)*

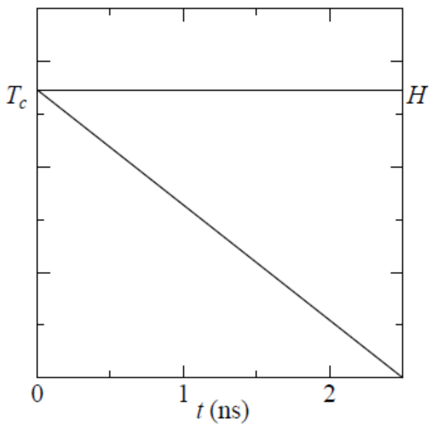


Figure 8. Simulation scheme of magnetization reversal at Curie temperature.

On RBW scheme, was obtained that to magnetize a nano-dot, at approximately 14 kOe to 15 kOe of reversal field was required. This writing field, which in 10^4 Oe order, becomes inapplicable for magnetic recording application. On second part of this paper, reversal magnetic scheme on Curie Point Writing (CPW) that has aim to decrease amount of reversal field will be discussed. Fig. 8 shows a scheme of CPW. Supplying of heat randomize the initial magnetization of nano-dot, then nano-dot is made cooled abruptly until it reaches room temperature during 2.5 ns with influence of H to +x axis direction. H is supplied with a purpose to aligning the orientation of ferromagnetic nano-dot magnetization. The calculation is performed with variation of 50 randomized numbers. The probability of that cooling process called as reversal probability P that can be formulated by:

$$P = \frac{\sum n_{//}}{\sum N}$$

where Σn// is magnetization that parallel to H, then ΣN is 50th given random magnetization number. Minimum field is required to magnetized 50th given random number parallel to H called as Threshold Field (HT)

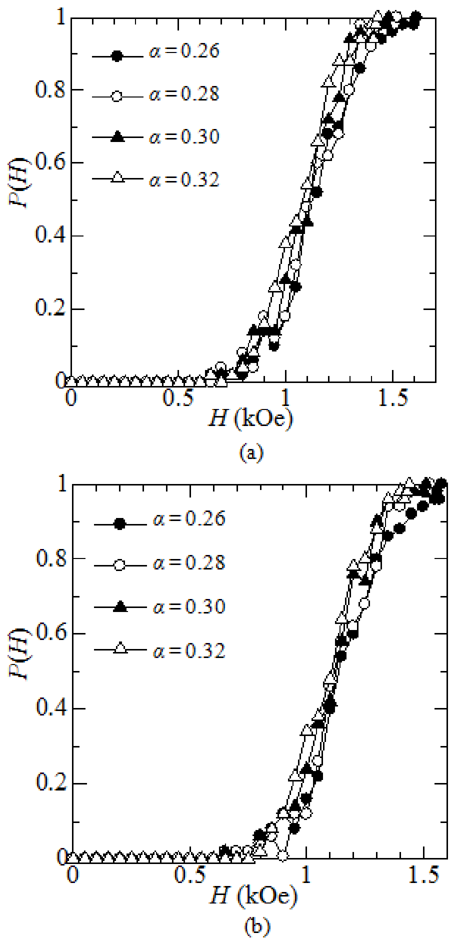


Figure 9. Dependence of P with respect to H on reversal magnetization with CPW scheme for (a) K⊥ = 3.51 × 106 erg/cm3, (b) K⊥ = 3.51 × 106 erg/cm3 with coresponding value of 4πMs = 5697.5 G.

From Fig. 9, can be observed the dependence of H with respect to bias magnetic field (H). When H = 0, P = 0, it indicates that instant cooling does not magnetizes nano-dot spontaneously parallel to +x axis. Therefore it needs H to magnetizes the nano-dot. However, if H is less than 600 Oe, it still has not been able to magnetizes nano-dot into +x direction. When the value of H is more than 600 Oe, P quickly increases until reach equal to 1. It means that 50th given random number have the magnetization inline to H.

Fig. 10 shows the declining of H_T along with increasing of α for two different values of $K_\perp$ with equal $4\pi M_s$. Nano-dot with larger value of α has a tendency to be more easily directed to its bias magnetic field orientation. On the contrary, for smaller α, nano-dot get harder to directed to the bias field. It is caused by an amount of Gilbert damping that rotates more easily directed towards the bias field, therefore, smaller reversal field is needed to magnetizes the nano-dot. From presented value of H_T in Fig. 10, it can be seen that there is a decreasing of reversal field value compared with result from the scheme of RBW that located in Fig. 5(b). On the scheme of RBW, the magnitude of reversal field for two different value of $K_\perp$ with four variation of α is approximately at 14 kOe - 15 kOe. Meanwhile on CPW scheme, size of reversal field descend up to approximately at 1.4 kOe - 1.6 kOe. Therefore, from this result can be concluded that thermal activation can effectively decrease the magnitude of reversal field up to ~ 90%.

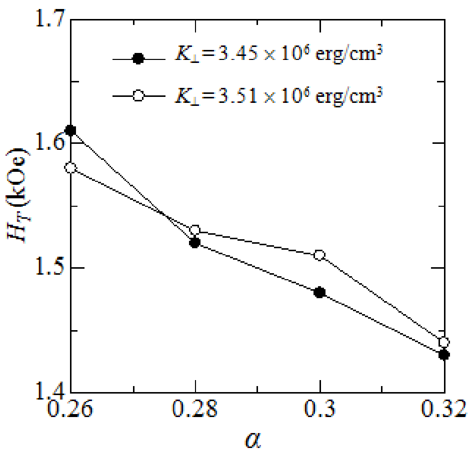


Figure 10. Comparison of α with H_T for two values of $K_\perp$ with $4\pi M_s$ = 5697.5 G.

IV. CONCLUSION

Micromagnetic simulation of perpendicular magnetized nano-dot has been performed to investigate the influence of Gilbert damping effect on thermally assisted magnetization reversal by solving Landau - Liftshitz Gilbert equation. At room temperature, for two different values of $K_\perp$, have been obtained that decreasing of ΔE along with the increasing of α is not followed by decreasing of H_{swt} which tend to fluctuate. In addition, for nano-dot with larger $K_\perp$, larger H_{swt} is required which is followed by excalation of t_{swt}. Activation of thermal has been succeeded to lowering an amount of reversal field up to ~ 90%. Moreover, H_T could be reduced by Gilbert dam-ping increment.

REFERENCES

[1] Wood R., Hsu Y and Schultz M. 2007. "Perpendicular Magnetic Recording Technology", in Hitachi Global Storage Technologies, White Paper, USA.

[2] Judy, J. H. "Past, Present and Future of Perpendicular Magnetic Recording". Journal of Magnetism and Magnetic Materials 235 (2001) 235–240.

[3] Wang, Y. 2011. **"**Physics and Micromagnetik Analysis of Advanced Recording Technologies". Desertasi Doctor of Phylosophy Department of Electrical and Computer Engineering. Pennsylvania: Carnegie Mellon University Pittsburgh.

[4] Purnama B., Koga M., Nozaki Y and Matsuyama K. 2009. "Stochastic Simulation of Thermally Assisted Magnetization Reversal in Sub-100nm Dots with Perpendicular Anisotropy". Department of Electronics .Kyushu University. Journal of Magnetism and Magnetic Materials 321 1325-1330

[5] Yoon S and Krishnan K. M. 2011. "Temperature Dependence of Magnetic Anisotropy Constant in Manganese Ferrite Nanoparticles at Low Temperature". J. appl. Phys. 109, 07B534.

[6] Mardona, Yasir M., Supriyanto E and Djuhana D.. 2012. "Observasi Pembalikan Magnetisasi Material Ferromagnet Bentuk Elemen Diamond-Shaped Dengan Simulasi Micromagnetic". Universitas Indonesia".

[7] Mardona. 2012. "Dinamika Domain Wall dan Efek Anisotropi pada Material Ferromagnet Co dan Ni Berbentuk Nanowire". Magister Phisycs Thesis. Universitas Indonesia.

[8] Schrefl T., Fidler J., Suess D., Scholz W., and Tsiantos V. 2006. "Handbook of Magnetic Materials: Micromagnetic Simulation of Dynamic and Thermal Effects". Tsihua University Press.

[9] L'ubomir Banas, 2005. "Numerical Methods for the Landau-Liftshitz-Gilbert Equation," In Numerical Analysis and Its Applications, pp.158-165.

[10] Nakatani Y., Uesaka Y and Hayashi N. "Direct Solution of the Landau-Lifshitz Gilbert Equation for Micromagnetics". Japanese Journal of Applied Physics, 28, pp. 2485-2507.

[11] Nosaki Y., Isowaki Y., Hashimoto A., Purnama B and Matsuyama K. 2006. "Numerical Analysis of Thermally Assisted Magnetization Reversal in Rectangular MRAM Cell Consisted of Exchange Coupled Bilayer," Journal Magnetic Soc. 30, pp. 574-577.

[12] Purnama B. 2009. "Thermally Assisted Magnetization Reversal in Perpendicularly Magnetized Thin Film". Doctor Thesis, Electronics Department Graduated School of Information Science and Electrical Engineering, Kyushu University : Japan.

Wahyu Natalis Handayani is a Bachelor students in physics education; Department of Physics, Facul-ty of Science and Mathematics, Satya Waca-na Christian University, Salatiga. She is a final year of undergraduate student for her research is Gilbert Damping Effect on Thermally Assisted Magnetization Reversal of Perpendicular Mag-netized Nano-dot.

Andreas Setiawan received his Ba-chelor degree (S.Si) at Physics Instrumentation; Department of Physics, Faculty of Science and Mathematics, Satya Wacana Christian University, Salatiga, Indo-nesia in 1999. Final project: "Data Acquisition Systems". In 2010 received his Master degree (M.T) in instrumentation and control; Department of Physics Engineering, Faculty of Industrial Engineering, Bandung Institute of Technology, Bandung, Indonesia. Thesis: "The Measurement of Ultrasonic Transit Time for Calculation of Manning Roughness Coeffisient and Flow Rate Deter-mination on open Chan-nel Through Weir VV-Notch 90˚ Methods". He is currently working at Physics Department of Satya Wacana Christian University, Salatiga, Indonesia.

Nur Aji Wibowo received his B.Sc at Sebelas Maret University, Surakarta, Indonesia in 2007. He received a M.Sc degree in the same university in 2011 for his research on Thermally Assisted Magnetization Reversal on Perpen-dicularly Magnetized Nano-dot. He is currently working at Physics Department of Satya Wacana Christian University, Salatiga, Indonesia. His current concentrating research is Thermally Assisted Magnetization Reversal on Perpendicular Ferromagnet Anisotropy.