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Research articles

# Vortex Mode of Magnetization Reversal in Nano Dot Magnetic Permalloy

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**Abstract**

Micromagnetic simulations are used to evaluate a minimum of external field needed to switch assisted by vortex. Nano dot magnetic studied has a size 100 × 50 × 60 nm was assumed to be a nano-sized magnetic permalloy. The initial conditions in the form of vortex are simulated by providing a nano second pulse duration of magnetic field. Then the initial condition used to evaluate a minimum switching field require for magnetization process. The results of the simulation show that the reduced magnetic switching up to 46.8% compared with conventional magnetization.

## 1. Introduction

Ferromagnetic materials will form small domain configuration of magnetic to achieve its minimal energy. Naturally the Wall will shows between two domains of magnetization which has different direction. There are two types of domain wall which is Bloch wall and Neel wall [1]. Bloch wall makes the direction of its magnetic moment perpendicular to the plane. If the thickness of materials is smaller than the width of Bloch wall, then Neel wall will be used which its magnetic moment is parallel to the plane [2]. An interesting phenomenon will happen when two Neel walls are intersecting to each other. A magnetic vortex will show up at the intersection.

In the last few years, this vortex phenomenon has made the interests of researchers to study it experimentally and theoretically. A magnetic vortex is a state of closed flux magnetic [3], which consists of magnetization with round structure in-plane oriented and a component of perpendicular with out-plane oriented. Vortex core can be observed in different kinds of forms i.e. oval, rectangle, circle and many more [4]. In previous studies, the dependence of the vortex anti-vortex pairs on the thickness and time dimensions of the magnetic nano dot has been studied using micromagnetic simulations. The results confirm that the duration of time required for the reversal magnetization process from the formation of the anti-vortex vortex is the same for thickness variations [3, 5].

Recent study has shown the dependency of vortex and anti-vortex at the dimension of nano magnetic-dot which is assessed by using micro-magnetic simulation. The results confirm that the duration needed to reverse its magnetization with variable of width is equal without the influence of external field. Therefore, in this study we will evaluate the minimum of external field needed to switch vortex. Initially, a nano-sized permalloy materials which has uniform magnetic polarization is simulated by giving in a field pulses to evoke initial condition of a vortex. Then we can evaluate switching process of the vortex by giving in a certain pulse which is shown by visual in the micromagnetic graphic results. Need to be declared that the units system we use is CGS system.

## 2. Experimental Method

To study the dynamic of vortex in permalloy nanoparticles, the reversal magnetization process is simulated by solving Landau-Lifshitz-Gilbert (LLG) as shown in Equation 1 [6, 7].

$$\frac{dM^i}{dt} = -|\gamma| M^i \times H^i_{eff} + \frac{\alpha}{M_s} M^i \times \frac{dM^i}{dt} \tag{1}$$

with $\gamma$ is a ratio of gyromagnetic ($|\gamma|$= 1,76 × $10^7$ $oe^{-1}$ $s^{-1}$ for free electrons), $H_{eff}$ is effective field, $\alpha$ is a parameter of Gilbert attenuation and $M_s$ is saturation magnetization. Effective field or $H_{eff}$ in LLG equation is an energy density of magnetization which is generally a total of its components and can be written in Equation 2 [4].

$$\boldsymbol{H_{eff}} = \frac{\boldsymbol{2A}}{\boldsymbol{M_s}} \boldsymbol{\nabla^2 m} + \boldsymbol{H_d} + \boldsymbol{H_a} + \boldsymbol{H_k} \tag{2}$$

From Equation 2 with $A$ is material constant ( $A=JS^2/a$, $a$= the lattice constants) [6], $H_d$ is a demagnetization energy, $H_k$ is anisotropy energy, dan $H_a$ is external energy.

In the simulation, the material we use is a nanoparticle of permalloy with dimension of 100 nm × 50 nm × 60 nm. Anisotropy of the material is considered to be in-plane with anisotropy constants of 5000 erg/cm$^3$ and saturation magnetization of $4\pi M_s$ = 1.0 × $10^4$ Gauss. Gilbert attenuation is given by a value of 0.3 and external field will be vary resulting some visual graphics of micromagnetic and the correlation of its magnetization to the effect of time pulse by step-time integration ($dt$ ) = 2.5×$10^{-13}$ s. For the results obtained, besides the correlation curve of reversal magnetization to the time function, there is also a micromagnetic graphic. In the micrograph which is shown its reversal process, the magnetization direction of each element for the nanoparticle finite element is shown by color. Generally, blue is showing the direction of magnetization to the x-axis, purple to they-axis, green to the negative y-axis, and orange to the negative x-axis.

## 3. Results and Discussion

The micromagnetic simulation has been done using a material which to be considered as permalloy nanoparticle. First, material is assumed to have uniform magnetic polarization. Then, to evoke the initial condition of a vortex is by giving pulses of external magnetic field. The external magnetic field which is used is given by the values of 1000, 1500, and 2000 Oersted. The result obtained is the correlation curve of reversal magnetization to the time function with the values of external field shown Figure 1.

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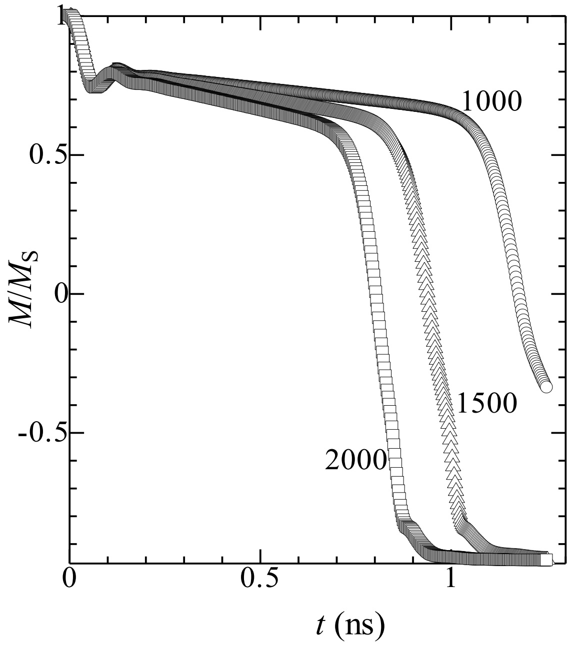


**Fig. 1.** Reversal magnetization curves (*M/Ms*) of the time function *(t)* with the magnitude of variations field *(Oe)*.

By observing the curve above, the magnetic reversal process for values of external field that is given are 1500 and 2000 oersted switching to the opposite direction. While the external field by the value of 1000 is given, the magnetization is not switching enough to the opposite direction, because the given energy is not enough to switch to the opposite direction. Red circle in the Figure 1, is an indicator to show a vortex phenomenon at the magnetization reversal process of its permalloy material. To confirm that phenomenon, then a micrograph from the result of simulation should be viewed at the Figure 2. Based on its reversal mode, for external field by the values of 1500 and 2000 Oersted is indeed a vortex happened and then switched to the opposite direction which is shown by the orange arrow. Meanwhile at the value of external field 1000 Oersted, the vortex is keep happening to the last condition of simulation. So, this condition is used as the initial condition at the second phase.

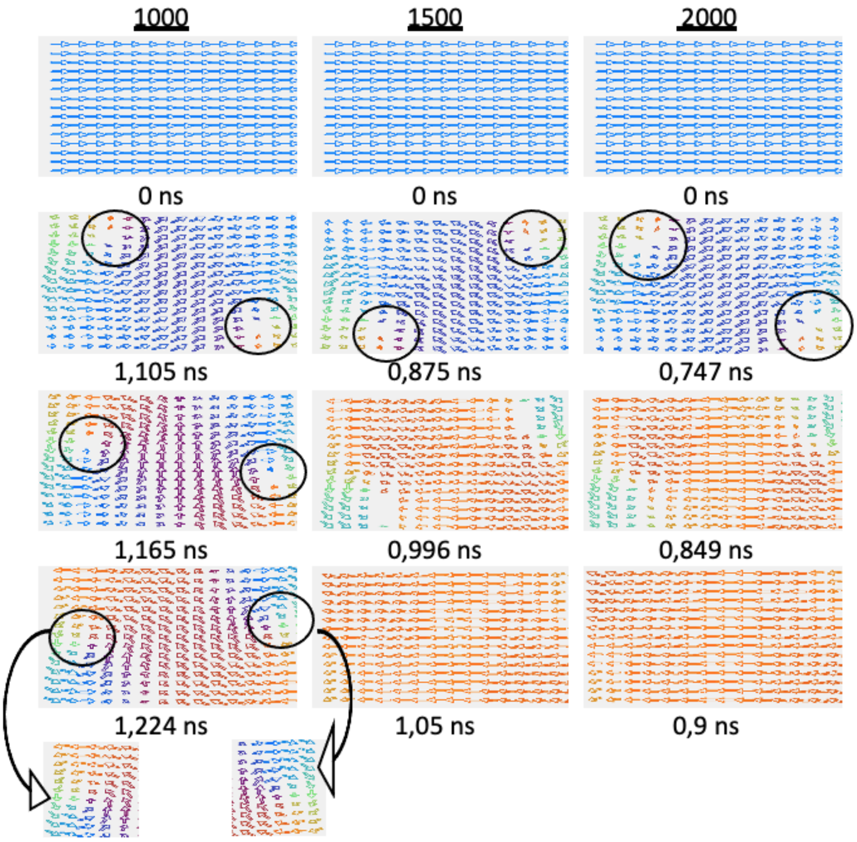


**Fig. 2.** Micromagnetic graphs of reversal magnetization process in nucleation and annihilation magnetic domains for external field variety (*H*).

At the second phase, permalloy nanoparticle is assumed to has initial condition of a vortex. Then it is given by field pulses to determine a minimum value of external magnetic field which is used to change the direction of its polarization to be parallel (switching). So the result is a correlation curve of reversal magnetization to the time function with the values of external field shown in Figure 3. But at the Figure 3, there two correlation curves which are initial condition of vortex and initial condition of its uniform magnetization pattern (without vortex).

By observing the curve at Figure 3, the magnetization reversal process at the second condition is switching to the opposite direction. At initial condition of vortex, the reversal process begins with a negative value of magnetization and contrary to the uniform initial condition (no vortex). But, the duration needed to switch a both condition is very distinctive. Initial condition of vortex has lesser duration to switch. By that, the minimum of external field needed to switch is smaller than the initial condition of uniform magnetization.

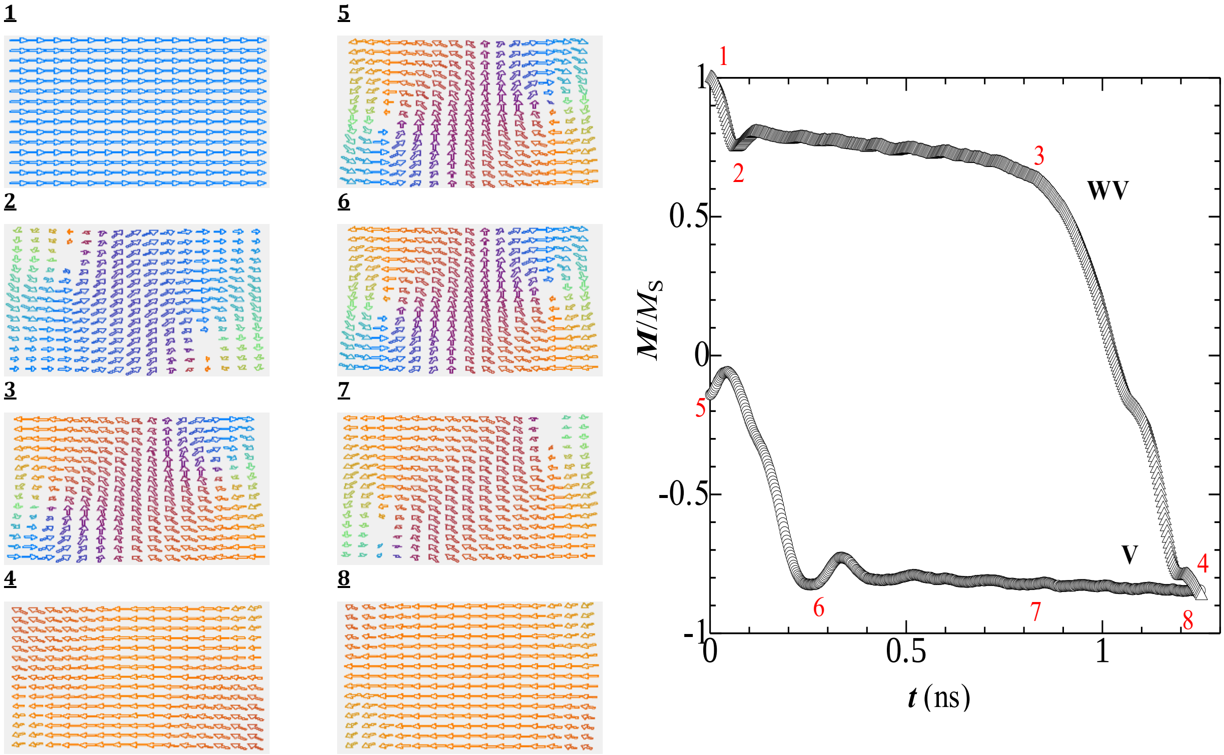


**Fig. 3.** The correlation curve of reversal magnetization as time function together with the result of its micrograph. The curve of initial condition (V). The curve of uniform initial condition (WV).

## 4. Conclusions

A study of micromagnetic simulation has been done to evaluate the minimum of external field required to switch vortex in the nanoparticle of permalloy. The minimum external field required to evoke initial condition in the form of vortex is at the value of 1000 oe. For the process from nucleation to annihilation of vortex configuration, the bigger the external field, the shorter the duration needed to achieve it. Furthermore, the study of vortex annihilation to switch has been done by evaluating the minimum external field that is required. The minimum external field required to switch from initial condition of vortex is smaller than the condition of no vortex.

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