

Study of A Phenomenon STT (Spin Transfer Torque) on the Material $La_{0.7}Sr_{0.3}MnO_3$ Shaped Nanowire Using Micromagnetic Simulation

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ABSTRACT

STT (Spin Transfer Torque) can be referred to as a process of manipulation and control of spin current in the field of spintronics. When the material is ferromagnetic nanowire $La_{0.7}Sr_{0.3}MnO_3$ injected currents will move the domain wall with accompanying changes of spin currents. In micromagnetic simulation shows that the application is capable of producing flow velocity or pressure of domain wall in the direction of electron flow. The domain wall pressure generating magnetization changes with increasing current density occurs. To that end, the simulation research was done in order to obtain the effect of the injection of electric current to the magnetization of the material. This phenomenon is simulated by modeling the material into the 3D geometry. The greater the current density is given the domain wall velocity or pressure on the nanowire faster so that the magnetization process is also faster. Changes in the velocity of the fastest domain wall is obtained when the material is injected with a current density as well as M-t get a graph showing oscillation pattern that is denser when the current is increased. Furthermore, the total energy analysis with variations in size diameter of 10 nm, 20 nm and 30 nm. The results show that with increasing diameter, total energy tends to increase.

Key words: spin transfer torque, $La_{0.7}Sr_{0.3}MnO_3$, magnetisation, domain wall, ferromagnetic

INTRODUCTION

$La_{0.7}Sr_{0.3}MnO_3$ (Lanthanum Strontium Manganese Oxide) is one of a ferromagnetic material CMR (Colossal Magnetoresistance) based in particular manganese oxide manganit have the general formula $A(MnO_3)$ with rare elements of the three tetravalent, usually rare earth elements. Material of $La_{0.7}Sr_{0.3}MnO_3$ formed of material $LaMnO_3$ have additional dopan divalent ion of Sr can change of the nature of transport electricity $LaMnO_3$ material. Material of $LaMnO_3$ who in doping by ion of Sr^{2+} would be followed by transition ion of Mn^{3+} to ion of Mn^{4+} it means there is one of electrons lost and created a hole that allows the occurrence of a leap of electrons that the material is metal (Rohman, 2013). Ferromagnetic material has high skill to form a magnetic field in it.

Magnetic moment spontaneous fixed produced although are on external magnetic field zero. The existence of moment magnetic spontaneous this shows that spin electron and magnetic moment material ferromagnetic composed regularly (Yani *et. al.*, 2014). The arrangement of magnetic moment in the domain

of a magnet that regular it can be developed in research on of magnetic properties material. In general research on the domain magnetic can be split into two parts those are that deals with the structure the domain of magnetic and that deals with the dynamics of the wall the domain. Second research is done with apply a magnetic field outside or an electric current through the phenomenon of spin transfer torque (Ismail, 2013).

Spin transfer torque simply can be produced when the injection an electric current so that change orientation a spin on magnetic moment. An electric current diinjeksikan flow on two a thin layer of ferromagnetik interspersed material non-magnetic. Electric current flows more easy when the domain magnetic field in a ferromagnetic oriented in one direction than opposite direction. When the current distributed and the torrent will affect the domain a magnet and value magnetization (Francin, 2009).

The application of the current conducted can produce pressure the wall the domains in the direction of a stream of electrons. Pressure the domain wall resulted in change magnetization as an increase in meeting of the current which

happened (Francin, 2009). Finally, shall be awarded to the value of magnetization vary in any variation meeting regional the stream and geometry material of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$. Therefore, need to research research to know the influence of injection an electric current on the material of ($x=0.3$). Next, value magnetization is obtained plotted in accordance variations of current electricity, so obtained a chart M-t. In addition, in this research there were also simulation variations diameter to total energy which includes demagnetisation energy and exchange energy.

METHODS

The research was done uses software licensed public that is NMAG (Nano Magnetic) that can run on an operating system GNU/Linux. Methods used in research that is a finite element of method. The fundamental concept of a method of elements until is completed a problem with way divide object analysis into parts small bloody. Those small parts were then analysis and the result combined return to to find the completion of a whole regions. Simulation micromagnetic it is based on equation LLG (Landau-Lifshitz-Gilbert) that is differential equations order one a function of time, as follows (Massoud *et. al.*, 2009):

$$\begin{aligned} \frac{\partial M}{\partial t} = & -\gamma' M \times H_{eff} - \frac{\alpha \gamma'}{M_s} M \frac{\partial M}{\partial t} \times (M \times H_{eff}) \dots \\ & - \frac{b'_j}{M_s^2} (1 + \alpha \xi) M \times (M \times (\nabla \cdot J) M) \dots \quad (1) \\ & - \frac{\xi b'_j}{M_s} (\xi - \alpha) M \times (\nabla \cdot J) M \end{aligned}$$

Variations of current given in such a way that current density (J) is $1 \times 10^{10} \text{ A/m}^2$, $2 \times 10^{10} \text{ A/m}^2$, $4 \times 10^{10} \text{ A/m}^2$, $6 \times 10^{10} \text{ A/m}^2$, $8 \times 10^{10} \text{ A/m}^2$. While geometry material used namely by long 70 nm and diameter of with variations 10 nm, 20nm and 30 nm. Parameter of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material shaped nanowire can be seen in Table 1. Defines a system a measure on this simulation can use equation which means dimensions size system has to larger than this and size of cellnya also have to be small or similar to exchange length (Rohman, 2013).

Table 1 Parameter of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ material

Parameter	Value
$\frac{E_{\text{ex}}}{M_s}$	$590 \times 10^3 \text{ A/m}$
A	$5 \times 10^{-12} \text{ J/m}$
K	$-0,3 \times 10^3 \text{ J/m}^3$
$\frac{K}{M_s}$	4,78 nm

Source: Ziese (2006).

After all parameter of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material inserted, so to be obtained data output of file “.vtk” and files “.ndt”. The file “.vtk” further used to visualize structure the domain. Visualize can show the direction of spin and value magnetization of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material. Next, the results of represented in graphical form relations magnetization respect to time (M-t) from file “.ndt”. In addition, done analysis total energy that deals with the dynamics of the wall the domain from exposure diameter wire of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material, in the phenomenon spin transfer torque with memvariasi diameter in injection current same.

RESULTS AND DISCUSSION

Variations an Electric Current Injection to Magnetization of $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) Material in the Phenomenon STT (Spin Transfer Torque)

Position the domain wall move along nanowiredetermined by using magnetization the direction of the axis x as a function of time for variations diameter nanowire. Position the domain wall to variation meeting current $1 \times 10^{10} \text{ A/m}^2$, $2 \times 10^{10} \text{ A/m}^2$, $4 \times 10^{10} \text{ A/m}^2$, $6 \times 10^{10} \text{ A/m}^2$, $8 \times 10^{10} \text{ A/m}^2$ on the $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material, shown in Figure 1.

In terms of change index color on the structure of domain taken at $t = 6 \text{ ns}$, can be observed configuration early the domain wall leading to the y axis shown with yellow horizontal, direction z with green color vertical, and the x axis that is direction magnetization with red horizontal. Each index such color describes

scale value magnetization. In the index such color, value magnetization the bigger on the x axis (color red). The presence of electrical currents who injected, happened shift the domain wall follow the direction of electric currents. If observed as a whole, shift the domain wall above, each in diameter the same follow any pattern the movement of color that is relatively the same, is on the direction of the axis x and magnetization in the direction corresponding by the provision of an electric current that is, to the direction of the axis x positive.

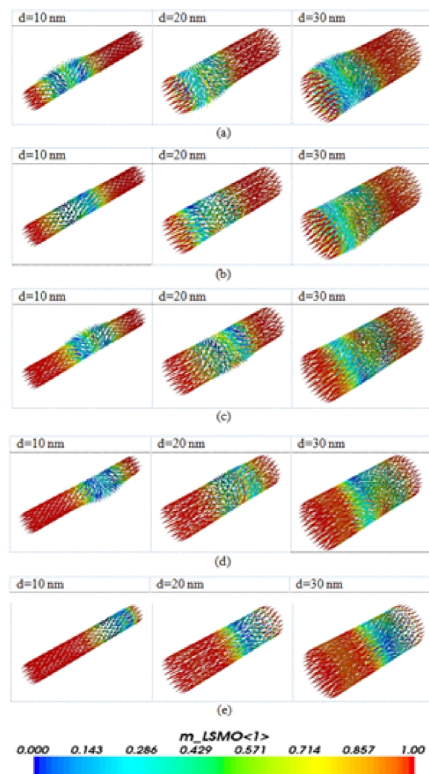


Figure 1. Evolution position domain wall in $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3(x=0,3)$ material with variations meeting current: (a) $1 \times 10^{10} \text{ A/m}^2$, (b) $2 \times 10^{10} \text{ A/m}^2$, (c) $4 \times 10^{10} \text{ A/m}^2$, (d) $6 \times 10^{10} \text{ A/m}^2$, (e) $8 \times 10^{10} \text{ A/m}^2$ where each index color on the under side represented scala value magnetization

An electric current influential on the structure of the the domain wall move along nanowire to maintain its structure due to injection of an

electric current. The walls of the domain with the structure the vortex will moved with a whirl of the x-axis positive. The interesting thing is that observation the structure of the walls of the domain, it turns out to have a meeting of the current which is the smallest (Figure 1 (a)) not able to press so that the walls of the domain second match of spin or torque experienced a change of position that minimum. For the meeting while the current (Figure 1 (e)) able to press the walls of the domain to the crown of nanowire left. Simulation this was done in the configuration of the time from $t = 0 \text{ ns}$ until $t = 6 \text{ ns}$. The difference this position we can conclude that the speed of a wall the domain increases with increasing meeting a given electrical current. This condition to happen to all the diameter of variation.

Speed value the domain shown in Table 2. Speed value shown in table 2 is average speed calculated uses the time resolved imaging variation in diameter to the current masing-masing meeting. The speed of the domain increase when the increased meeting. This shows that the current density gives more power to push the domain along nanowire.

Table 2. Average speed the domain wall

Current Density	Average Speed (m/s)		
	d=10 nm	d=20 nm	d=30 nm
$1 \times 10^{10} \text{ A/m}^2$	0.76	0.63	0.51
$2 \times 10^{10} \text{ A/m}^2$	1.78	1.4	1.01
$4 \times 10^{10} \text{ A/m}^2$	3.43	3.3	2.92
$6 \times 10^{10} \text{ A/m}^2$	5.21	5.09	5.09
$8 \times 10^{10} \text{ A/m}^2$	6.87	6.87	7.38

Variations an electric current to magnetization, can be shown in Figure 2 to diameter 10 nm, Figure 3 diameter 20 nm and Figure 4 to diameter of 30 nm. Third these graphs it show a response the dynamics of magnetization against the implementation of the electric current on each diameter material. If observed from third charts, provides information that the bigger a given electrical current so oscillations magnetization tends to increase. This result shows that the movement of the wall the domain increase quickly as an electric current increased.

In addition, density oscillations magnetization shows that application an electric current large take more a bit for changes the spin (Gerretsen, 2008).

In Figure 2 showing graphically magnetization all variations of current in diameter 10 nm where magnetization experienced oscillations. Oscillations most meeting shown at a current density which indicated by a line of bold green tosca. In diameter 20 nm show an oscillation the meeting compared to oscillations magnetization in diameter 10 nm with oscillations magnetization most meeting produced at a current density which indicated with red. In diameter 30 nm oscillations magnetization most meeting indicated when the injection current density shown with green color. This support outcomes value speed the wall the domain where the same speed the wall the domain tended to decline with increase in diameter that is proven with the meeting oscillations magnetization.

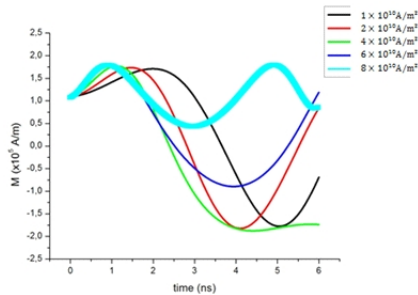


Figure 2. Charts magnetization respect to time to variations of current in diameter material 10 nm.

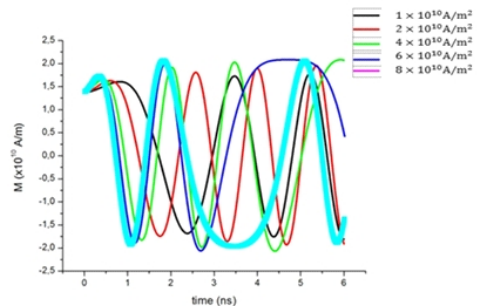


Figure 3. Charts magnetization respect to time to variations of current in diameter material 20 nm.

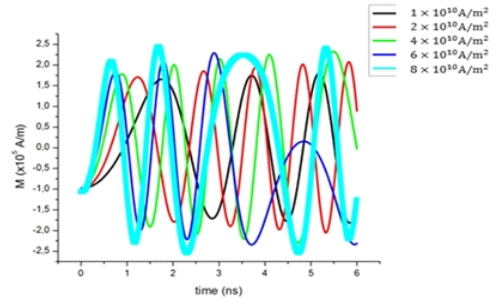


Figure 4. Charts magnetization respect to time to variations of current in diameter material 30 nm.

Variations Diameter Nanowire to Total Energy in $La_{1-x}Sr_xMnO_3(x=0,3)$ Material Shaped Nanowire

Analysis on total energy represented in energy per a unit of volume in diameter different with variations of current electricity, as shown in Figure 5. Total energy can be obtained by add up energy-energy which contribute to nanowire system namely Zeeman energy, exchange energy and demagnetisation energy. In an image visible total energy increase by increase in diameter. Increase in volume nanowire, tends to be led to an increase in total energy (Mardona, 2012).

Besides analysis total energy, the research also analyse exchange energy and demagnetisation energy. The results of the analysis demagnetisation energy and exchange energy shows that demagnetisation energy is higher than exchange energy to diameter different. Direct observation understandable that in this condition magnetic free pole much give a contribution to demagnetisation energy. Then slowly demagnetisation energy decline, while exchange energy slowly increased.

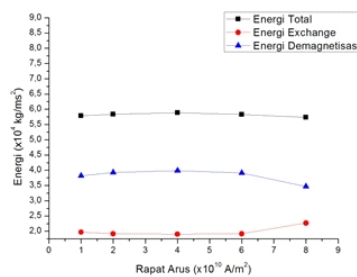


Figure 5. Chart relations energy to current density to diameter 10 nm

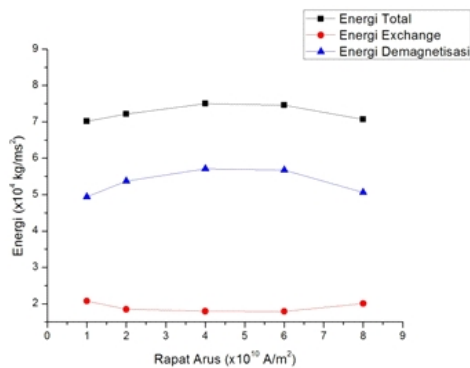


Figure 6. Chart relations energy to current density to diameter 20 nm

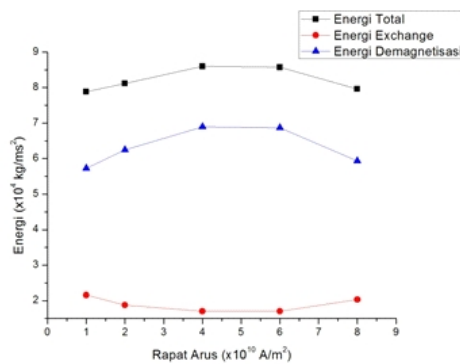


Figure 7. Chart relations energy to current density to diameter 30 nm

CONCLUSIONS

Based on discussion the research the study of a phenomenon STT (*Spin Transfer Torque*) on $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material shaped nanowire using simulation micromagnetic obtained the conclusion that outcomes simulation in the phenomena spin transfer torque for all variation meeting the stream and diameter that is given on $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0,3$) material shows magnetization are different shown with an index color on the structure of the domain. The results of says that the bigger meeting of the current which given so gyrations the wall the domain in nanowire the sooner that the process magnetization also the sooner.

Speed the domain wall maximum produced at the time of material injection current density 8×10^{10} A/m² in diameter 30 nm is 7,38 m/s. While the minimum velocity produced at the time of material injection current density 1×10^{10} A/m² in diameter 30 nm is 0,51 m/s. Next, total energy analysis shows total energy increase by increase in diameter nanowire. This can be caused by energy contribution of demagnetisasi increases with increase in volume. While in exchange energy less than demagnetisasi energy to diameter different.

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