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New Model of Switching Delay Induced by Modulation Effect of Damping and STT Pumping Balance with Programing Current and Interference Phenomena in p-MTJ Array

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Abstract
In this paper, we propose a new model of switching delay in p-MTJ array with interference phenomena considering time dependent fluctuation of effective field originated by oscillatory stray field from unselected cells. We clarified that switching delay is determined by balance between programing current and oscillatory stray field by using LLG micro magnetic simulation. Our new model is useful for design of high performance STT-MRAM with high speed operation and high density cell array.

1. Introduction

Spin transfer torque (STT) MRAM with magnetic tunnel junctions with perpendicular anisotropy (p-MTJs) is one of the promising candidates for next generation non-volatile working memory. In our previous study, we found that it is indispensable to suppress the effect of inter-cell interference between magnetic elements which brings about switching delay in programing cell [1,2], to realize high density STT-MRAM array with vertical body-channel MOSFET such as $4F^2$ cell size [3]. However, the mechanism of switching delay due to interference has not been clarified. In this study, we propose the new model switching delay and we clarified that switching delay due to interference phenomena is determined by modulation effect of damping and STT pumping balance with programing current in p-MTJ array.

2. Proposal model of switching delay

Figure 1 shows the model system with 3x3 10 nm p-MTJs cell array, where p-MTJs consist of CoFeB-MgO based stack as shown in Fig. 2 [4]. The programing cell was set to parallel (P) state and the unselected cells were set to antiparallel (AP) state at the initial state. Programing current passed through only the programing cell. Figure 3 shows proposal model of switching delay in array case. For stand-alone p-MTJ, it is enough to consider only the constant effective field. For array case, we should consider time dependent fluctuation of effective field originated by oscillatory stray field from unselected cells. This field brings about time dependent modulation of balance between damping and STT pumping, leading to switching delay due to magnetization oscillation of programing cell. Based on this model, we evaluated switching delay using LLG micro magnetic simulation [5].

3. Results and discussion

a) Impact of damping and STT pumping balance to switching delay

Figure 4 shows the time-evolutional transfer curve of normalized magnetization of programing cell. When $J = 11$ MA/cm^3, oscillation of m_z ($= M_z/M_s$) is observed during interference period as shown in Fig. 4 (a), which brings about switching delay. On the other hand, when $J = 18$ MA/cm^3, no m_z oscillation is observed as shown in Fig. 4 (b), indicating that switching delay is negligibly small. Figure 5 shows time-evolutional transfer curve of angle of magnetization to z axis of programing cell θ_p and unselected cell θ_u. Figure 6 shows time-evolutional transfer curve of difference of phases $d\varphi$ between magnetization in programing cell φ_p and stray field from unselected cells $-\varphi_u$. As shown in Fig. 5 (a) and Fig. 6 (a), while θ_p, θ_u and $d\varphi$ are nearly constant during interference period, θ_p, θ_u and $d\varphi$ largely change after interference period. On the other hand, as shown in Fig. 5 (b) and Fig. 6 (b), there is no time region when θ_p, θ_u and $d\varphi$ are nearly constant. These results indicate that difference of phase $d\varphi$ is important factor that dominates the switching delay. Then, φ_p and $-\varphi_u$ for each time during interference period are plotted on Fig. 7. Moreover, to clarify the impact of damping and STT pumping balance to switching delay, we overlay dm_z/dt when $\theta_p = 35.1$, $\theta_u = 10.6$ degree calculated by LLG equation for each φ_p and $-\varphi_u$. The red area is STT pumping dominated area and the blue area is damping dominated area. The blue area disappears with an increase of J and the value of dm_z/dt becomes smaller as shown in Fig. 7 (b), indicating that the effect of oscillatory stray field becomes small. Note that dots concentrate in the white area ($dm_z/dt = 0$) where damping and STT pumping are balanced. This indicates that damping and STT pumping balance due to oscillatory stray field from unselected cell during interference period impacts on switching delay.

b) Modulation of damping and STT pumping balance by programing current and its impact for cell array design

Figure 8 shows the current density dependence of $1/T_0$ as a function of cell distance S. Current density dependence of $1/T_0$ is divided two region at $J = 16$ MA/cm^3. Magnetization oscillation is observed below 16 MA/cm^3, and disappears above 16 MA/cm^3 as shown in previous section. Moreover, the switching delay decreases with an increase of array space S because the effect of stray field becomes small. Therefore, it is clarified that switching delay is determined by balance between programing current and oscillatory stray field from unselected cells.

4. Conclusions

We propose a new model of switching delay due to interference phenomena in p-MTJ array and clarified the impact of modulation effect of damping and STT pumping balance with current density during interference period. The effect of stray field becomes smaller with an increase of switching current density. These results are useful knowledge for design high performance STT-MRAM with high speed operation and high density cell array.

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References

[1] S. Ohuchida et al, 59th MMM Conference, FE-10, 2014
[2] S. Ohuchida et al, SSDM, O-5-2, 2015
[3] T. Endoh, AWAD, 2B-11, 2009
[4] S. Ikeda et al, Nature Materials 9, 721–724 (2010)
[5] http://llgmicro.home.mindspring.com/

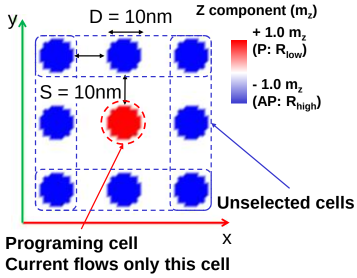
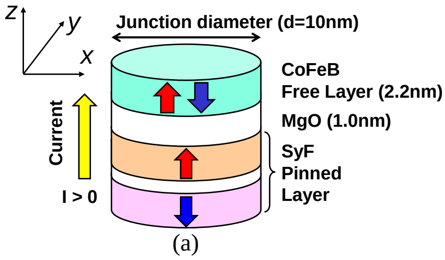


Fig. 1 Model system of p-MTJ array.



(a)

Parameter	Value
Saturation Magnetization M_s	1.58 [T]
Anisotropy constant K_u	1.0×10^6 [J/m^3]
damping factor α	0.005
Initial angle θ_0	5 [degree]

(b)

Fig. 2 (a) p-MTJ structure and (b) magnetic parameters in a free layer

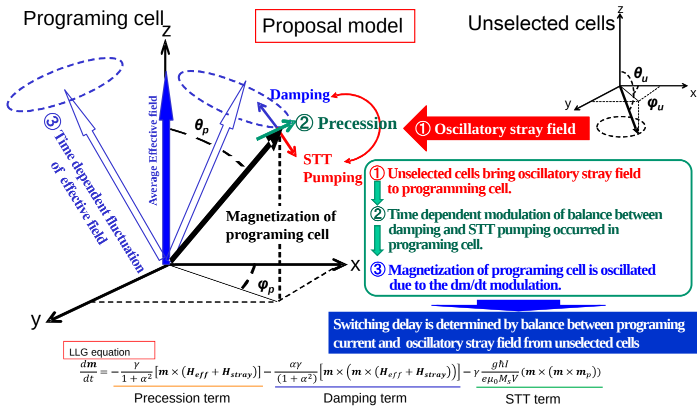


Fig. 3 Proposal model of switching delay in p-MTJ array with interference phenomena due to oscillatory stray field from unselected cells

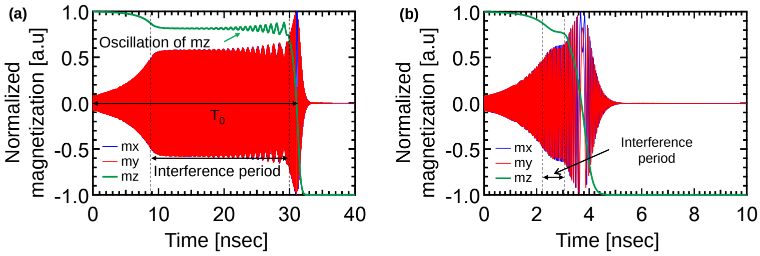


Fig. 4 Time-evolutional transfer curve of normalized magnetization of programing cell when (a) J = 11 MA/cm^3 and (b) J = 18 MA/cm^3.

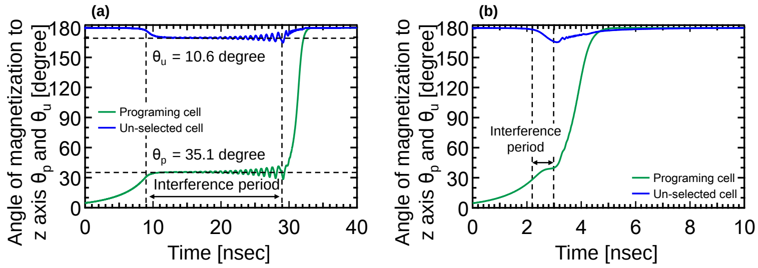


Fig. 5 Time-evolutional transfer curve of angle of magnetization to z axis θ_p and θ_u of programing cell when (a) J = 11 MA/cm^3 and (b) J = 18 MA/cm^3.

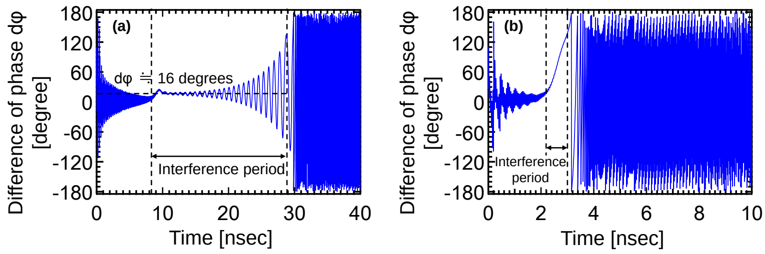


Fig. 6 Time-evolutional transfer curve of difference of phase between magnetization in programing cell and stray field from unselected cells dφ when (a) J = 11 MA/cm^3 and (b) J = 18 MA/cm^3

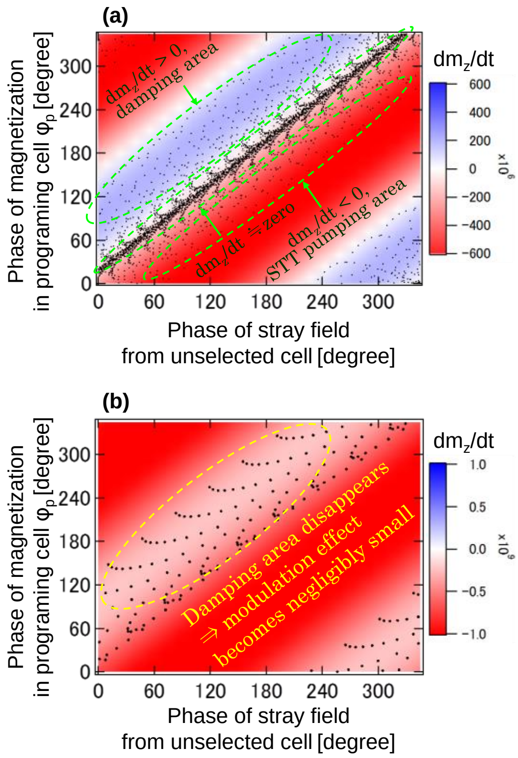


Fig.7 Magnetization phase dependence on modulation effect of damping and STT pumping balance during interference period when (a) J = 11 MA/cm^3 and (b) J = 18 MA/cm^3

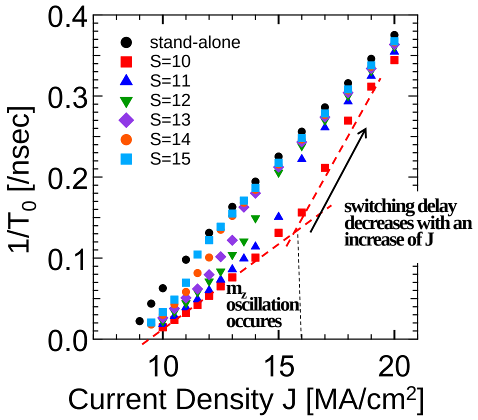


Fig8. Current density dependence of 1/T_0 as a function of cell distance S.