Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp456-457

Impact of Sub-Volume Excitation for Improving Overdrive Delay Product in Sub-40nm p-MTJ and Its Beyond

Satoshi Ohuchida[1], Kenchi Ito[2] and Tetsuo Endoh[1,2]
[1] Graduate School of Engineering, Tohoku University, 6-6 Aramaki aza Aoba, Aoba-ku, Sendai 980-8579, Japan,
[2] Center for Innovative Integrated Electronic Systems, Tohoku Univ., 468-1 Aramaki aza Aoba-ku, Sendai 980-0845, Japan
Phone: +81-22-796-3400 E-mail: tetsuo.endoh@cies.tohoku.ac.jp

Abstract

We investigated the impact of sub-volume effect on improving the overdrive delay product P_{od} in sub-40nm p-MTJ and its beyond using LLG micro magnetic simulation. Simulation results show over 26 percent reduction of the overdrive delay product by suppressing sub-volume excitation. We found the overdrive delay product can be reduced by scaling down junction diameter or enlarging exchange stiffness. These results show that p-MTJ of embedded MRAM should be scaled down under 40nm to suppress sub-volume excitation, not only for high-density but also for high speed programing.

1. Introduction

Spin transfer torque magnetic random access memory (STT-MRAM) with perpendicular magnetic tunnel junctions (p-MTJs) is one of the promising candidates for next generation non-volatile working memory [1]. Suppression of power consumption and switching speed with a few nanoseconds are required in the L3 or higher-level caches. In other words, it is necessary to decrease the product of driving power and switching delay. The switching time can be divided into two time regions: incubation time and transit time [2]. Incubation time is possible to decrease by background writing scheme as demonstrated by previous reports [3,4]. On the other hand, the method of decreasing transit time has not been found except for increasing driving current. Our previous study reported the sub-volume excitation impacts on transit time in a precessional regime [5]. Therefore the delay of transit time is significant bottleneck to realize high speed switching. In this paper, we investigated the dependence of the overdrive delay product on junction diameter and exchange stiffness in a precessional regime of magnetization reversal by using Landau-Lifshitz-Gilbert (LLG) micro magnetic simulations.

2. Simulation method

We simulated the STT magnetization reversal of p-MTJs which consist of CoFeB/MgO (1nm) based synthetic antiferromagnetic pinned layer. Figure 1 shows schematic of p-MTJ structure. Saturation magnetization M_s, anisotropy constant K_u and damping factor α are 1.58T, 1.0×10^7erg/cm^3 and 0.015, respectively. We defined the incubation time and the transit time as follows: incubation time T_{in} is the time when M_z decreases from 1.0 to -0.8, transit time T_{tr} is time when M_z decreases from +0.8 to -0.8 in magnetization reversal as shown in Fig. 2. T_0 is time before M_z decreases to zero. T_0 can be globally scaled by the well-known macro spin theory [6].

$$T_0 = \ln(\pi/2\theta_0)/(I/I_{c0}-1)\alpha\gamma H_{eff,} \quad (1)$$

where I is switching current, I_{c0} is the threshold current, γ is the gyromagnetic constant, H_{eff} is the effective field, and θ_0 is the initial misalignment angle of magnetization of a free layer to the z axis. In this paper, θ_0=5 degree in all simulations. We estimated I_{c0} (and H_{eff}) by fitting for T_0 and I using eq. (1). The overdrive I/I_{c0}-1 and the product of overdrive and delay of transit time P_{od} ware calculated.

3. Result and Discussion

Figure 3 shows the junction diameter dependence of time evolution of M_z when overdrive I/I_{c0}-1=0.5. Figure 4 shows magnetization configuration in free layer of p-MTJ with a diameter of 20nm, 40nm and 70nm, respectively. Magnetization configuration was a macro spin motion in the p-MTJ with a diameter of 20nm. Sub-volume excitation was observed in p-MTJ with a diameter over 40nm. These results corresponded with the experiments results [7]. Figure 5 shows the overdrive dependence of T_{tr} in p-MTJs. In the same overdrive, the value of T_{tr} decreased as the junction diameter was scaled down. Larger overdrive is required to realize high speed operation for p-MTJ with a diameter of 70nm. It has a problem from the view of low power operation. Therefore scaling down of junction diameter is the key to reduce P_{od}. Figure 6 shows the junction diameter and A_{ij} dependence of T_{tr} when I/I_{c0}-1=0.5 in detail. In this simulation, A_{ij} was set to 1.0, 1.9 and 3.1μerg/cm, respectively. For p-MTJs with a diameter below 20nm, T_{tr}s were nearly same value in each A_{ij}. On the other hand, the value of T_{tr} decreased with an increase in A_{ij} for p-MTJ with a diameter of 40nm. Figure 7 shows the dependence of P_{od} on overdrive. The value of P_{od} decreased as the junction diameter was scaled down when overdrive was the same. This result shows over 86% reduction of overdrive delay product by scaling down the junction diameter from 70nm to 10nm when overdrive I/I_{c0}-1=0.5. For p-MTJ with a diameter above 40nm, the increase rate of P_{od} was larger with an increase in overdrive as shown in Fig.8. Figure 9 shows the dependence of P_{od} on overdrive for each junction diameter in p-MTJ. The value of P_{od} was independent of the value of A_{ij} in p-MTJ with a diameter below 20nm. On the other hand, P_{od} decreased with an increase of A_{ij} in p-MTJ with a diameter of 70nm. Figure 10 shows overdrive and A_{ij} dependence of P_{od} in p-MTJ with a diameter of 40nm and 70nm, respectively. It is possible to decrease about 26% the value of P_{od} in p-MTJ with a diameter of 40nm by increasing A_{ij} from 1.0 to 3.1. Therefore it is one approach that increasing A_{ij} by annealing at 350°C to realize high-speed and low power switching of p-MTJ since sub-volume excitation is suppressed[8].

4. Conclusions

In summary, we investigated the impact of sub-volume effect on improving the overdrive delay product P_{od} in sub-40nm p-MTJ and by using LLG micro magnetic simulation. Simulation results show over 26 percent reduction of the overdrive delay product by suppressing sub-volume excitation. We found the overdrive delay product can be reduced by scaling down junction diameter or enlarging exchange stiffness. These results show that p-MTJ of embedded MRAM should be scaled down under 40nm that is safety size from sub-volume effect, not only for high-density but also for high speed programing.

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Acknowledgements

This research is (partly) supported by METI through its "R&D Subsidiary Program for Promotion of Academia-industry Cooperation", and JST, ACCEL.

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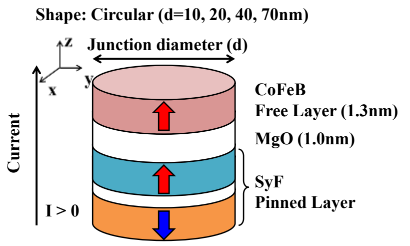

Fig. 1 Schematic of p-MTJ structure in this simulation.

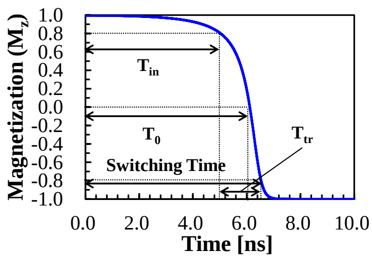

Fig. 2 The definition of incubation time T_{in}, T_0 and transit time T_{tr}.

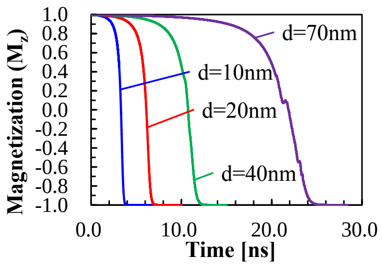

Fig. 3 Time evolution of M_z in magnetization reversal when I/I_{c0} -1=0.5.

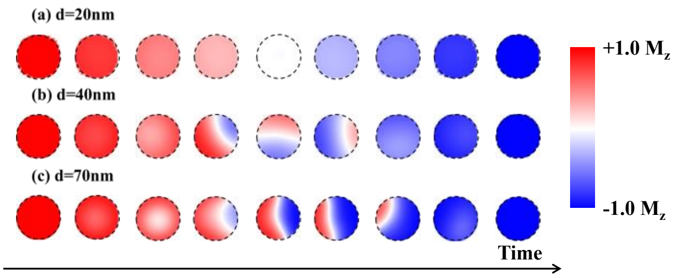

Fig. 4 Time evolution of magnetization configuration in free layer of p-MTJs (a)d=20nm, (b)d=40nm and (c)d=70nm.

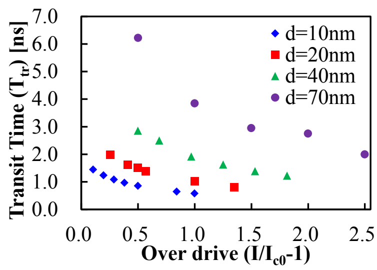

Fig. 5 Overdrive dependence of transit time when A_{ij}=1.9uerg/cm.

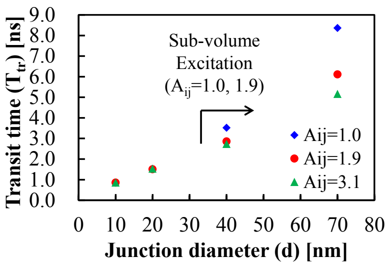

Fig. 6 Junction diameter and A_{ij} dependence of transit time when I/I_{c0}=0.5.

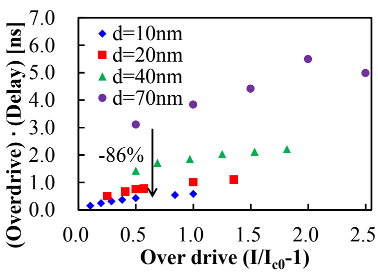

Fig. 7 Overdrive and junction diameter dependence of P_{od}.

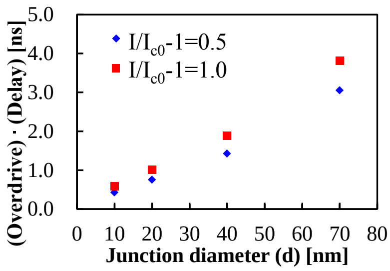

Fig. 8 Junction diameter dependence of P_{od} increasing rate.

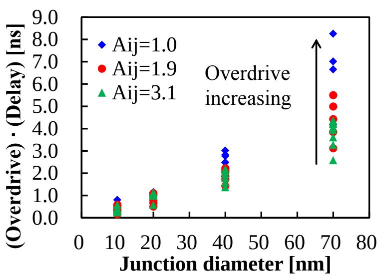

Fig. 9 Dependence of P_{od} on overdrive for each junction diameter in p-MTJ.

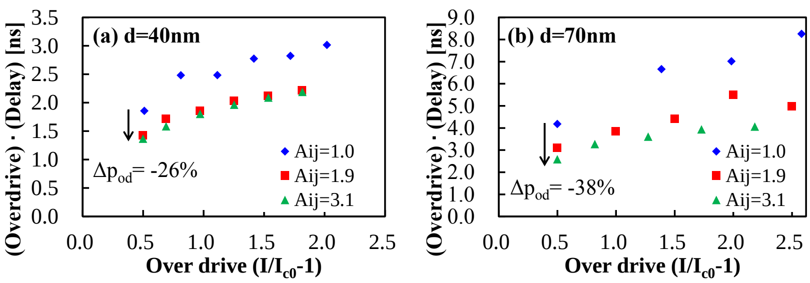

Fig. 10 Overdrive and A_{ij} dependence of P_{od} in p-MTJ (a)d=40nm (b)d=70nm.