A Model Reflecting Preheat Effect by Two-step Writing Technique for High Speed and Stable STT-MRAM

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INTRODUCTION

Spin-transfer-torque MTJ based STT-MRAMs gather attention as nonvolatile working memory candidate. Especially, low switching current, high TMR, high thermal stability are available even at 40nm size by CoFeB/MgO based perpendicular MTJ (pMTJ) [1]. However, large current is needed to improve the switching probability as the write pulse width decreases. For this issue, a two-step writing method demonstrates that the switching characteristics are improved by a base pulse which preheats MTJ [2]. However, a model reflecting a preheat effect by two-step writing is necessary for optimization of a base pulse of two-step pulse. In this paper, a switching probability model reflecting an intrinsic critical current dependence on temperature is proposed to consider the preheat effect by base pulse.

RESULT AND DISCUSSION

Fig.1 shows R-H curve of measured CoFeB/MgO based pMTJ (100nmφ). Fig.2 (a) shows schematic pulse waveform applied to pMTJ. Pulse application trials were performed 50 times for each pulse condition in the switching probability measurement. Fig.2 (b) shows a schematic measurement setup. In this setup, current flowing through MTJ is observed as a voltage at an oscilloscope. Fig.3 shows an example of observed waveform which MTJ switched from parallel (P) state to anti-parallel (AP) state. We evaluated P→AP direction here. Fig.4 shows switching probabilities. In Fig.4, the plotted point is the measured result by two-step writing. The dashed line is the switching probability calculated from the switching probability in thermal activation region [3]

$$P(t_p) = 1 - \exp\left[-\left(\frac{t_p}{\tau_0}\right)\exp\left\{-\frac{E_b}{k_B T}\times\left(1-\frac{J}{J_{C0}}\right)\right\}\right] \quad (1)$$

Here, T is temperature, J is critical current density, J_{C0} is intrinsic critical current density, E_b is energy barrier, k_B is Boltzmann's constant, t_p is switching pulse width, and τ_0 is attempt time. τ_0 was assumed as 1ns. However, the calculated switching probability from eq. (1) is not matched to the measured probability. We assumed that this is because the preheat effect by base pulse is not conciderd. To evaluate the preheat effect due to base pulse, we took account for the temperature dependence of I_{C0} in eq. (1). We measured the I_{C0} (Fig.5). By substituting this temperature dependence to eq. (1), the switching probability is expressed as,

$$P(t_p) = 1 - \exp\left[-\left(\frac{t_p}{\tau_0}\right)\exp\left\{-\frac{E_b}{k_B T}\times\left(1-\frac{I}{-0.97\times(T-273)+288}\right)\right\}\right] \quad (2)$$

To evaluate the preheat effect due to base pulse, the temperature T in eq. (2) was fitted to the measured result by changing T. We estimated the preheated effect was 14K (solid line in Fig.6).

CONCLUSION

The model which reflect the preheat effect by two-step writing was proposed. In this model, the I_{C0} dependence on temperature was took account. We considered that the calculated switching probability was well fitted to the measured result with this model.

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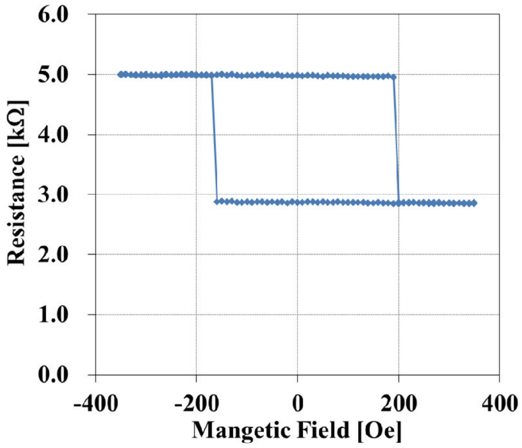

Fig. 1. R-H characteristic of measured MTJ.

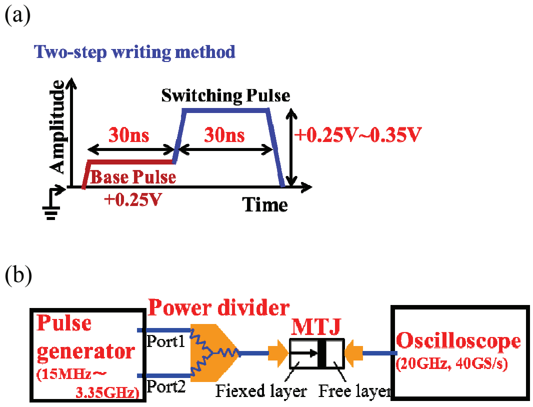

Fig. 2. (a) Schematic applied pulse. (b) Measurement setup.

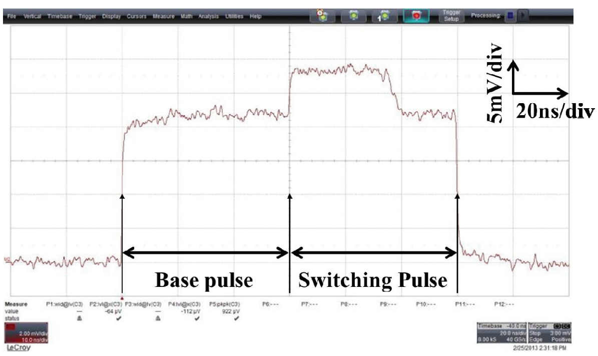

Fig. 3. Example of observed switching waveform (P→AP).

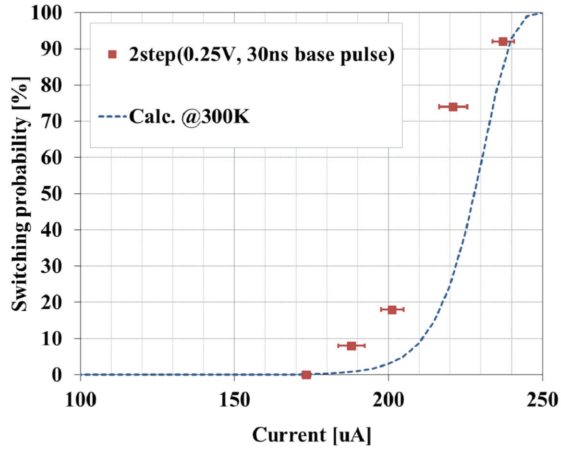

Fig. 4. Switching probabilities by two-step writing (P→AP).

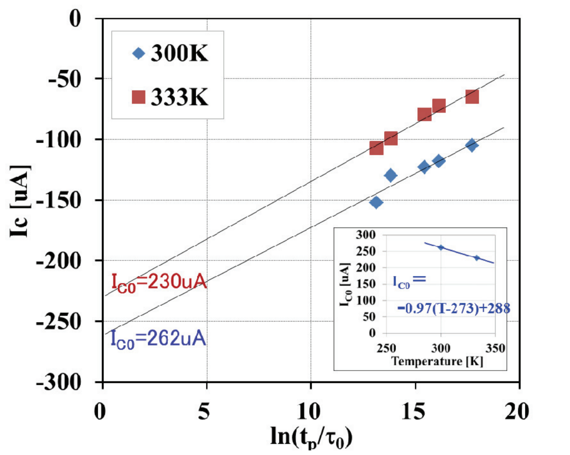

Fig.5. Critical current (I_C) vs. of $\ln(t_p/\tau_0)$. Inset is the intrinsic critical current (I_{C0}) dependence on temperature.

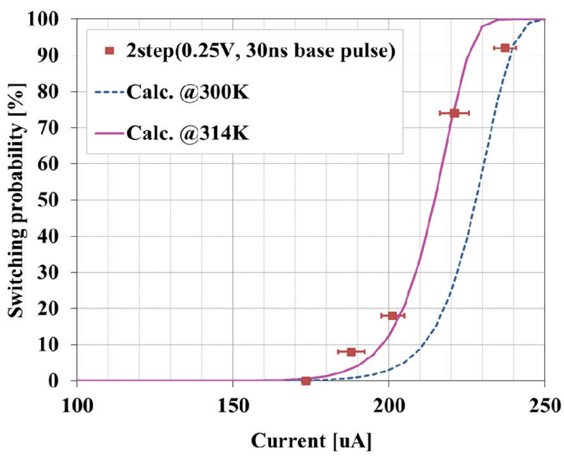

Fig. 6. Switching probabilities by two-step writing and the switching probability calculated by eq.(1) and eq.(2).