Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp1142-1143

High speed spin-transfer switching in GMR nanopillars with perpendicular anisotropy

Hiroyuki Tomita[1], Takayuki Nozaki[1], Takeshi Seki[1], Toshihiko Nagase[2], Eiji Kitagawa[2], Masatoshi Yoshikawa[2], Tadaomi Daibou[2], Makoto Nagamine[2], Sumio Ikegawa[2], Naoharu Shimomura[2], Hiroaki Yoda[2] and Yoshishige Suzuki[1]

[1]Osaka University, Department of Materials Engineering Science,Graduate School of Engineering Science
1-3 Machikaneyama, Toyonaka, Osaka, 560-8531, Japan
Phone: +81-6-6850-6427 Email: hiro.tomita@spin.mp.es.osaka-u.ac.jp
[2]Toshiba R & D center,1
Toshiba-Komukai-cho, Saiwai-ku, Kawasaki, Kanafawa 980-8577, Japan

1. Introduction

Spin-transfer switching has received increasing attention as a novel technique of magnetization switching with low energy consumption and high speed operation. To realize high density magnetoresistive random access memory using spin-transfer switching (Spin-RAM), reduction in the critical switching current density (J_{c0}) with maintaining high thermal stability factor (Δ) is important. In this point, perpendicularly magnetized system is suitable and of current interest [1]. In addition, the operating speed for a RAM, which is strongly dependent on the switching speed of information bits, becomes a key point. In this study, we investigated high-speed (>sub-nano second) spin-transfer switching properties of giant magnetoresistance (GMR) nanopillar systems with perpendicular magnetic anisotropy using sub-nano second current pulses.

2. Experiments and results

GMR spin valve structure films were sputter-deposited on thermally oxidized Si substrates. The multilayers were patterned into 100 nm diameter dot nanopillars using conventional lithography techniques. In this structure, both top free and bottom reference magnetic layers, which are separated by a Au spacer layer, are consisted of perpendicularly magnetized CoFe-based multilayer structure. The reference layer was designed to have higher perpendicular magnetic anisotropy and coercivity than that of the free layer. Figure 1 shows major (gray dots) and minor (black dots) MR curves measured under perpendicular magnetic field (H). Steep resistance change was observed in the switching process. From the major loop, the switching of the free and reference layers occur at H = 2.2 kOe and 4.6 kOe. In the minor loop, which was measured under the condition that the reference layer is along the positive direction, coercive field of free layer and dipole field from the reference layer were evaluated to be 1.5 kOe and 0.7 kOe, respectively.

Spin-transfer switching probability (P_{sw}) was examined by injecting current pulse with various pulse widths. The measurement process is as follows. First, we initialize a magnetization state by applying large current pulse and measure the resistance by a lock-in amplifier. Then we applied pulse currents for the switching and monitored the sample resistance again to confirm the switching event.

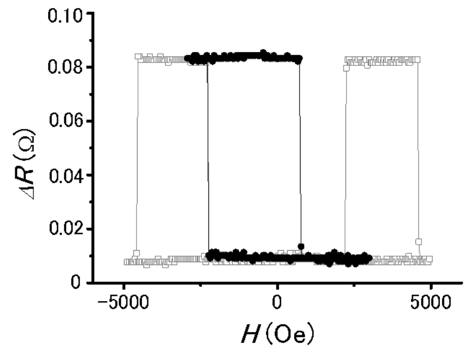

Fig 1. MR curve of the GMR nanopillar measured under a perpendicular magnetic field. (Black dots: minor loop, Gray dots: full loop)

This procedure was repeated 250 times under each measurement condition to calculate the switching probability.

Figure 2 shows P_{sw} under H = -1.2 kOe as functions of pulse width (t_{pulse} : 0.3 ~ 3.5 nsec) and current amplitudes (I : -6 ~ -15 mA). In our measurement condition, negative current corresponds to the current flowing from the bottom reference layer to the top free layer. This means that negative current prefers anti-parallel state (P to AP switching). Under this condition, we succeeded in observing high-speed switching of sub-nano second range, e.g. P_{sw}=0.5 was achieved at t_{pulse} = 700 psec with I = -15 mA.

The observed pulse amplitude dependence of the switching speed can be explained by Sun's macro-spin dynamic reversal model [2].

$$\tau_{sw} = \tau_1 \frac{\ln(\pi/2\theta_0)}{[(I/I_{c0})-1]} \propto \frac{1}{I - I_{c0}} \quad (1)$$

$$(\tau_1 = 1/\alpha\gamma H)$$

In this formula θ_0, I_{c0}, α, γ and H are initial relative angle of the reference and the free layer's magnetization, critical switching current at zero temperature, damping constant, gyro magnetic constant and effective magnetic field respectively. From the fitting using the results at P_{sw}=0.5, we could estimate the critical switching current I_{c0} = -6.6 mA (current density J_{c0} = -8.4 x 10^{+7} A/cm^2).

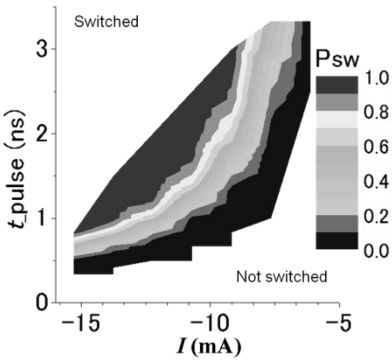

Fig 2. Switching probability as functions of the pulse current amplitude and width under H = -1300 Oe.

We also evaluated switching speed distributions. These distributions come from distributions of θ_0 which arise from the thermal fluctuation of magnetization at room temperature. But including this thermal effects, P_{sw} can be expressed by this formula [3].

$$P_{sw} = 1 - \frac{\pi^2}{4} \Delta \exp\left(-\frac{t}{\tau}\right) \quad (2)$$

Using eq.(2) we fitted P_{sw} at I = -14 mA in long time limit as shown in the figure 3. From the fitting, thermal stability factor (Δ) and feature time in coherent switching (τ) were estimated to be Δ = 140 and τ = 140 psec, respectively.

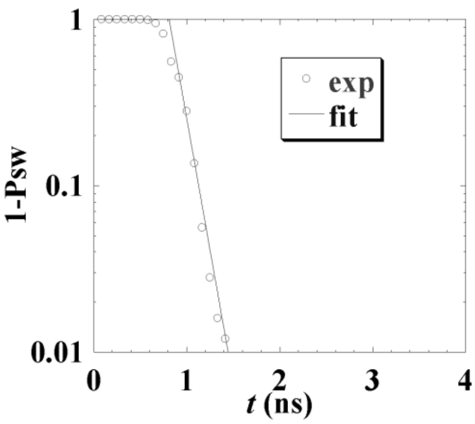

Fig 3. Logarithmic scale of the non-switching probability (1-P_{sw}) as a function of pulse width (I = -14 mA).

In the presentation, we will discuss details of switching probability, for instance distribution of P_{sw} as a function of pulse width and pulse amplitude.

3. Conclusions

We evaluate switching probability in high speed spin-transfer switching in the sub-nano second region. By applying -15 mA short current pulse, we could obtain the P_{sw} = 0.5 by the application of short current pulse of 700 psec. The observed pulse width and current amplitude dependence of the P_{sw} could be explained well by using Sun's macro-spin model. And we also investigated about the switching time distribution, which arise from the thermal fluctuation of the initial relative angle of magnetizations. By including an influence of the thermal fluctuation to the Sun's macro-spin dynamic reversal model, exponential decay of the switching time distributions were explained well. From the fitting, we could evaluate the thermal stability factor and feature time in coherent switching of our GMR device. For the fastest case, the feature time in coherent switching of about 140 pico-second was obtained at under -14 mA

Acknowledgements

This work was partly supported by NEDO spintronics nonvolatile device project. H. Tomita. is supported by Research Fellowship of the JSPS for Young Scientists.

References

[1] S. Mangin et al, Nature Mat. **5** 210 (2006)
[2] J. Z. Sun, Phys. Rev. B **62** 570 (2000)
[3] J. He, J. Z. Sun, S. Zhang, Jour. App. Phys. **101** 09A501 (2007)