Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp19-20

Saving Energy Consumption of Memory Systems by Voltage-Control Spintronics Memory (VoCSM)

H. Yoda, Y. Ohsawa, Y. Kato, N. Shimomura, M. Shimizu, K. Koi, S. Shirotori, T. Inokuchi, H. Sugiyama, S. Oikawa, B. Altansargai, and A. Kurobe

Toshiba Corp.
1, Komukai-Toshiba-cho, Saiwai-ku,
Kawasaki 212-8582, Japan
Phone: +81-80-6673-8602 E-mail: hk.yoda@toshiba.co.jp

Abstract

We designed a voltage-control spintronics memory unit-cell, VoCSM, with high write-efficiency to prove a potential to reduce writing energy per bit. By optimizing a self-aligned, the cell has the critical switching current (Icsw) smaller than 50μA at 20 nsec. for designed MTJ size of about 50×150 nm^2. The value is much smaller than that for matured STT-MRAM with the similar dimension.

1. Introduction

MRAM has been developed since 1980s until now with several ups and downs. The ultimate purpose is to realize non-volatile working memories to save energy consumption of conventional volatile working memories such as SRAM and DRAM. However all of non-volatile memories including MRAM have been facing a dilemma of non-volatility and high energy consumption in their active mode because non-volatility has led to large writing-energy consumption, Ew.

As a result, they have been used as data storages and none of them overcame the historical dilemma for busy applications. This is the one of the reasons why MRAM has not had big markets so far.

Recently, the possibilities of overcoming the dilemma were demonstrated by both STT-MRAM and VoCSM [1], [2]. STT has better maturity but less room for further improvement. On the other hands, VoCSM has poor maturity but better potentials in terms of higher writing efficiency and better endurance [3].

In this talk, STT technologies and VoCSM technologies is reviewed with respect to saving energy consumption and remaining issues for VoCSM will be discussed

2. POSSIBILITY OF SMALL CRITICAL SWITCHING ENERGY PER BIT, ECSW, OF VOCSM

An STT cell and a VoCSM cell are shown in fig.1. In the VoCSM cell, one electron can applies spin-torque several times, while in the STT cell, one electron can applies spin-torque once. Application of negative voltage to the VoCSM cell further reduces the critical switching current, I_{csw}, because of the voltage dependence as shown in fig.2.

The critical switching current for VoCSM with voltage, V, applied is given by the equation (1) [4].

$$I_{csw}(\mathrm{VoCSM}) = 4e\alpha^{*}_{eff} / \hbar\ \theta_{SH} \cdot \triangle E_{sw}(V) \cdot t_{SH} / w_{f} \quad (1)$$

Here, α^{*}_{eff}, e, $\hbar$, θ_{SH}, $\triangle E_{sw}$, t_{SH}, w_f are the effective damping constant, charge of an electron, reduced Plank's constant, the spin-Hall angle(spin polarization), the switching energy-barrier, the thickness of the spin-Hall electrode, and the width of the storage-layer, respectively. In this case, the width of spin-Hall electrode is assumed to be the same as w_f, i.e. MTJs are self-aligned with the electrode.

Small I_{csw} of 37μA at write pulse-width of 20nsec. was successfully demonstrated due to high efficiency of spin-Hall writing and combined the voltage-assist [5]. The value of the I_{csw} is almost the same as that for STT-writing, even though the size of MTJ for VoCSM-writing (~50nm×150nm) is much larger than that of STT-writing(30nmø).

Critical switching energy per bit for VoCSM-writing, e_{csw} (VoCSM), is the product of I_{csw}, write pulse-width (t_p), and voltage across the spin-Hall electrode. It is roughly given by the equations (2), assuming the spin-Hall electrode has square in-plane shape [4].

$$e_{csw}(\mathrm{VoCSM}) = \{4e\alpha^{*}_{eff}/\hbar\theta_{SH} \cdot \triangle E_{sw}(V) \cdot t_{SH}/w\}^{2} \cdot t_p \cdot R_{sh} \quad (2)$$

Here, R_{sh} is the sheet resistance of spin-Hall electrode with the typical value of 200-500Ω.

Similarly, critical switching current and critical switching energy per bit for STT-MRAM are given by the equation (3) and (4) [4], [6].

$$I_{csw}(\mathrm{STT}) = 4e\alpha_{eff}/\hbar\ g(\theta) \cdot \triangle E_{sw} \quad (3)$$

$$e_{csw}(\mathrm{STT}) = \{4e\alpha_{eff}/\hbar\ g(\theta) \cdot \triangle E_{sw}\}^{2} \cdot t_p \cdot R_{MTJ} \quad (4)$$

Here, α_{eff}, g (θ), and R_{MTJ} are the effective damping constant, the spin polarization, and the resistance of MTJ with a typical value of 10kΩ.

Fig.3 shows reduction trend of the e_{csw}s for STT-writing and VoCSM-writing.

The typical properties of the MTJ for VoCSM are the tunnel magnetoresistance (TMR) ratio of 170-180%, the resistance area product (RA) of 0.8-1.0 kΩμm^2 and the saturation magnetization (Ms) of the storage layer of 1550 emu/cm^3. The VCMA coefficient was about 77 fJ/{(V/m) m^2} and the spin Hall angle (θSH) was about -0.09--0.18.

Even though the maturity of VoCSM is poor, the smallest e_{csw}s of about 10fJ/bit have been demonstrated by VoCSM.

3. PRACTICALLY UNLIMITED ENDURANCE OF VOCSM

In VoCSM, write-current flows in the spin-Hall electrode made of heavy metal such as Ta having high melting temperature. Due to this, unlimited endurance of 1E+13 was demonstrated even at write pulse-width of 5nsec. as shown in fig.6 [3].

4. CONCLUSIONS

Both non-volatility and low energy consumption have been proved to coexist in VoCSM. Further, VoCSM cell has practical unlimited endurance of 1E+13. Therefore, it is concluded that VoCSM has a potential to solve the historical dilemma of non-volatility and high energy consumption even for busy applications.

Acknowledgements

This work was partly supported by the ImPACT Program of the Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

References

[1] H. Yoda, *et al.*, "The Progresses of MRAM as a Memory to Save Energy Consumption and Its Potential for Further Reduction," *2015 Symposium on VLSI Technology*, T104-105

[2] H. Yoda, *et al.*, "Voltage-Control Spintronics Memory (VoCSM) Having Potentials of Ultra-Low Energy-Consumption and High-Density," *Digests of 62th IEDM*, 27.6 (2016)

[3] H. Yoda, *et al.* , "High-Speed Voltage-Control Spintronics Memory," *2017 IEEE 9th International Memory Workshop*, p165-p168

[4] H. Yoda, *et al.*, "VOLTAGE-CONTROL SPINTRONICS MEMORY HAVING POTENTIALS FOR HIGH-DENSITY AND HIGH-SPEED APPLICATIONS," presented at TMRC2017, http://www.nims.go.jp/mmu/tmrc2017/att/F1.pdf

[5] Y. Ohsawa, *et al.*, "Ultra-high-efficient Writing in Voltage-Control Spintronics Memory (VoCSM); the Most Promising Embedded Memory for Deep Learning." presented at EDTM2018

[6] H. Yoda, *et al.*, "VOLTAGE-CONTROL SPINTRONICS MEMORY HAVING POTENTIALS FOR HIGH-DENSITY AND HIGH-SPEED APPLICATIONS," presented at Intermag2018,

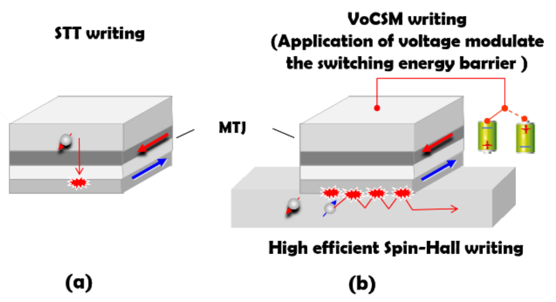

Fig. 1 Writing mechanisms and cell structures of STT writing and VoCSM writing.

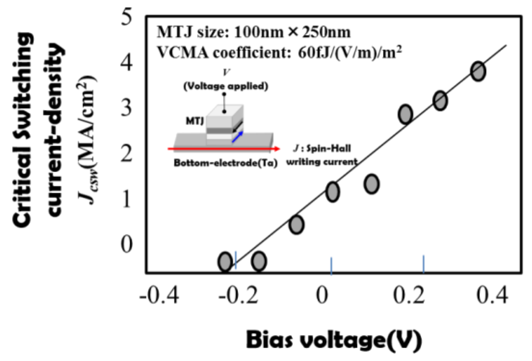

Fig.2 Fundamental VoCSM write property

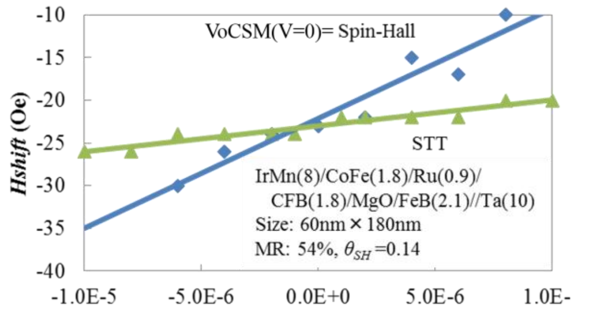

Fig.3 Write efficiency experimental results for STT writing and VoCSM with no voltage applied.

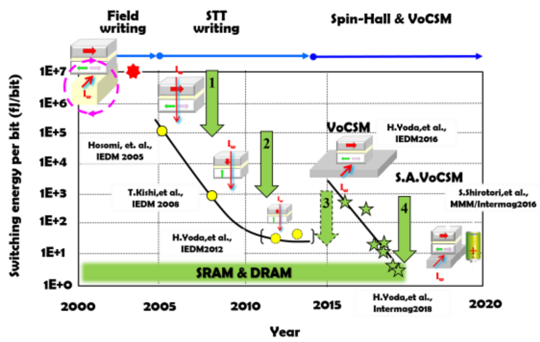

Fig. 4 Switching energy reduction trend of spintronics memories.

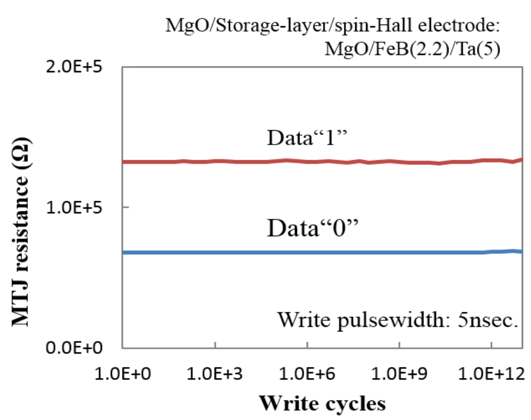

Fig.5 Endurance test results of VoCSM