VOLTAGE-CONTROL SPINTRONICS MEMORY HAVING POTENTIALS FOR HIGH-DENSITY AND HIGH-SPEED APPLICATIONS

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I. INTRODUCTION

In order to reduce energy consumption of memory hierarchy, several non-volatile memories have been developed. However all of the candidates consume more energy in active modes than save in stand-by modes for busy mobile applications. Therefore, usage of non-volatile memories has been limited to storage of data. This is a historical dilemma that all the candidates have not solved.

In this paper, developments and performances of voltage-control spintronics memories (VoCSM) cell are explained and a potential of reduction in writing-charge, Q_w is discussed.

II. FUNDAMENTAL WRITING PROPERTY OF THE VoCSM CELL

In its writing mode, voltage is applied to the top-electrodes of the MTJs to control the switching energy-barrier by changing surface perpendicular anisotropy, K_s of the storage-layer due to VCMA-effect. The write-current, I_w flows in the bottom spin-Hall electrode made of 5d heavy metal such as Ta to write data due to spin-Hall effect.

The fundamental writing property of the cell is shown in Fig.1. In case of the CoFeB/MgO/ CoFeB/Ta junction, positive voltage lowers K_s and the switching current-density, J_{csw}, increases. On the contrary, negative voltage heightens K_s and J_{csw} decreases as shown in Fig.1. This properties is the necessity for VoCSM cell must possess.

III. DEMONSTRATION OF VoCSMS

(a) High-density VoCSM

The high-density VoCSM memory architecture employs a string of MTJs as memory cells as shown in Fig. 1 (a). The string consists of eight MTJs (bits) located on the bottom-electrode.

In writing-mode, a set of two writing-currents, I_w, flow in the electrode to apply spin-Hall torque while voltage is applied to the bits to control the switching energy-barrier. In order to select bits to write data, negative voltage referred to as activating voltage (V_a) is applied, while positive voltage referred to as deactivation voltage (V_{da}) is applied to non-selected bits that heightens the switching energy-barrier to avoid write-disturbance.

In reading mode, positive voltage is applied to avoid read-disturbance.

The write error-rate curve is shown in Fig.2 (b). The curves are the typical deterministic spin-transfer-torque curve. Selective-writing scheme was applied to MTJs and the results are shown in Fig.2 (c). There observed no writing-errors for total of 160 sets of writing-pulses. This indicates that selective-writing scheme does work.

(b) High-speed VoCSM

The high-speed VoCSM architecture employs a string-structure of two MTJs as shown in Fig.3 (a).

In its reading mode, differential reading is employed to compensate relatively large RC delay of the order of nsec. due to large resistance of MTJs.

In its writing mode, acceleration voltage, V_a , is applied to the MTJs to accelerate switching speed.

The write-currents, I_w flow in the bottom-electrode at the same timing in opposite directions for the two MTJs to be applied spin-torques in opposite directions. Then, magnetizations of the two MTJs switch to opposite polarities with each other. The writing scheme is called complementary flash-writing. Fig. 3 (b) shows the results of the complementary flash-writing with V_a=−0.8V. The flash-writing does work.

I_w pulsewidth dependences of I_{csw} are shown for both conventional spin-Hall writing and VoCSM in Fig.3 (c). If the same write current-density, J_w, for example J_w= 0.6 J_{co} is fed for the both cases, tconventional spin-Hall writing may have switching speed of 1000nsec. but VoCSM may have switching speed of 10nsec. A potential to have ultra-high-speed writing of the VoCSM is proved

IV. DISCUSSION ON REDUCTION IN Q_w

I_{csw} scales with the junction area as shown in Fig.4. All we should do to lower I_w is to scale the area, as

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far as the switching energy-barrier is bigger than the retention energy-barrier, to achieve small Q_w.

V. CONCLUSION

The VoCSMs were proved to work and the I_w scales with the junction area. Therefore, it is concluded that the VoCSMs have a potential to solve the historical dilemma.

ACKNOWLEDGMENT

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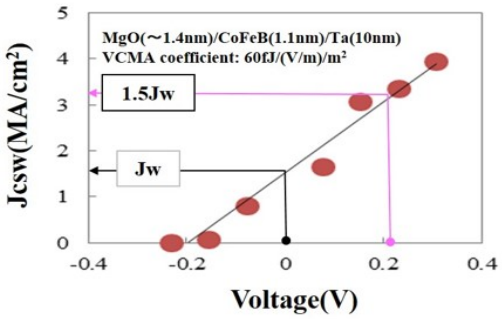

Figure 1. Voltage dependence of Critical switching current density of a VoCSM cell

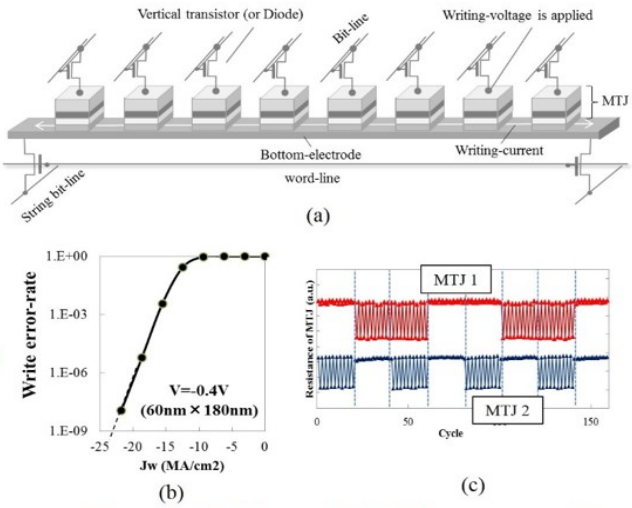

Figure 2. High density VoCSM demonstration[1] A schematic drawing of the unit-cell (b)WER of the VoCSM (c) Demonstration of Flash-writing

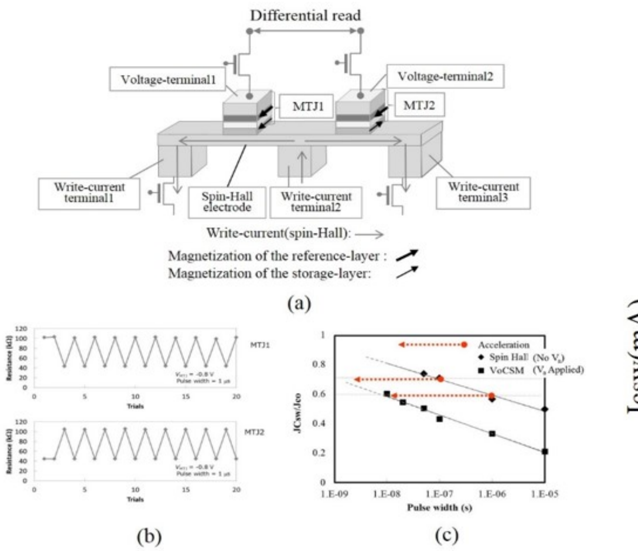

Figure 3. Demonstration of high-speed VoCSM [2]
(a) A schematic drawing of the unit-cell
(b) Demonstration of complementary flash-writing
(c) Pulsewidth dependence of Icsws for spin-Hall writing and VoCSM

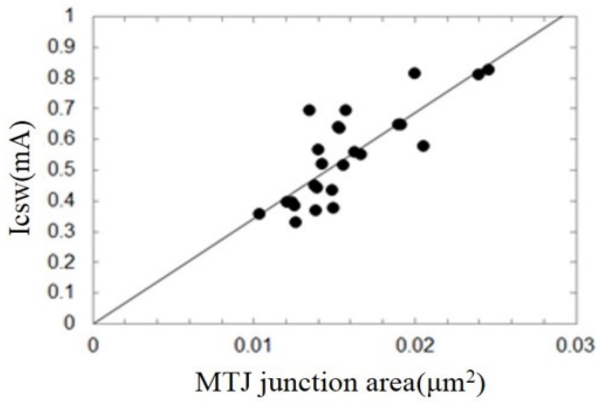

Figure 4. Junction area dependence of Critical switching current of a VoCSM cell[3]