VOLTAGE-CONTROL SPINTRONICS MEMORY (VoCSM) FABRICATED BY TWO-STEP SELF-ALIGNED (TSSA) PROCESS

Y. OHSAWA, H. YODA, S. SHIROTORI, H. SUGIYAMA, M. SHIMIZU, B. ALTANSARGAI, N. SHIMOMURA, Y. SAITO, T. INOKUCHI, Y. KATO, K. KOI, S. OIKAWA, M. ISHIKAWA, Y. KAMIGUCHI, K. IKEGAMI, A. TIWARI, and A. KUROBE

Toshiba Corporation, Kawasaki, Japan, yuichi.osawa@toshiba.co.jp

I. Concept of VoCSM and TSSA process

The voltage-control spintronics memory (VoCSM) whose writing principle using spin Hall effect (SHE) under voltage-controlled magnetic anisotropy (VCMA) effect and device structure of multi-MTJs lining up on the same SHE electrode is designed for high density, low energy consumption, and high robustness against read-disturbance. The first conceptual demonstration was performed successively [1]. The two-step self-aligned (TSSA) process of VoCSM is designed for low write current (*i.e.* low energy consumption) and mass production by means of coincidence in widths of SHE electrode and magnetic tunnel junctions (MTJs) each other.

II. Experimental

The TSSA process is shown in Fig. 1. A mask pattern in a stripe configuration is formed on the MTJ stack located on the SHE electrode film (a). The MTJ stack is patterned into multi-stripes configuration on the SHE electrode film to form parallel aligned MTJ multi-wires by means of Ar-ion-beam etching (b). Both the multi-wires and remaining SHE electrode film are then etched using stripe masks orthogonal to the multi-wires (c)-(d). Finally, voltage-controlled magnetic anisotropy (VCMA) electrodes which apply assist voltage for write or no-write control of each storage layer are formed on the MTJs, respectively (e). A cross-sectional transmission electron microscope (XTEM) image of one of the MTJs on the SHE electrode is shown in (f). Since the edges of MTJ and SHE electrode coincides each other by means of TSSA process, the write current flows in the SHE electrode would interacts to the storage layer effectively. Conformation of writing is performed by tunnel magnetoresistance (TMR) readout between the VCMA and SHE electrodes.

MTJs with in-plane anisotropy whose easy axis aligns orthogonal to direction of write current are used for write tests. The mainly used MTJ stack and SHE electrode films are Ta (5nm)/ IrMn (8nm)/ CoFe (1.8nm)/ Ru (0.9nm)/ CoFeB (1.8nm)/ MgO (1.7nm)/ CoFeB (1.2nm)[storage layer] / Ta (10nm) [SHE electrode] from top. The films were sputter-deposited on a thermally-oxidized Si wafer. The TMR ratio and resistance-area product (*RA*) of the films are around 150% and 1kΩ μ m^2, respectively.

III. Results and discussion

Figure 2 shows I_c for a writing pulse width of 20 ns as a function of the MTJ area without any voltage assist. The inset shows configuration of the MTJ/SHE element schematically. The short axis widths of the storage layer were changed from 35 nm to 55 nm and the long axis widths were changed from 145 nm to 345 nm which were the same width as the SHE electrode widths. We find intrinsic scalability in MTJ size dependence of a critical write current (I_c) which is defined as current with a 50% writing probability. The I_c decreases monotonically as the MTJ size decreases. About 200µA of I_c at 20nsec for a MTJ size of 7600 nm^2 whose value was comparable to that for STT-writing with the similar dimension was obtained. Furthermore, I_c

Yuichi OHSAWA
E-mail: yuichi.osawa@toshiba.co.jp
tel: +81-44-5492130

decreased about 50µA at a -0.8V-VCMA electrode voltage due to the VCMA effect. The linear correlation between MTJ area and I_c predicts much smaller I_c would be obtained by means of reduction in size of MTJs, *i.e.* decrease in cross section of SHE electrode (width x thickness), and moreover increase in VCMA effect would also decrease in I_c as well.

IV. Conclusion

The I_c of about 200µA was obtained at 20nsec writing pulse width whose value is comparable to that for matured STT-MRAM with the similar dimension. It is concluded that by applying both the SHE and the VCMA effect, the VoCSM using TSSA process has a potential of high write-efficiency and strong candidate for spintronic memories.

Acknowledgement

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REFERENCES

1) H. Yoda et al., "Voltage-Control Spintronics Memory (VoCSM) Having Potentials of Ultra-Low Energy-Consumption and High-Density", IEDM16-679

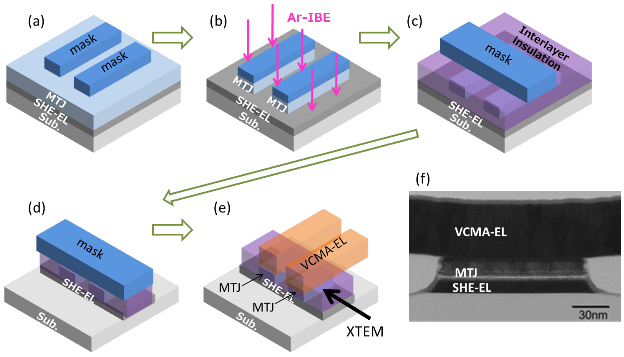

Fig. 1. Illustration of TSSA process. XTEM image (f) was observed from the direction indicated by the arrow in (e)

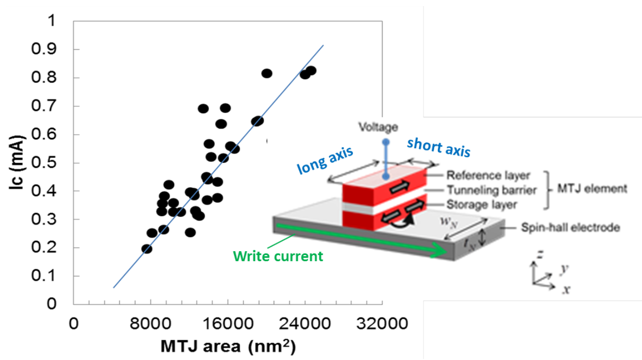

Fig. 2. I_c as a function of MTJ area. The line is a guide for the eyes. The inset shows configuration of the MTJ/SHE element. Easy axis in the storage layer aligns along the long axis.