Precession orbital transition in voltage-driven magnetization switching induced by thermal activation

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Introduction Induction of coherent magnetization switching [1] by the voltage-controlled magnetic anisotropy (VCMA) in ferromagnetic thin films [2] has opened a way of realizing ultralow-energy manipulation of magnetization in magnetic random access memory (MRAM) cells. To realize such voltage-controlled MRAM, there is a strong demand of reducing the write error rate (WER) of each cell. Recently, we reported a WER of ~ 2×10^{-5} in a perpendicularly-magnetized magnetic tunnel junction (p-MTJ) having a Ta/$(Co_{31}Fe_{69})_{80}B_{20}$ (1.1 nm)/MgO structure [3] and a further lower WER of ~ 2×10^{-6} by optimizing the fall time as well as the duration (t_{pulse}) of write pulse [4]. Yet how the WER is affected by the external fields and thermal fluctuations has not fully been understood. Therefore, here we study the voltage-driven magnetization switching in p-MTJs combining both experiment and numerical simulation. We show that the WER exhibits a local maximum at a certain t_{pulse} as we increase the external magnetic fields, which is well explained by taking into account transitions of magnetization between two different precession orbits.

Experiment The experiment was carried out using the experimental setup illustrated in Fig. 1(a). The p-MTJ consists of a Ta (5)/$(Co_{31}Fe_{69})_{80}B_{20}$ (1.1)/MgO (1.4) (parentheses in nm) free layer and a 1.4-nm-thick $(Co_{10}Fe_{90})_{80}B_{20}$ reference layer whose magnetization direction was fixed by a [Co/Pt]-based perpendicularly-magnetized synthetic antiferromagnetic layer. Voltage pulses with various t_{pulse} were generated in the arbitrary waveform generator, and were fed to the p-MTJ to induce the voltage-driven magnetization switching. The magnetization configuration in the p-MTJ was monitored by using the real-time oscilloscope. These measurements were carried out at a tilted static magnetic field H with a polar angle θ. The simulation was done by numerically solving the Landau-Lifshitz-Gilbert equation using macrospin approximation.

The red open circles in Fig. 1(b) display the dependence of WER on t_{pulse} measured at H = 950 Oe and θ = 21°. In addition to a dip around t_{pulse} = 0.25 ns corresponding to half the period of magnetization precession, a local maximum is clearly visible around t_{pulse} = 0.15 ns. We found that this local maximum originates from the fluctuation of precession orbit of magnetization. In fact, as shown in Fig. 1(b), the experimental data were well reproduced by the numerical simulation taking into account transition of magnetization between precession orbits during the relaxation process. We also show that the increase of WER due to the orbit transition can be avoided by setting t_{pulse} to a proper value.

This work was partly supported by ImPACT Program of Council for Science, Technology.

References [1] Y. Shiota et al., *Nat. Mater.*, **11**, 39 (2012). [2] T. Maruyama et al., *Nat. Nanotech.*, **4**, 158 (2009). [3] Y. Shiota et al., *Appl. Phys. Lett*, **111**, 022408 (2017). [4] T. Yamamoto et al., *The 78th JSAP Autumn Meeting, 2017*

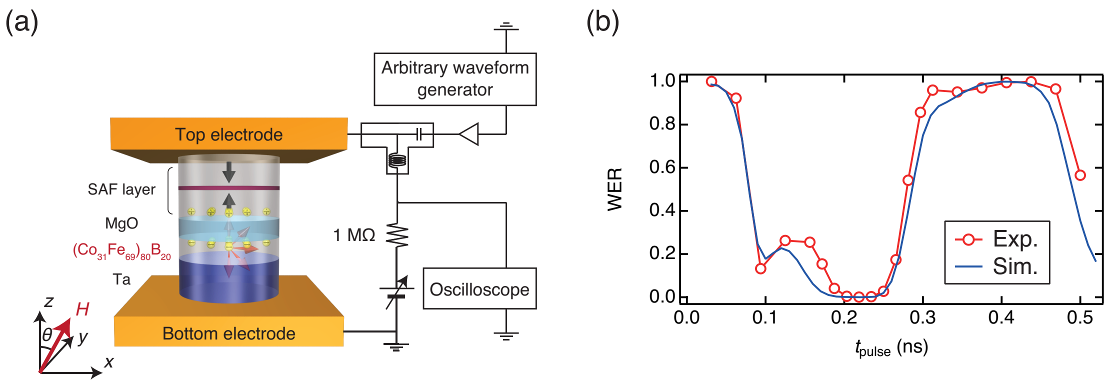

Figure 1 (a) Schematic illustration of the p-MTJ along with the measurement circuit. (b) WER as a function of t_{pulse}. Open red symbols and blue line correspond to the data obtained from the experiment and the numerical simulation, respectively.