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 to reduce the write error rate (WER) of each cell. Recently, we reported a WER of \(-2 \times 10^{-6}\) in a perpendicularly-magnetized magnetic tunnel junction (p-MTJ) having a Ta/(Co\(_{31}\)Fe\(_{69}\))\(_{20}\) (1.1 nm)/MgO structure [3] and a further lower WER of \(-2 \times 10^{-6}\) by optimizing the fall time as well as the duration \(t_{\text{pulse}}\) of write pulse [4]. Yet how the WER is affected by the external fields and thermal fluctuations has not yet been understood. Therefore, here we study the voltage-driven magnetization switching in p-MTJs combining both experimental and numerical simulation. We show that the WER exhibits a local maximum at a certain \(t_{\text{pulse}}\) 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\(_{69}\))\(_{20}\) (1.1 nm)/MgO (1.4 nm) free layer and a 1.4-nm-thick (Co\(_{31}\)Fe\(_{69}\))\(_{20}\) reference layer whose magnetization direction was fixed by a [Co/Pt]-based perpendicularly-magnetized synthetic antiferromagnetic layer. Voltage pulses with various \(t_{\text{pulse}}\) 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 \(\theta\). 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 \(t_{\text{pulse}}\) measured at \(H = 950\) Oe and \(\theta = 21^\circ\). In addition to a dip around \(t_{\text{pulse}} = 0.25\) ns corresponding to half the period of magnetization precession, a local maximum is clearly visible around \(t_{\text{pulse}} = 0.15\) 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 \(t_{\text{pulse}}\) to a proper value.

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References


Figure 1 (a) Schematic illustration of the p-MTJ along with the measurement circuit. (b) WER as a function of \(t_{\text{pulse}}\).

Open red symbols and blue line correspond to the data obtained from the experiment and the numerical simulation, respectively.