Voltage-driven magnetization switching using inverse-bias scheme

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Introduction Voltage-controlled magnetic anisotropy (VCMA) induced by sub-nanosecond voltage pulses can dynamically switch magnetizations in magnetic tunnel junctions (MTJs) [1], and that has attracted much attention as a promising technique enabling energy-efficient manipulation of magnetizations in magnetic random access memory (MRAM) cells. However, the voltage-driven magnetization switching generally exhibits higher write error rates (WERs), which is the main issue for the practical applications. Recently, we demonstrated that the WER can be reduced by improving both the thermal stability factor and the VCMA effect in MTJs [2]. We also revealed the existence of thermally induced precession orbit transition during the voltage-driven magnetization switching [3], and that has reminded us of controlling the pulse shape to reduce the WER. Indeed, there is a proposal for reducing WER by using the *Inverse-bias* scheme [4]. As shown in Fig. 1(a), in the inverse-bias scheme, a bias voltage whose polarity is opposite to the write pulse is applied before and after the write pulse. The inverse bias acts to enhance the uniaxial magnetic anisotropy K_u and hence reduce the thermal fluctuations before and after the write pulse. Although this effect has been investigated numerically [5], it still lacks experimental evidences. In this work, we study experimentally the voltage-driven magnetization switching using the inverse-bias scheme. We also employ detailed numerical simulations for understanding the magnetization dynamics and the dependence of WER.

Experiment The MTJ used for the experiment consists of a Ta (5 nm)/$(Co_{31}Fe_{69})_{80}B_{20}$ (1.1 nm)/MgO (1.4 nm) free layer and a 1.4-nm-thick $(Co_{10}Fe_{90})_{80}B_{20}$ reference layer. The duration of the inverse bias before and after the write pulse (t_{before} and t_{after}, respectively) as well as the write pulse width t_{pulse} were controlled independently using an arbitrary waveform generator. The magnetization configuration in the p-MTJ was monitored by using the real-time oscilloscope. The numerical simulations were done by numerically solving the Landau-Lifshitz-Gilbert equation using macrospin approximation.

Fig. 1(b) displays the dependence of WER on t_{pulse} obtained from the experiments. The application of inverse bias *after* the write pulse reduces the WER. However, in contrast to the initial prediction, the application of inverse bias *before* the write pulse was found to rather increase the WER, and a lowest WER was achieved when inverse bias is applied only after the write pulse. These experimental results were well reproduced by the numerical simulations, and the increase of WER was explained by the increased probability that the magnetization relaxes from an energetically higher position.

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References [1] Y. Shiota et al., *Nat. Mater.*, **11**, 39 (2012). [2] Y. Shiota et al., *Appl. Phys. Lett.*, **111**, 022408 (2017). [3] T. Yamamoto et al., *Phys. Rev. Applied*, accepted. [4] H. Noguchi et al., *IEDM Tech. Dig.*, 2016, 27.5 [5] T. Ikeura et al., *Jpn. J. Appl. Phys.*, **57**, 040311 (2018).

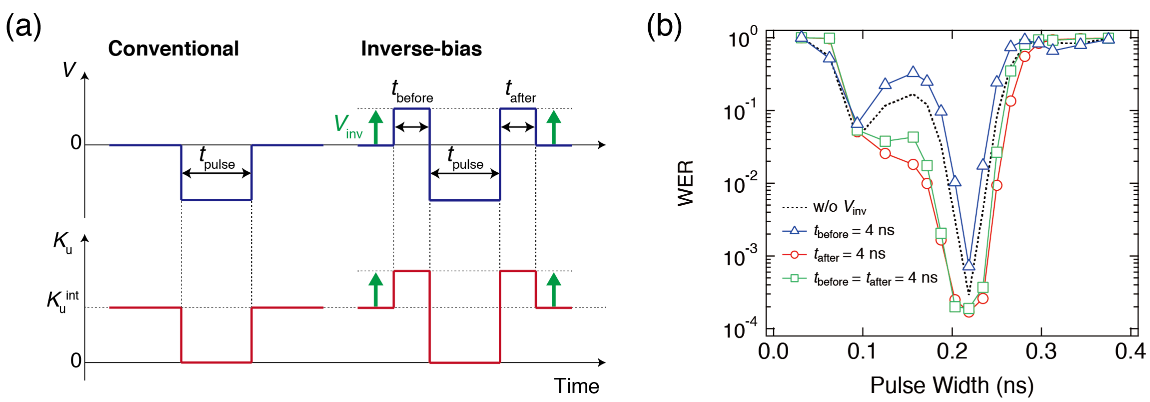

Figure 1 (a) Voltage sequences of the conventional and the inverse-bias schemes. (b) Experimentally obtained WER as a function of t_{pulse}.