Recent progresses and future challenges in voltage-controlled magnetic anisotropy effect

T. Nozaki[1], Y. Shiota[1], A. Kozioł-Rachwał[1, 2], M. Tsujikawa[3,4], T. Yamamoto[1], X. Xu[5], T. Ohkubo[5], T. Tsukahara[6], S. Miwa[6, 7], M. Suzuki[8], S. Tamaru[1], H. Kubota[1], A. Fukushima[1], K. Hono[5], M. Shirai[3,4], Y. Suzuki[1, 6, 7], and S. Yuasa[1]

1) AIST, Spintronics Research Center, Tsukuba, Ibaraki, 305-8568
2) AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland
3) Research Institute of Electrical Communication, Tohoku Univ., Sendai, Miyagi 980-8577, Japan
4) Center for Spintronics Research Network, Tohoku University, Sendai, Miyagi, 980-8577, Japan
5) NIMS, Research Center for Magnetic and Spintronic Materials, Tsukuba, Ibaraki 305-0047, Japan
6) Graduate School of Engineering Science, Osaka Univ., Toyonaka, Osaka 560-8531, Japan
7) Center for Spintronics Research Network, Osaka Univ., Toyonaka, Osaka 560-8531, Japan
8) Japan Synchrotron Radiation Research Institute (JASRI), Sayo, Hyogo 679-5198, Japan

The development of electric-field manipulation of magnetism is strongly demanded for the reduction in operation power of future spintronic devices. The voltage-controlled magnetic anisotropy (VCMA) effect in an ultrathin ferromagnetic metal layer [1, 2] is a promising and practical approach due to its high applicability in an MgO-based magnetic tunnel junction (MTJ) with high-speed response [3,4]. The VCMA effect originates from voltage-induced charge accumulation/depletion and induction of electron redistribution at the interface between ultrathin ferromagnet and dielectric layers [5]. To show the feasibility of MRAM controlled by voltage, called voltage-torque MRAM [6], we need further improvement in VCMA coefficient. For example, for giga-bit class memory applications, VCMA coefficient of more than a few hundreds or even 1000 fJ/Vm is required [7]. However, high speed VCMA effect is limited to be 100 fJ/Vm at present [8].

In this talk, recent progresses in materials research for the enhancement in the VCMA effect, especially focusing on an epitaxial Fe/MgO MTJs, will be reviewed. Large VCMA coefficient of about 300 fJ/Vm has been achieved by interface engineering using a transition metal doping at the ultrathin Fe/MgO interface.

We'll also introduce the evaluation of write error rate (WER) of precessional magnetization switching induced by VCMA effect in perpendicularly magnetized MTJs [9]. By optimizing the thermal stability and VCMA coefficient in the voltage-controlled free layer, lowest WER of 2×10^{-5} has been demonstrated [10]. Future strategy to realize the practical low WER value will also be discussed.

This work was supported by ImPACT Program of Council for Science, Technology and Innovation, and a Grand-in-Aid for Scientific Research (No. 26709046).

References

1) M. Weisheit *et al*. *Science* **315**, 349 (2007).
2) T. Maruyama *et al. Nature Nanotech*. **4**, 158 (2009).
3) Y. Shiota *et al. Nature Mater.* **11**, 39 (2012).
4) T. Nozaki *et al. Nature Phys.* **8**, 491 (2012).
5) S. Miwa et al. *Nat. Commun.* in press
6) H. Noguchi *et al*. *IEEE Tech. Dig. IEDM*, 27.25 (2016).
7) T. Nozaki *et al. Phys. Rev. Appl*. **5**, 044006 (2016).
8) T. Nozaki et al. *Appl. Phys. Exp.* **7**, 073002 (2014).
9) Y. Shiota *et al. Appl. Phys. Exp.* **9**, 013001 (2016).
10) Y. Shiota *et al*. *The 64th JSAP Spring Meeting*, 15p-501-2 (2017).