New method for field-free detection of in-plane magnetization switching induced by spin-orbit torque

Tokyo Tech.[1], Univ. Tokyo[2], JST-CREST[3]
°Nguyen Huynh Duy Khang[1] and Pham Nam Hai[1, 2, 3]
E-mail: nguyen.h.ai@m.titech.ac.jp

Magnetization switching induced by spin-orbit torque (SOT) has increasingly attracted interest as a new writing technique for ultrafast magnetoresistive random access memory (MRAM). There are the huge efforts in investigating fast and reliable magnetization switching in bilayers without implementation of full stack three-terminal magnetic tunnel junctions (MTJ) for short turn-around development of SOT-MRAM. In type-Z SOT switching of perpendicularly magnetized ferromagnetic layers, the anomalous Hall effect (AHE) is commonly used. However, the critical switching current density J_c for type-Z SOT switching is as high as 10^7~10^8 Acm^{-2}, and a bias external magnetic field is required. Meanwhile, type-Y switching can reduce J_c to the order of 10^6 A cm^{-2} [1], and the bias external magnetic field is not required. In type-Y switching, since the magnetization is in-plane, a differential planar Hall effect (PHE) technique was proposed to detect magnetization switching. In the differential PHE technique, after each writing pulse current, a magnetic field is applied to slightly tilt the magnetization toward the *x* direction, which would generate a difference in the planar Hall voltage under a small reading current when the magnetization is reversed [2-3].

In this study, we proposed and demonstrated a new detection method where SOT is used not only for switching but also for detection of in-plane magnetization switching. Our method can detect arbitrary M_x and M_y component without an external magnetic field, which is useful for fast characterization of type-X, type-Y, and type-XY SOT magnetization switching [4]. For this purpose, we prepared a 20 μm × 60 μm Hall bar of Si/SiO_2 substrate/Fe (1 nm)/Pt (0.8 nm)/BiSb (10 nm) stack by magnetron sputtering. Figure 1(a) illustrates details of our SOT switching and SOT detection scheme. Before each measurement, we applied a large magnetic field to align the magnetization to the *x* direction. We then applied 100-ms pulse currents along the *x* direction for switching. After each pulse, we applied an alternating reading current (J^{BiSb} = 0.33×10^5 Acm^{-2}) along the *x*(*y*) directions for detection of the M_x(M_y) component. SOT effects by the reading current induce oscillation of the magnetization which generates a second harmonic Hall signal proportional to M_x(M_y) via the AHE, PHE, anomalous Nernst effect, and spin Seebeck effect. Figure 1(b) shows SOT switching loops measured with a reading current applied along the *x* direction (upper) and the *y* direction (lower). The critical switching current density in the BiSb layer is as low as 4.5×10^5 Acm^{-2} thanks to the giant spin Hall effect of BiSb. We observed that SOT switching can occur without a perpendicular magnetic field H_z, which can be explained by the existence of an easy axis misaligned from the *x* direction by 13°. The field-free SOT switching and SOT detection are very reproducible as demonstrated in Fig. 1(c). Our method is also useful for detection of in-plane magnetic domains in race-track memory without using Kerr effect microscopy or magnetic force microscopy.

References: [1] S. J. Shi *et al.*, Phys. Rev. Appl. **9**, 011002 (2018). [2] G. Mihajlovíc *et al.*, Appl. Phys. Lett. **109**, 192404 (2016). [3] Y. Takahashi *et al.*, Appl. Phys. Lett. **114**, 012410 (2019). [4] N. H. D. Khang and P. N. Hai, Appl. Phys. Lett. **117**, 252402 (2020).

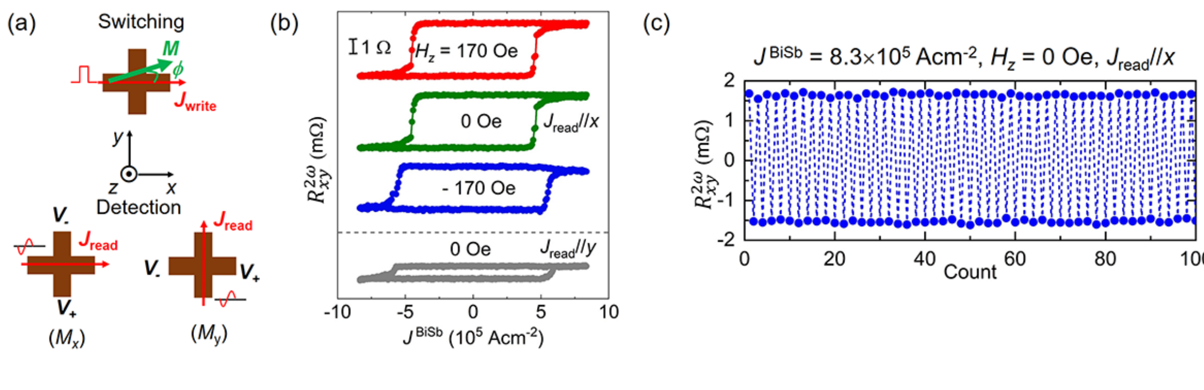

Fig. 1. (a) Our proposed SOT switching and SOT detection scheme, where in-plane M_x and M_y components are detected by an alternating reading current applied along the *x* and *y* direction, respectively. (b) SOT switching loops of 20 μm × 60 μm Hall bar of Si/SiO_2 substrate/Fe (1 nm)/Pt (0.8 nm)/BiSb (10 nm) stack, measured with a reading current applied along the *x* direction (upper) and the *y* direction (lower). (c) Multiple SOT switching by J^{BiSb} = 8.3×10^5 A cm^{-2}, detected by a reading current applied along the *x* direction.