Field-free detection of in-plane magnetization switching induced by spin-orbit torque in topological insulator / ferromagnet heterostructure

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Magnetization switching by spin-orbit torque (SOT) induced by the spin Hall effect has become a key technique in studies of spintronic devices. Fast and reliable detection of SOT switching in SOT layer/ferromagnet bilayers without implementation of full stack three-terminal magnetic tunnel junctions is essential for fast turn-around research and development of magnetoresistive random access memory. In bilayers with perpendicular magnetic anisotropy (type-Z), detection of SOT switching is based on the anomalous Hall effect (AHE). However, the critical switching current density J_c in type-Z bilayers is as high as 10^7 ~ 10^8 $A\cdot cm^{-2}$, and an extra external magnetic field H_{ext} is required for breaking symmetry. On other hand, in bilayers with in-plane magnetization aligned perpendicular to the current direction (type-Y), J_c can be reduced to the order of 10^6 $A\cdot cm^{-2}$ [1], where the differential planar Hall effect (PHE) is used for detection of SOT switching [2-3]. However, type-Y bilayers still need an alternating external field $\pm H_{ext}$ for detection of in-plane magnetization switching.

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. Our method can detect arbitrary M_x and M_y component of magnetization 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. Here, BiSb is a topological insulator with a giant spin Hall effect [5]. For in-plane magnetization switching, we applied a large magnetic field to align the magnetization to the current direction (*x* direction). We then applied 100-ms pulse currents along the *x* direction for switching. After each pulse, we applied an alternating reading current ($J^{BiSb} = 0.33\times10^5$ $A\cdot cm^{-2}$) along the $x(y)$ directions for detection of the $M_x(M_y)$ component. The critical switching current density in the BiSb layer is as low as 4.5×10^5 $A\cdot cm^{-2}$, and the direction of Fe magnetization can be detected without an external magnetic field by using our detecting method even for in-plane magnetization. This method can be also used for electrical detection of in-plane magnetic domains in race-track memory without using Kerr effect microscopy or magnetic force microscopy.

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