Current-induced out-of-plane torque in a single permalloy layer controlled by geometry

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Magnetization switching of a ferromagnetic material (FM) with perpendicular magnetic anisotropy (PMA) due to the current-induced torque is expected to improve both durability and device integration of the magnetoresistive random access memory. However, neither the current-induced torque via the spin Hall effect nor the Rashba-Edelstein effect cannot switch the magnetization of the PMA unless external magnetic field for breaking the symmetry is applied because generated spin is oriented along the in-plane (IP) direction. Recently, current-induced torque via out-of-plane (OOP) spin polarization in a 2D material with broken lateral inversion symmetry in its crystal has been proposed to enable field-free switching of the PMA [1]. However, realization of it with versatile materials is still desirable in terms of industrial application.

In this research, we investigated current-induced torque in a single permalloy layer with broken lateral inversion symmetry in device structure as shown in Figure 1. From the symmetry of the spin-torque ferromagnetic resonance spectrum with respect to magnetic field direction [2], we estimated four kinds of current-induced torques: IP damping-like (DL) [~ $\boldsymbol{M} \times (\boldsymbol{M} \times \mathbf{y})$], IP field-like (FL) (~ $\mathbf{y} \times \boldsymbol{M}$), OOP DL (~ $\boldsymbol{M} \times (\boldsymbol{M} \times \mathbf{z})$), and OOP FL (~ $\mathbf{z} \times \boldsymbol{M}$) torques, where $\boldsymbol{M}$ is the magnetization vector. Figure 2 shows torque efficiencies, ξ, as a function of the geometrical channel difference, Δl [3]. Only the OOP torques that enable field-free switching of the PMA showed apparent Δl dependence, indicating the OOP torques can be well controlled by the device geometries. Possible origins of the OOP torques are also discussed in our presentation.

[1] Q. Shao *et al.*, IEEE Trans. Magn. **57**, 1 (2021). [2] J. Sklenar *et al.*, Phys. Rev. B **95**, 224431 (2017).

[3] M. Aoki *et al.*, Phys. Rev. B, submitted.

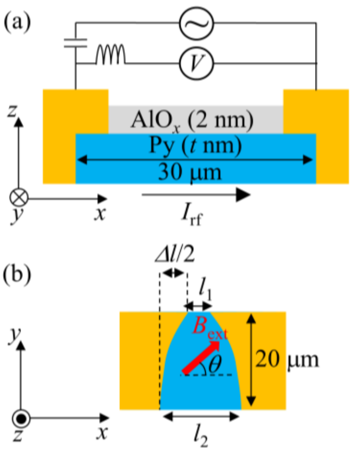

Fig. 1. View of the device structure from (a) y axis and (b) z axis.

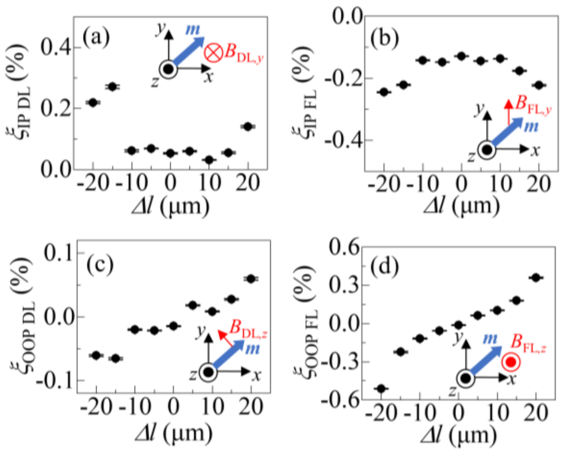

Fig. 2. Torque efficiencies as a function of Δl for (a) IP DL, (b) IP FL, (c) OOP DL, and (d) OOP FL torques. Insets show direction of effective fields corresponding to each torque.