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Non-volatile electric-field control of spin-orbit torques in perpendicular ferromagnet- $SrTiO_3$ systems

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The realization of magnetization switching induced by in-plane current injection in heavy metal/ferromagnetic heterostructures has drawn an increasing attention to spin-orbitronics, and lead to the advent of spin-orbit torques magnetoresistive random access memories (SOT-MRAM). Compared to heavy metals, oxide 2D electron gases have emerged as alternative spin-orbitronics material systems. They benefit from an efficient spin-charge interconversion through the direct and inverse Edelstein effects, which appear at their interfaces where the broken inversion symmetry induces a Rashba SOC [1]. Recently, we have demonstrated an enhancement of the spin-to-charge conversion efficiency by two orders of magnitude in $SrTiO_3$-based 2D gas [2] (compared to conventional heavy metals), along with a non-volatile electric-control of the spin-to-charge conversion [3]. While the sign and efficiency of the SOTs are fixed by the stack of materials in conventional SOT devices, achieving an electric-control of the mirror charge-to-spin conversion would be of great interest for developing reconfigurable SOT-MRAM and logic gates.

Here we report the electric-field control of spin orbit torques, with electrical remanence, in a perpendicular ferromagnet - $SrTiO_3$ system. Non-volatile electric-field control of the sheet resistance is achieved with 1150% contrast, with two switchable and remanent high and low resistivity states of the 2D electron gas. Spin-orbit torques effective fields are further measured using second harmonic Hall methods. A remanent electric-field control of the SOT efficiency is demonstrated, with inversion of the sign of the SOT anti-damping-like effective field. Anti-damping-like and field-like torque effective fields per 2D current density of 1.6 and 0.1 mT. A. cm^{-1} respectively are reached in the 2D gas low resistivity state. These results are consistent with a combination of both intrinsic modulation of the SOT efficiency together with extrinsic modulation due to the non-volatile electric-control of the current injection in the 2D gas. The non-volatile control of the SOT effective field is further evidenced by reproducible inversion of the SOT torques after initializing with negative or positive voltage pulses of ±130 V, opening the way to reconfigurable spin-orbit torque memory and logic gate architectures.

[1] E. Lesne et al., Nature Materials, 15, 1261–1266 (2016).
[2] D. C. Vaz et al., Nature Materials, 18, 1187–1193(2019).
[3] P. Noel et al., Nature 580, 483–86 (2020).

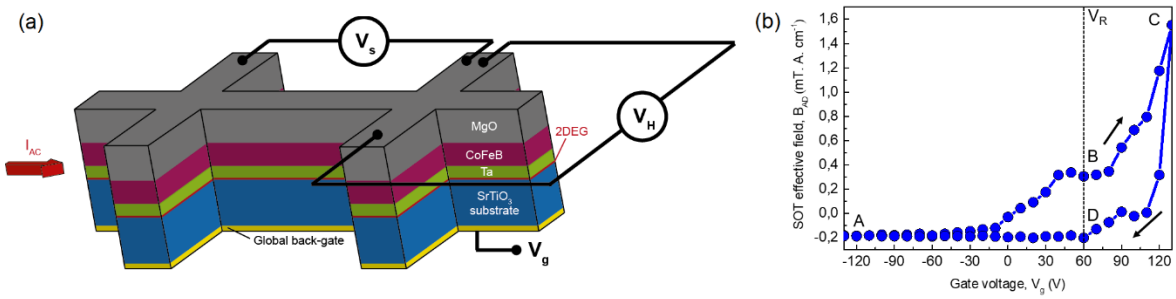

Figure 1. Electric-field control of spin orbit torques with electrical remanence. (a) Structure of the sample and measurement geometry. (b) Gate dependence of the spin-orbit torques anti-damping-like effective field.