Ultra-low power bias-driven magnetization switching by quasi-Fermi level control at an interface of a $La_{0.67}Sr_{0.33}MnO_3$-based magnetic tunnel junction

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Controlling the magnetic anisotropy (MA) by a bias voltage is important for reducing the power consumption of magnetization switching in spin devices. In ferromagnetic (FM) materials, the MA is strongly correlated to the symmetry of the magnetization-direction dependence of the density of states (DOS) around the Fermi level [1]. This correlation thus suggests that we can achieve highly effective control of MA of the FM materials by applying a bias voltage and moving the Fermi level between band components with different orbital symmetries. Here in a $La_{0.67}Sr_{0.33}MnO_3$ (LSMO)-based magnetic tunnel junction (MTJ), we demonstrate a magnetic-field-free 90°-magnetization switching solely by applying an extremely small electric field of 0.05 V/nm on the tunnel barrier. This electric field moves the Fermi level from the e_g band to the t_{2g} band at the interface between LSMO and the tunnel barrier, and induces a sharp change in the in-plane MA.

The studied MTJ consists of LSMO [18 unit cell (u.c.)] / $SrTiO_3$ (STO, 10 u.c.) / LSMO (40 u.c.) grown on an STO (001) substrate by molecular beam epitaxy [see Fig. 1(a)]. We probed the MA of the LSMO layers by measuring the θ_H-dependence of tunneling magnetoresistance (TMR), where θ_H is the in-plane angle of the magnetic field **H** measured from [100]. The TMR ratio depends on the relative angle $\Delta\theta$ between the magnetization vectors of the top ($\mathbf{M}_t$) and bottom ($\mathbf{M}_b$) LSMO layers. When increasing the bias voltage V applied to the MTJ from 15 mV to 200 mV, which corresponds to a transition of the quasi Fermi level from the e_g band to the t_{2g} band [2], we found that the MA of the top LSMO switches from a two-fold symmetry to a four-fold symmetry [Fig. 1(b)]. Due to this MA switching, the easy axis of $\mathbf{M}_t$ along [110] at V = 200 mV becomes a hard axis at V = 15 mV, while the $[\bar{1}10]$ axis is always an easy axis. Thus, the magnetization initially pointed toward [110] at V = 200 mV is rotated toward $[1\bar{1}0]$ when V is changed to 15 mV, and remains in that position ($[1\bar{1}0]$) even after V is returned to 200 mV. This bias-driven magnetization rotation of LSMO was detected by monitoring the change in tunneling resistance R at zero magnetic field when varying V in the following sequence: 200 mV → 15 mV → 200 mV [Fig. 1(c)] after initializing the $\mathbf{M}_t$ and $\mathbf{M}_b$ in the [110] direction by a strong **H**. The R values before and after the bias sequence changed by ΔR_2 that corresponds to a rotation of $\mathbf{M}_t$ by 87.7° without the need of any assisting magnetic field. The operation requires an infinitesimal current density of ~ 10^{-2} A/cm^2, which is ~8 orders of magnitude smaller than that in the present magnetic random access memory [3].

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References: [1] H. Saito *et al.*, Phys. Rev. Lett. **95**, 086604 (2005). [2] L. D. Anh *et al.*, Sci. Rep. **7,** 8715 (2017). [3] L. D. Anh *et al.*, submitted.

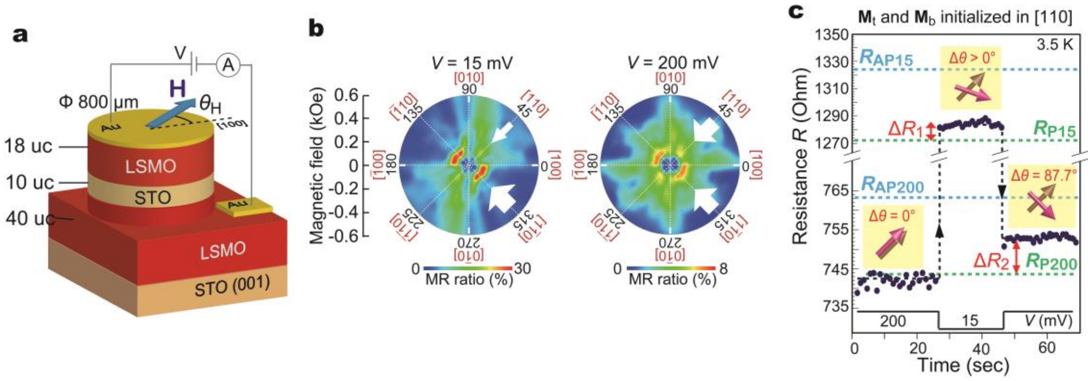

Fig. 1. (a) Device structure. (b) θ_H-dependence of TMR at V = 15 and 200 mV. (c) R (blue dots) measured at zero **H** with a bias sequence of V = 200 mV → 15 mV → 200 mV after initializing the $\mathbf{M}_t$ and $\mathbf{M}_b$ along [110]. R_{P200} (R_{P15}) and R_{AP200} (R_{AP15}) express the R values at **H** = 0 when $\mathbf{M}_t$ and $\mathbf{M}_b$ are initialized in the parallel and antiparallel configurations at V = 200 mV (15 mV), respectively.