# Correlation between the bias dependence of tunneling anisotropic magnetoresistance and tunneling magnetoresistance in a $La_{0.67}Sr_{0.33}MnO_3$-based magnetic tunnel junction

L. D. Anh[1,2], T. Yamashita[1], H. Yamasaki[1], D. Araki[1], M. Tanaka[1,3] and S. Ohya[1,2,3]
[1]*Department of Electrical Engineering and Information Systems, The University of Tokyo*
[2]*Institute of Engineering Innovation, The University of Tokyo*
[3]*Center for Spintronics Research Network (CSRN), The University of Tokyo*

$La_{0.67}Sr_{0.33}MnO_3$ (LSMO) is one of the most promising oxide materials for spintronic devices due to its high Curie temperature ($T_C \sim 370$ K), colossal magnetoresistance [1], and its half-metallicity [2]. The band structure of LSMO around the Fermi level $E_F$, specifically that at the LSMO / $SrTiO_3$ (STO) tunnel barrier interface, is known to be a complex mixture of the different *d*-band components, the up-spin $e_g$ and $t_{2g}$ states. The $t_{2g}$ states are located at ~0.5 eV below $E_F$ in the bulk, but are pushed up closer to $E_F$ at the interface [3]. Hence in LSMO, when the carrier energy is tuned between the interfacial $e_g$ and $t_{2g}$ bands, a sharp change of the angular dependence of the density of states (DOS) on the magnetization direction is expected, like in the quantum wells of ferromagnetic semiconductor GaMnAs [4].

Here in this work, using a magnetic tunnel junction (MTJ) consisting of, from the top surface, LSMO [18 unit cell (u.c.)] / STO (10 u.c.) / LSMO (40 u.c.) grown on an STO (001) substrate by molecular beam epitaxy [see Fig. 1(a)], we simultaneously probed the carrier energy dependence of the anisotropy of the DOS, by measuring the magnetic-field-direction dependence of the tunneling anisotropic magnetoresistance (TAMR), and the magnetic-field-direction dependence of the tunneling magnetoresistance (TMR). We measured TAMR by monitoring the change in the tunneling conductance d*I*/d*V* when the magnetizations of the top and bottom LSMO layers ($\mathbf{M}_b$ and $\mathbf{M}_t$) were rotated together in the film plane by rotating a strong external magnetic field **H** = 10 kOe. As shown in Fig. 1(b), d*I*/d*V* as a function of $\theta_H$, which is defined as the angle of **H** measured from the [100] axis, shows a change of about ±1.5%, indicating that the DOSs of the LSMO layers change when rotating $\mathbf{M}_b$ and $\mathbf{M}_t$. Figure 1(b) also indicates that two-fold symmetries along [100] and [110] are dominant in the small bias region ($-0.14$ V < $V$ < 0.08 V). Interestingly, the directions of **H** at which the DOS reaches maximum (~15°, ~195°) rotates by 90° when the bias voltage $V$ is changed through $V_p$ = (0.06 – 0.095 V) or $V_n$ = (-0.15 — -0.13 V) [Fig. 1(b), purple bands]. This signifies a transition of the band character of the tunneling carriers from the $e_g$ band (at $E_F$, $V_n < V < V_p$) to the $t_{2g}$ band (below $E_F$, $V < V_n$ or $V > V_p$) with changing $V$ [5]. Also, we have found that the $\theta_H$-dependence of TMR changes with $V$. Using the TAMR data and the TMR data, we discuss their correlations [6] in the presentation.

This work was partly supported by Grants-in-Aid for Scientific Research, CREST program of Japan Science and Technology Agency, and Spintronics Research Network of Japan (Spin-RNJ).

**References:** [1] A. Asamitsu *et al.*, Nature **373**, 407 (1995). [2] J.-H. Park *et al.*, Nature **392**, 794 (1998). [3] J. D. Burton *et al.*, Phys. Rev. B **93,** 24419 (2016). [4] I. Muneta et al., Nat. Commun. **8**, 15387 (2017). [5] L. D. Anh *et al.*, Sci. Rep. **7,** 8715 (2017). [6] H. Saito *et al.*, Phys. Rev. Lett. **95**, 086604 (2005).

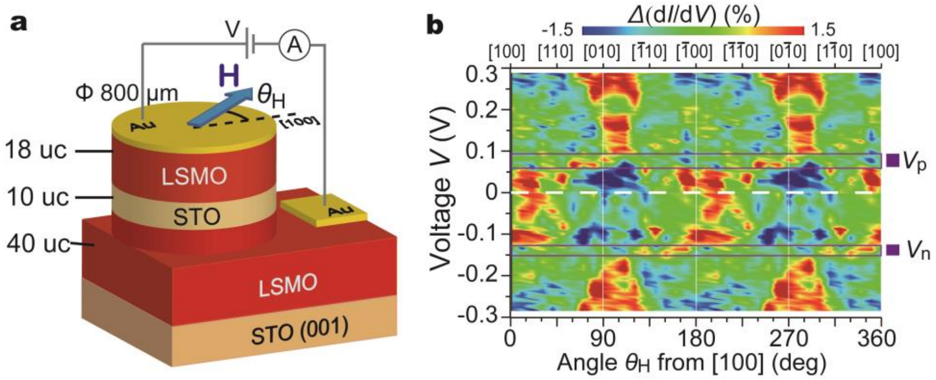


Fig. 1. (a) Device structure and measurement configuration of the tunneling transport of the LSMO/STO/LSMO MTJ structure. (b) Color-mapping plot of the change in d*I*/d*V* as a function of $\theta_H$ and $V$. The directions of **H** where d*I*/d*V* reaches maximum rotate by 90° when $V$ is changed through $V_p$ (= 0.06 – 0.095 V) and $V_n$ (= -0.15 — -0.13 V) (purple bands).