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

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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 ($T_C$ ~ 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 $dI/dV$ when the magnetizations of the top and bottom LSMO layers (M$_t$ and M$_b$) were rotated together in the film plane by rotating a strong external magnetic field $H = 10$ kOe. As shown in Fig. 1(b), $dI/dV$ as a function of $\theta_H$, which is defined as the angle of $H$ measured from the [100] axis, shows a change of about $\pm 1.5\%$, indicating that the DOSs of the LSMO layers change when rotating M$_t$ and M$_b$. 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 ($\sim 15^\circ$ $-$ $195^\circ$) rotates by $90^\circ$ 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:

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 $dI/dV$ as a function of $\theta_H$ and $V$. The directions of $H$ where $dI/dV$ reaches maximum rotate by $90^\circ$ when $V$ is changed through $V_p$ (= 0.06 $-$ 0.095 V) and $V_n$ (= -0.15 $-$ -0.13 V) (purple bands).