Influence of the quantization of the d_{xy} band on spin-to-charge conversion at the $LaAlO_3$ / $SrTiO_3$ interface

○S. Arai[1], S. Kaneta[1], L. D. Anh[1,2], M. Tanaka[1,3], and S. Ohya[1,2,3]

[1] *Department of Electrical Engineering and Information Systems, The Univ. of Tokyo*

[2] *Institute of Engineering Innovation, Graduate School of Engineering, The Univ. of Tokyo*

[3] *Center for Spintronics Research Network(CSRN), Graduate School of Engineering, The Univ. of Tokyo*

E-mail: shoma.arai@cryst.t.u-tokyo.ac.jp

The recently observed various phenomena of spin-to-charge-current conversion have attracted much attention for the realization of low-power-consumption devices, such as magnetoresistive random access memory. The $LaAlO_3/SrTiO_3$ (LAO/STO) interface is very promising for efficient spin-to-charge conversion due to the two-dimensional electron gas (2DEG) with a large Rashba spin-orbit interaction(SOI) induced by broken space-inversion symmetry. Due to the Rashba SOI, the Fermi surface is spin-split, which leads to efficient spin-to-charge conversion in this 2DEG. This effect is called the inverse Edelstein effect (IEE). Previously, we achieved a large spin-to-charge conversion efficiency, the so-called inverse Edelstein length λ_{IEE}, up to 6.7 nm at the LAO/STO interface [1]. In this previous work, we carried out band-structure calculations based on the effective mass approximation to explain the experimental results; however, the 2nd d_{xy} subband was not taken into account (only the 1st d_{xy} subband was considered) for simplicity. Because this band has a relatively large group velocity, it may have a large contribution to λ_{IEE}.

In this study, we have incorporated the 2nd quantized d_{xy} subband into our calculation. Fig. 1 shows the calculated Fermi surface with the spin direction and group velocity v_x in the x direction when the Fermi level E_F relative to the conduction band bottom is 120 meV, where the Rashba spin split is most enhanced due to band crossing. Due to the Rashba effect, the Fermi surface is split into inner and outer bands. One can see that the 1st d_{xy} subband and 2nd d_{xy} subband have large v_x, meaning that they have a large contribution to λ_{IEE}. Here, we assume that the injected spin current only has a y component of spin. For the inner band (see the right side of Fig. 1), we see that the 1st d_{xy} subband and 2nd d_{xy} subband have the same spin direction along $-y$ at $k_y = 0$, so these two bands have the same sign of contribution to λ_{IEE}. We also calculated $j_c^{2D} / \delta s$ as a function of E_F (Fig. 2), where j_c^{2D} is a two-dimensional charge current density and δs is the spin accumulation. The calculated $j_c^{2D}/ \delta s$ was larger than that obtained without considering the 2nd d_{xy} subband for most of the energy region, as we expected above. In the inset of Fig. 2, $j_c^{2D}/ \delta s$ in our presentation decreases more slowly than that obtained in our previous calculation. In our presentation, we compare λ_{IEE} ($= j_c^{2D}/\delta s \times \tau / e$, where τ is a relaxation time and e is the elementary charge) obtained with this model and the experimental λ_{IEE} in detail.

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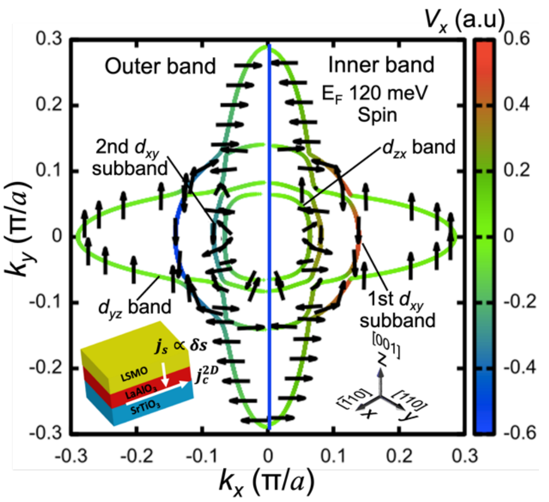

Fig. 1 Fermi Surface with the spin direction and group velocity v_x in the x direction at $E_F = 120$ meV. The left (right) side corresponds to the outer (inner) band of each spin-split band due to the Rashba effect. Inset shows the sample structure and x, y, z coordinate system used in this study.

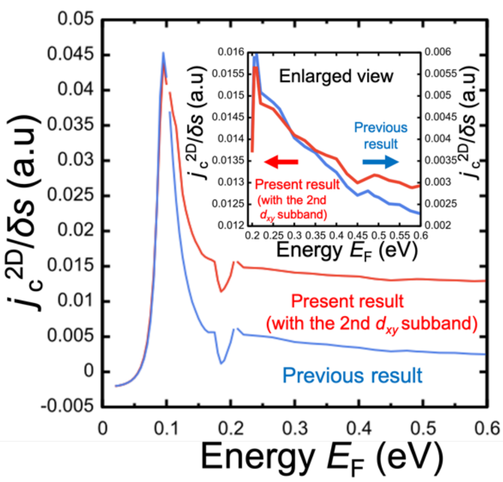

Fig. 2 Fermi level E_F dependence of $j_c^{2D} / \delta s$. One can see that $j_c^{2D} / \delta s$ becomes larger by incorporating the 2nd d_{xy} subband.