Theoretical understanding of the efficient intrinsic spin-to-charge current conversion in $La_{0.67}Sr_{0.33}MnO_3/LaAlO_3/SrTiO_3$

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The two-dimensional-electron gas (2DEG) formed at the interface between perovskite insulating oxides $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) is very promising for efficient spin-charge conversion, the so-called (inverse) Edelstein effect (IEE). This interface has the large Rashba spin-orbit interaction, which makes this system very attractive. There have been several reports on the IEE at LAO/STO, but the previous results contradict each other; the conversion signal was clearly observed at 7 K in Ref. [1], while the conversion signal strongly decreased to zero with decreasing temperature in Refs. [2,3]. Previously, we showed a very efficient IEE, which is drastically enhanced with decreasing temperature, with the conversion efficiency (λ_{IEE}) up to +3.9 nm at 20 K, using a high-quality all-epitaxial single-crystal $LaSrMnO_3$ (LSMO)/ $LaAlO_3$ (LAO)/ $SrTiO_3$ (STO) heterostructure grown via molecular beam epitaxy [Fig. 1(a)] [4]. This value of λ_{IEE} is the largest positive value ever reported for LAO/STO. Here, we show that our band-structure calculation can well reproduce this behavior of λ_{IEE} and predicts further possible enhancement of the IEE by controlling the density and relaxation time τ of the 2DEG [5].

In this study, we have derived λ_{IEE} using the band-structure calculation of LAO/STO with the effective-mass Hamiltonian, atomic spin-orbit coupling, and interorbital nearest-neighbor hopping based on the six $3d$–t_{2g} orbitals of Ti in STO. As shown in Fig. 1(b), calculated λ_{IEE} increases with decreasing temperature as with experimental λ_{IEE}, confirming that our experimental result originates from the intrinsic IEE. As shown in Fig. 1(c), derived $j_c/\delta s$ (= $e\lambda_{IEE}/\tau$) was nearly constant as a function of the Fermi level E_F in the range of our sheet carrier density from 2×10^{14} cm^{-2} (20 K) to 8×10^{14} cm^{-2} (140 K), which corresponds to the E_F value from 210 to 580 meV. Here, j_c is the generated two-dimensional current and δs is the non-equilibrium spin density. This means that τ determines λ_{IEE} in our experiment. However, our calculation predicts that $j_c/\delta s$ and thus λ_{IEE} will be strongly enhanced, if E_F is tuned at around the Lifshitz point [*i.e.* $E_F \approx 100$ meV in Fig. 1(c)].

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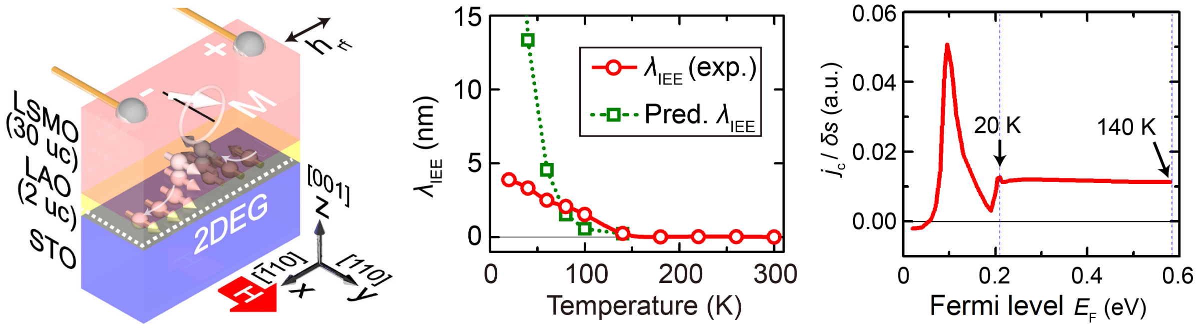

Fig. 1. (a) Schematic sample structure measured in this study: (001)-oriented full-epitaxial multilayer structure of LSMO/LAO grown on an STO (001) substrate. (b) Temperature dependences of experimental λ_{IEE} and predicted λ_{IEE}. (c) Calculated $j_c/\delta s$ (= $e\lambda_{IEE}/\tau$) as a function of E_F.

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