Spin injection into a high-mobility two-dimensional electron gas in all-epitaxial $La_{0.7}Sr_{0.3}MnO_3/LaAlO_3/SrTiO_3$ using spin pumping

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The high-mobility two-dimensional electron gas formed at the $LaAlO_3$/ $SrTiO_3$ (LAO/ STO) interface exhibits many interesting properties such as large spin-orbit interaction (SOI), ferromagnetism, and superconductivity, which have attracted much attention for spintronics applications [1, 2]. Recently, utilizing the large SOI, a highly efficient spin-to-charge conversion via the inverse Edelstein effect (IEE) has been demonstrated at the LAO/ STO interface using spin pumping with polycrystalline permalloy ($Ni_{81}Fe_{19}$) as the spin injector [3]. Here, instead of permalloy, we use single crystalline ferromagnetic $La_{0.7}Sr_{0.3}MnO_3$ (LSMO), which can be coherently grown on LAO/ STO and is thus promising for improving the spin-to-charge conversion efficiency due to the suppression of spin scattering at the interfaces.

We have grown LSMO (60 unit cell (uc))/ LAO (2 uc) on a TiO_2-terminated STO(001) substrate using a shuttered growth technique of molecular beam epitaxy (MBE). We have successfully obtained a high mobility μ up to 1.4×10^4 cm^2/Vs at 3.5 K, which was confirmed in a reference LAO (8 uc)/ STO sample grown with the same conditions (Fig. 1). For the spin pumping experiment, the LSMO/ LAO/ STO sample was cut into a rectangular shape (1.0×2.0 mm^2) with the [110] axis, which is a magnetic easy axis at low temperatures, along its short side [4]. The sample was placed at the center of a TE_{011} cavity, and the static magnetic field H and the radio-frequency magnetic field h_{rf} were applied along the short and long sides of the sample, respectively. As shown in Fig. 2, at the ferromagnetic resonance (FMR) condition with the magnetic field of H_r, the derivative microwave absorption intensity dI/dH was clearly enhanced both at 300 K and 90 K. By decreasing the temperature from 300 K to 90 K, the current density j_c at the LAO/ STO interface, which was estimated by the symmetric component of the observed electromotive force V, was largely enhanced, and the sign was inverted. The electromotive force was not observed in a reference sample of LSMO on STO grown with the same conditions, thus we can eliminate the contribution of the planar Hall effect and anomalous Hall effect in the signals of Fig. 2. Therefore, our results indicate that the spin-to-charge conversion was successfully observed at the LAO/ STO interface using LSMO for the first time.

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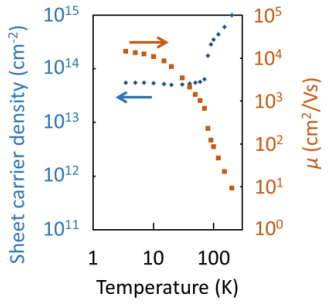

Fig. 1 Temperature dependence of the sheet carrier density (blue squares) and μ (orange squares).

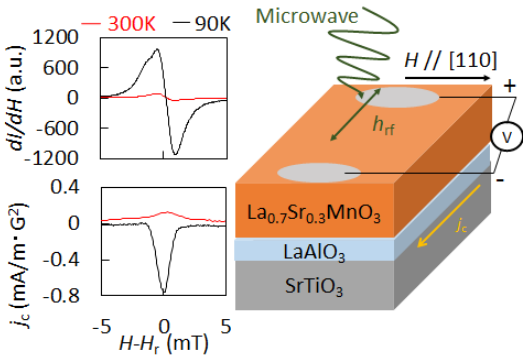

Fig. 2 FMR spectra and j_c - H curves for LSMO/ LAO/ STO at 300 K (red lines) and 90 K (black lines).