Electronic Compressibility and Magnetism at the LaAlO$_3$/SrTiO$_3$ Interface

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Introduction
The recently discovered conductive interfaces between oxide-insulators [1] are potentially new two-dimensional electronic system. Many novel phenomena have been observed at the interface between LaAlO$_3$ (LAO) and SrTiO$_3$ (STO), such as superconductivity, quantum criticality, and a possible hysteretic magneto-resistance [2]. The mobile charge carriers are proposed to come from the polar discontinuity between layers, which triggers the movement of the charges at the interface. A result of this process and the lattice relaxation is the orbital ordering and a possible ferromagnetic state [3]. However, experimental evidences are not yet clear for this proposed ferromagnetism.

Experimental
We fabricated Nb ohmic contacts to the interface and deposited YBCO top gates on the LAO/STO wafer. Capacitance measurements were carried out on the capacitor devices formed by a top gate and the interface. The torque magnetometry studies were performed in SCM2 using home-built metal cantilevers.

Results and Discussion
To investigate the electronic state of the 2D system, capacitance spectroscopy is applied to infer the density of states. Fig 1(left) displays the capacitance $C$ vs. gate voltage $V_g$ traces on a capacitor device [4]. At $V_g$ < -0.2 V, $C$ is greatly diminished, demonstrating the fully depletion of the mobile carriers. Moreover, $C$ is enhanced greatly at -0.2 V < $V_g$ < -0.1 V, exceeding the geometric capacitance given by the sizes of the device. This capacitance enhancement is common in high-mobility semiconducting 2D device, and indicates the electronic compressibility is negative in the low carrier density region. Inferred from this capacitance measurement as well as in the field penetration studies, the electronic compressibility is negative and agrees with the calculations using exchange energy picture of the 2D ground state.

Torque magnetometry results give us some clues of the magnetic state. The torque signal of a LAO/STO wafer is shown in Fig. 1(right). Although the signal is quite small, we still observed a hysteresis loop at $H < 5$ T. The hysteresis persists even at 10 K, which excludes the possible cause of the Nb contacts since the superconducting temperature of Nb is below 9 K.

Conclusions
The electric field effect is demonstrated at the LAO/STO interface by using top gates. Our results suggest the negative electronic compressibility and strongly indicate the existence of the 2D electron gas at the interface. In addition, the hysteresis in torque vs. $H$ curves may be an intrinsic property of the interface. Our thermodynamic measurements of the electronic compressibility and magnetization suggest that the interface at LAO/STO may be a ferromagnetic 2D electron gas.

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References