# SUPPORTING INFORMATION

# The Effect of Polar Fluctuation and Lattice Mismatch on Carrier Mobility at Oxide Interfaces

*Zhen Huang,*[†,‡] *Kun Han,*[†,‡] *Shengwei Zeng,*[†,‡] *Mallikarjuna Motapothula,*[†,‡] *Albina Y. Borisevich,*[§,∥,⊥] *Saurabh Ghosh,*[§,#] *Weiming Lü,*[□] *Changjian Li,*[†] *Wenxiong Zhou,*[†,‡] *Zhiqi Liu,*[■] *Michael Coey,*[†,○] *Thirumalai Venkatesan,**[†,‡,●,△,▲] *and Ariando**[†,‡,▲]

[†]NUSNNI-NanoCore, National University of Singapore, 117411 Singapore

[‡]Department of Physics, National University of Singapore, 117542 Singapore

[§]Materials Science and Technology Division, [∥]Institute for Functional Imaging of Materials, and [⊥]The Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, United States

[#]Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, United States

[□]Condensed Matter Science and Technology Institute, School of Science, Harbin Institute of Technology, Harbin 150081, P.R. China

[■]Department of Materials Science and Engineering, University of California, Berkeley, California 94720, United States

[○]School of Physics and CRANN, Trinity College, Dublin 2, Ireland

[●]Department of Electrical and Computer Engineering, National University of Singapore, 117576 Singapore

[△]Department of Materials Science and Engineering, National University of Singapore, Singapore 117575, Singapore

[▲]National University of Singapore Graduate School for Integrative Sciences and Engineering (NGS), 28 Medical Drive, Singapore 117456, Singapore

Zhen Huang and Kun Han contributed equally to this work.

*E-mail: venky@nus.edu.sg  *E-mail: ariando@nus.edu.sg

**FIGURE S1**

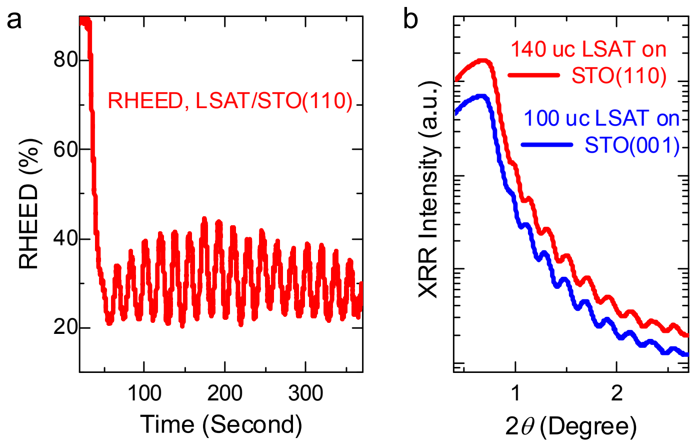


Figure S1 Oscillation and thickness in (001)- and (110)-orientated LSAT/STO films. (a) *In-situ* RHEED oscillations for (110)-orientated LSAT/STO interface. (b) XRR for 100 uc (001) and 140 uc (110) orientated LSAT/STO films. The thickness can be calculated to be 38 nm. Hence, one RHEED oscillation is about 0.38 nm for LSAT/STO (001), and 0.27 nm for LSAT/STO (110) films.

**FIGURE S2**

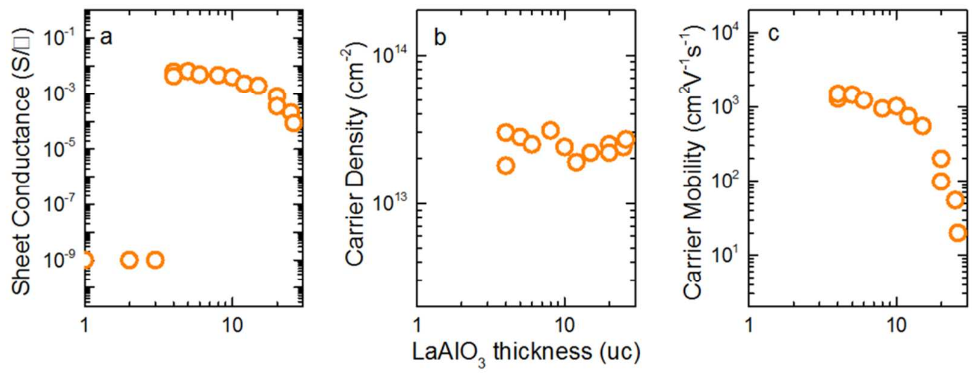


Figure S2 (a) Sheet conductance, (b) carrier density, and (c) carrier moblity of (001) LAO/STO interfaces are shown as a function of LAO thickness at 2 K.

**FIGURE S3**

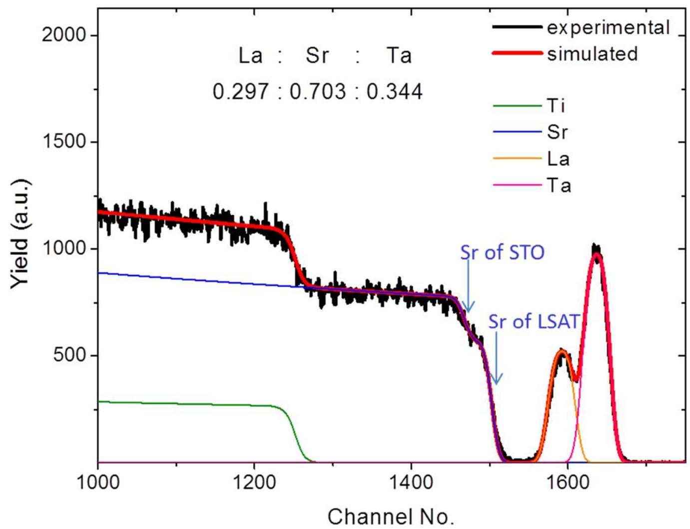


Figure S3 Chemical composition for LSAT/STO (001) sample. By fitting experimental RBS data of 100 uc LSAT/STO (001) sample, the chemical ratio of La: Sr: Ta can be obtained as 0.297$\pm$0.015 : 0.703$\pm$0.035 : 0.344$\pm$0.017, which is very close to the bulk value with 0.3:0.7:0.35. The Sr from STO and LSAT is denoted by arrows respectively.

**FIGURE S4**

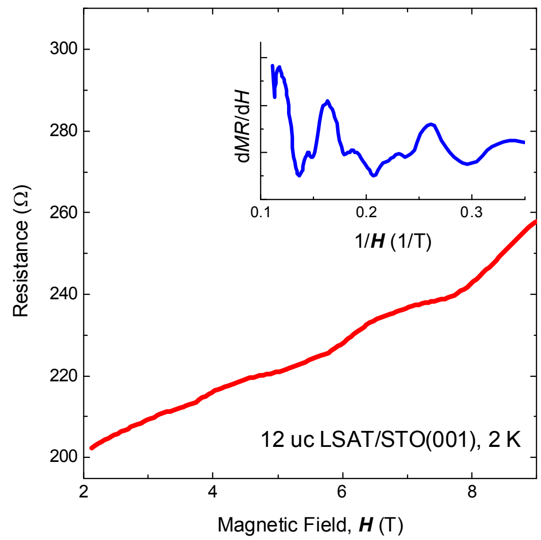


Figure S4 Shubnikov-de Haas conductance oscillations for annealed 12 uc LSAT/STO (001) interface.

**FIGURE S5**

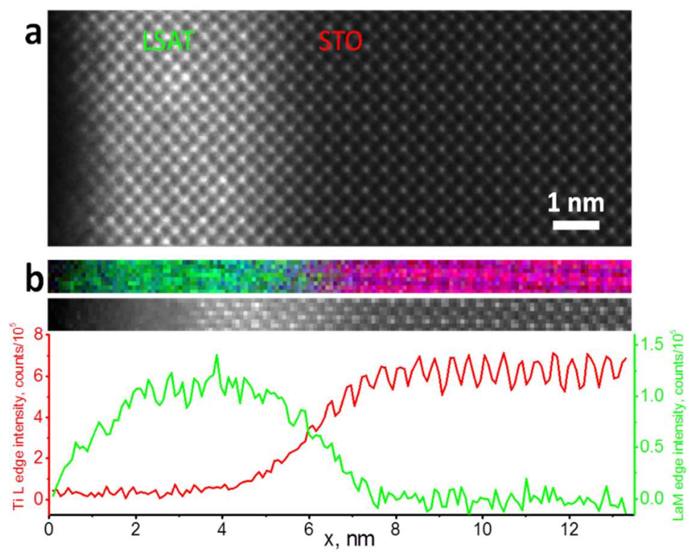


Figure S5 HAADF STEM and EELS studies of the films. (a) HAADF STEM image of the LSAT/STO thin film. (b) an EELS spectrum image acquired from a similar region of the film. From the top in (b): composite chemical map, where La M edge is represented by green, Ti L – red, and O K – blue color, respectively; simultaneously acquired HAADF signal; line profiles of La and Ti edges across the interface. Note that the top of the LSAT film is not crystalline due to rapid beam-induced amorphization.

**NOTE S1**

## Experimental Methods:

**Sample Growth.** Pulsed laser deposition (PLD) with *in-situ* reflection high-energy electron diffraction (RHEED) was used to fabricate the samples. The STO substrates were treated with HF and annealed to obtain atomically-flat surfaces, and the single crystal LSAT is used for PLD target. The growth parameters for crystalline interface samples were as follows: 1.8 $J/cm^2$ for laser energy, 800 $^{O}C$ for the deposition temperature, and $2\times10^{-3}$ Torr for oxygen partial pressure. The *ex-situ* annealing was performed at 600 $^{o}C$ in 1 bar oxygen for 1 hour.

**Surface, Interface, and Crystal Structure.** The surfaces of the samples were examined by atomic force microscopy (AFM) using Agilent 5500. The interface and crystal structure of the samples were characterized by X-Ray Reflectivity (XRR), X-Ray Diffraction (XRD), and Reciprocal Space Mapping (RSM) using $CuK\alpha_1$ radiation ($\lambda$ = 1.5406 Å, Bruker D8 Discover).

**Electrical Measurements.** The sheet resistance, carrier densities and carrier mobility are measured by Van der Pauw method on a 9 T Physical Property Measurement System (PPMS, Quantum Design).

**NOTE S2**

**Calculation of LSAT (001) Polarization:**

For the i$^{th}$ LSAT layer, the electric diploe moment $\boldsymbol{p}_i$ can be characterized by

$\boldsymbol{p}_{\mu,i} = 0.65(\boldsymbol{P}_0V) + 0.35(-\boldsymbol{P}_0V) = 0.3\boldsymbol{P}_0V$ ;

$\sigma^2_{p,i} = 0.65[(\boldsymbol{P}_0V)^2 - \boldsymbol{p}^2_{\mu,i}] + 0.35[(-\boldsymbol{P}_0V)^2 - \boldsymbol{p}^2_{\mu,i}] = 0.91(\boldsymbol{P}_0V)^2$ ,

where $\boldsymbol{p}_{\mu,i}$ is the mean value of $\boldsymbol{p}_i$, and $\sigma^2_{p,i}$ is the variance of $\boldsymbol{p}_i$.

If there are $t$ layers of LSAT, the total diploe moment $\boldsymbol{p}$ can be characterized by

$\boldsymbol{p}_\mu = t\boldsymbol{p}_{\mu,i} = 0.3t\boldsymbol{P}_0V$ ;

$\sigma^2_p = t\sigma^2_{p,i} = 0.91t(\boldsymbol{P}_0V)^2$ ,

where $\boldsymbol{p}_\mu$ is the mean value of $\boldsymbol{p}$, and $\sigma^2_p$ is the variance of $\boldsymbol{p}$.

For $t$ layers of LSAT, the total volume is $tV$. Hence, the polarization $\boldsymbol{P}$ is $\boldsymbol{p}/(tV)$.

So, $\boldsymbol{P}$ can be characterized by

$\boldsymbol{P}_\mu = \boldsymbol{p}_\mu/(tV) = 0.3\boldsymbol{P}_0$ ;

$\sigma^2_{\boldsymbol{P}} = (\sigma_p/tV)^2 = 0.91\boldsymbol{P}_0^2/t$ .