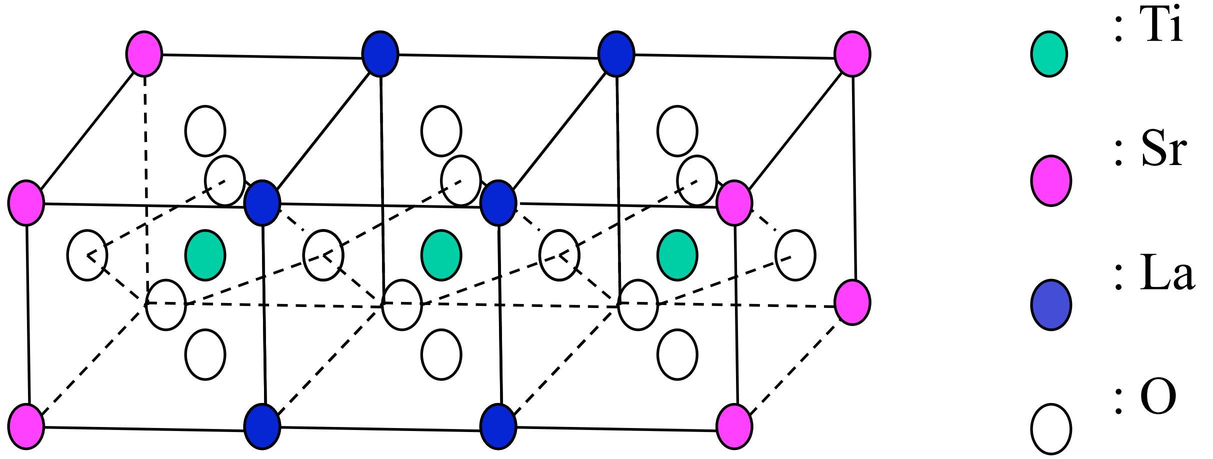
001 Superlattice
ex: $(LaTiO_3)_2/(SrTiO_3)_2$



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Interface Classifications

Homometallic: same transition metal; different counterion

$LaTiO_3/SrTiO_3$ **$LaMnO_3/SrMnO_3$** **$LaVO_3/LaVO_4$**

$La_2CuO_4/La_{2-x}Sr_xCuO_4$

potential of counterion defines quantum well
physics: change of charge density and of local symmetry

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Classifications

Heterometallic: change in transition metal across interface. quantum well + different local physics

Case A: “hard wall”

$LaAlO_3/SrTiO_3$ **$LaAlO_3/LaVO_3$**

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Classification

Heterometallic: change in transition metal across interface. quantum well + different local physics

Case B: two different correlated materials

$LaMnO_3/YBa_2Cu_3O_7$

$SrTiO_3/LaVO_3$

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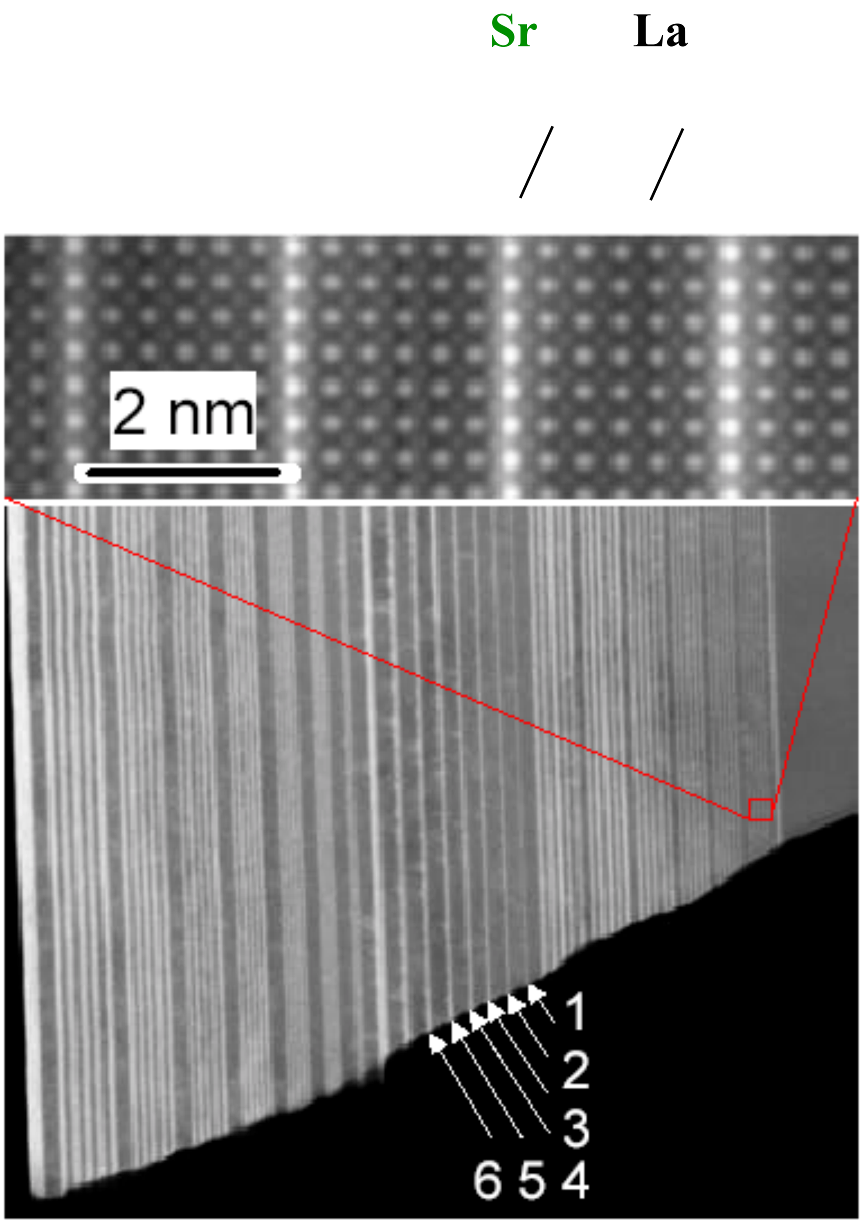

Dark field image

Ohtomo, Muller, Grazul, Hwang, Nature 419 378 (2002)

$(LaTiO_3)_n/(SrTiO_3)_m$

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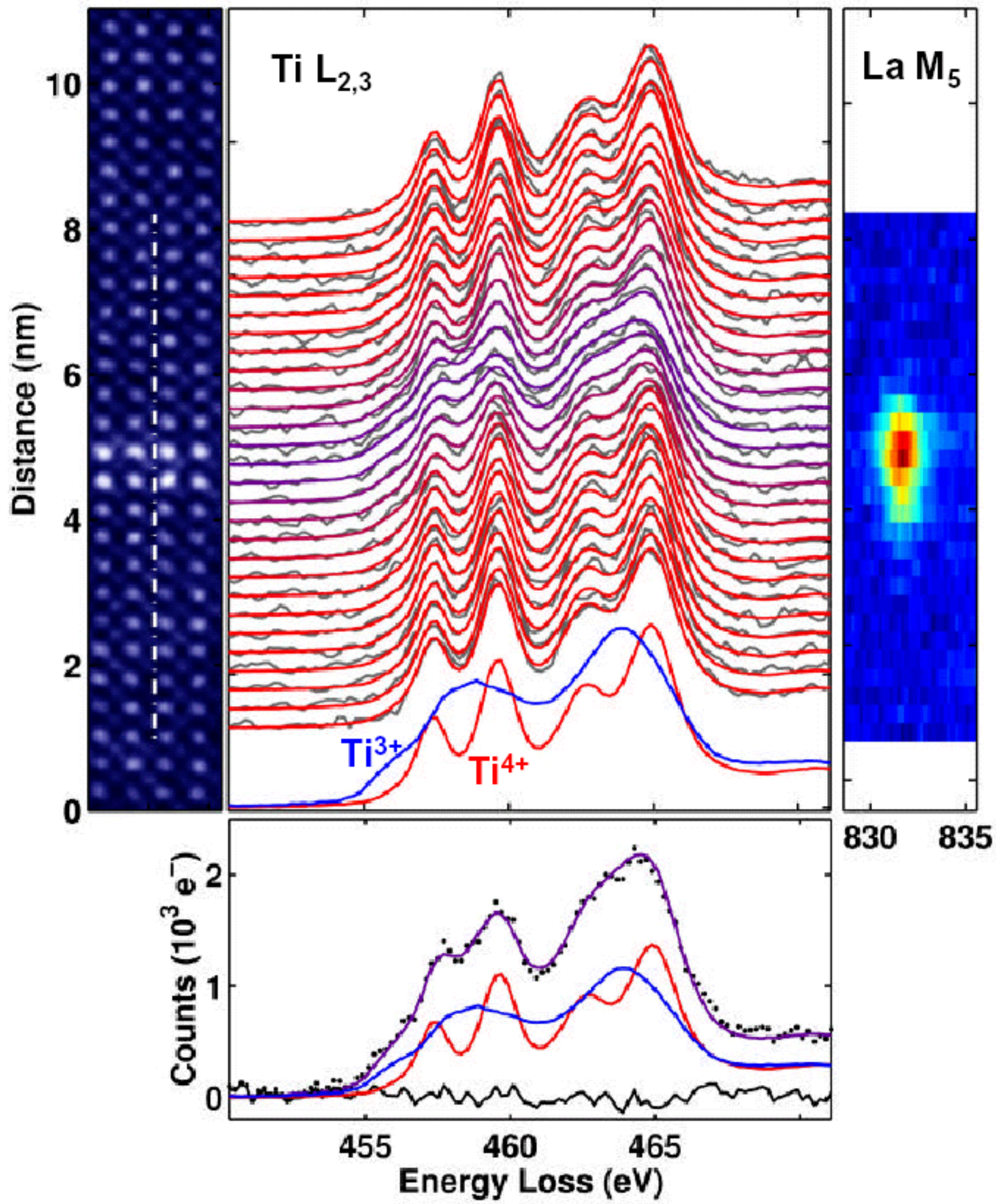
TEM/ EELS



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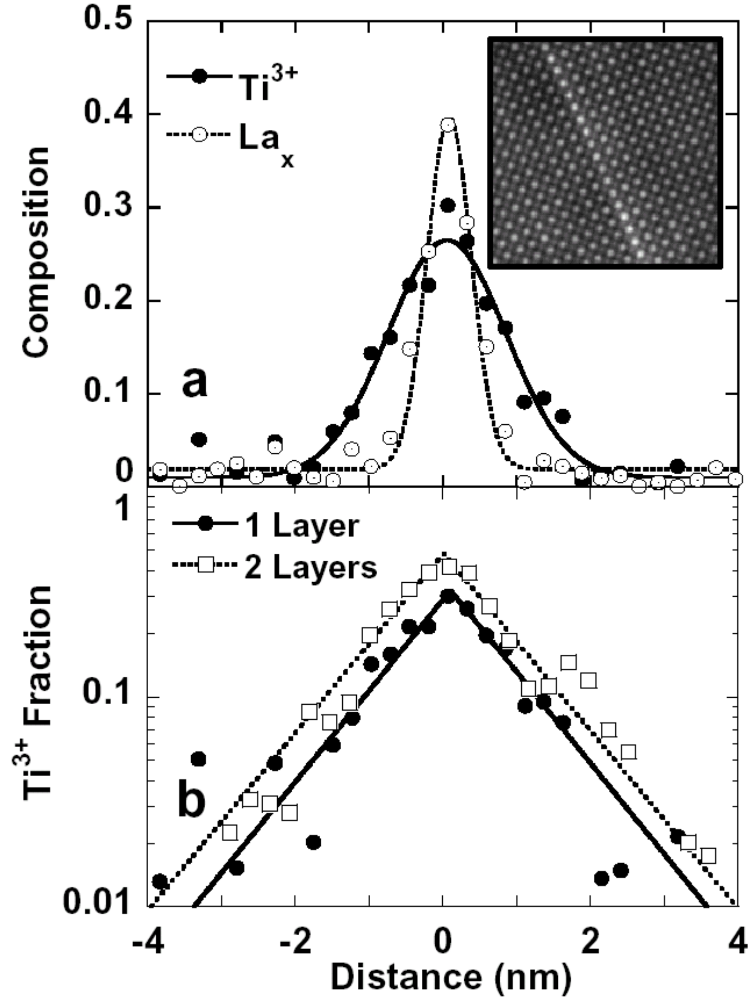
Resulting charge profile (1nm=2.5 u.c.)



Note: Ti^{3+} density integrates to 1 per La

Plausible that there are negligible oxygen vacancies.

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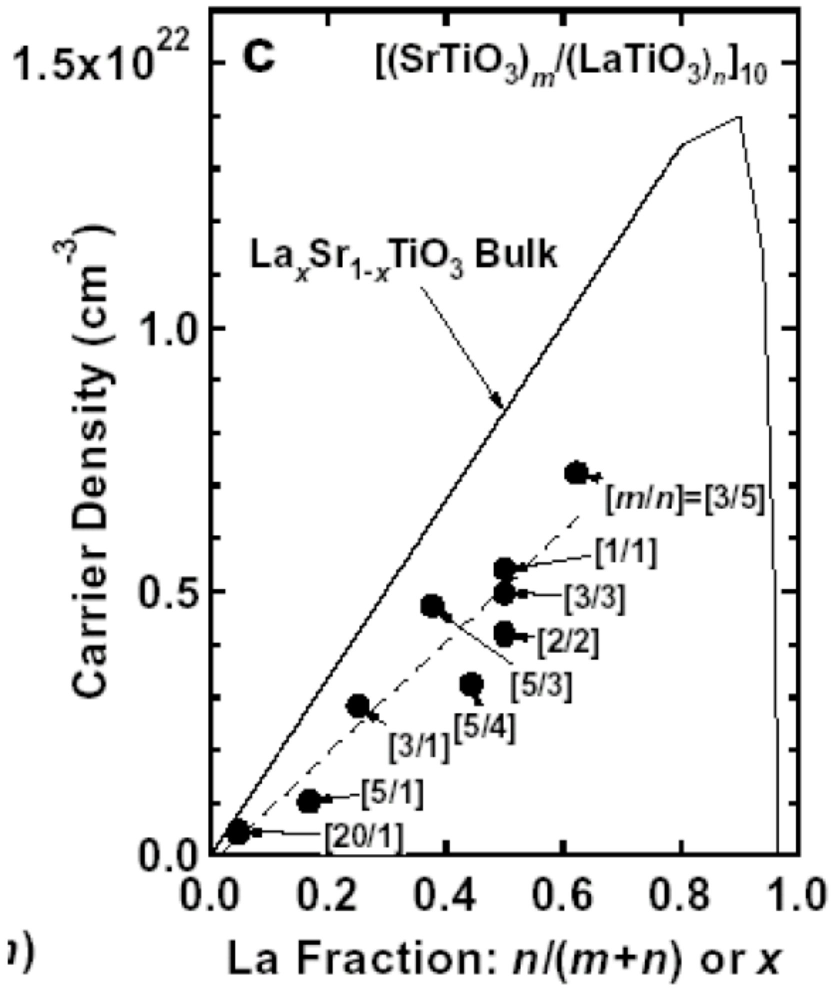
Thin structures: ~ 1 carrier per La



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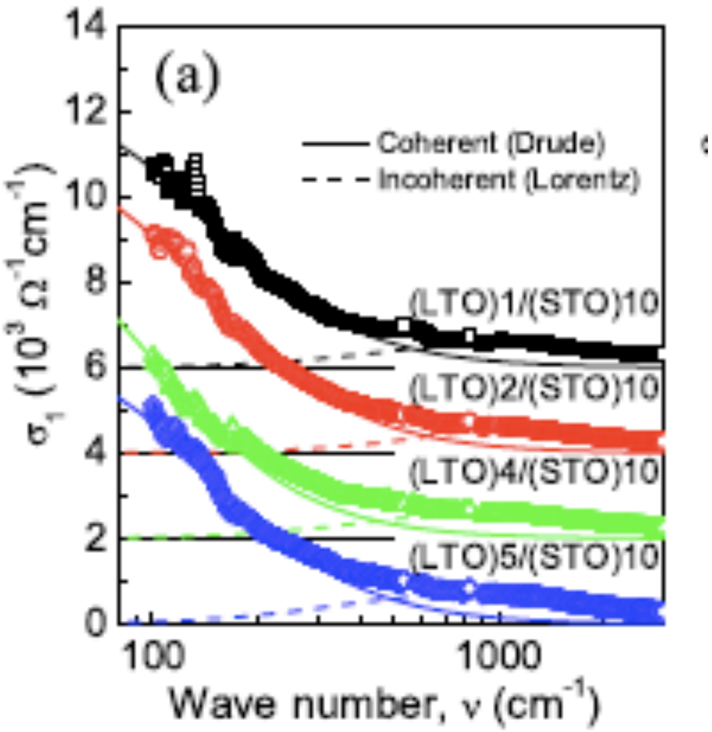
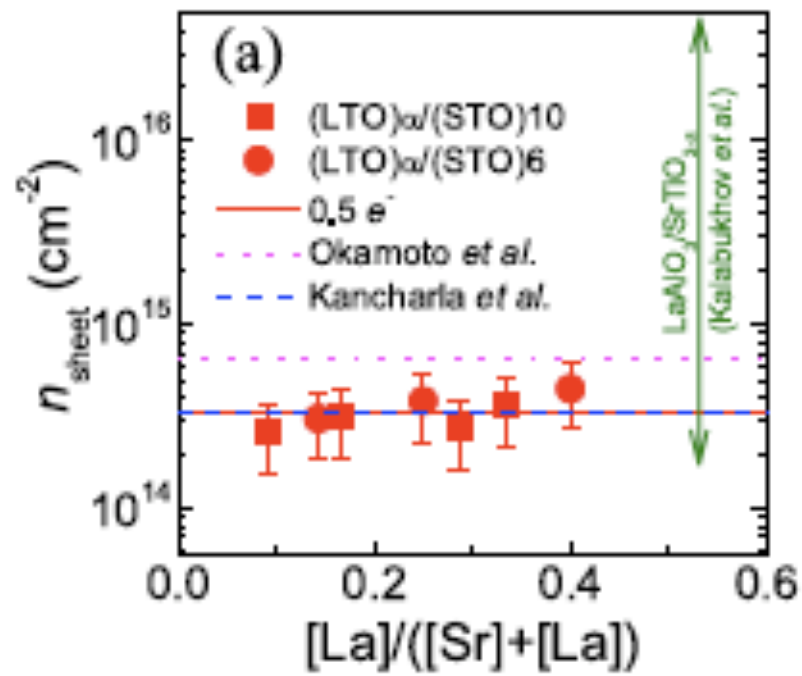
Optical Data now coming on line

PRL **99,** 266801 (2007) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2007

Optical Study of the Free-Carrier Response of $LaTiO_3/SrTiO_3$ Superlattices

S. S. A. Seo,[1,*] W. S. Choi,[1] H. N. Lee,[2] L. Yu,[3] K. W. Kim,[3] C. Bernhard,[3] and T. W. Noh[1,†]





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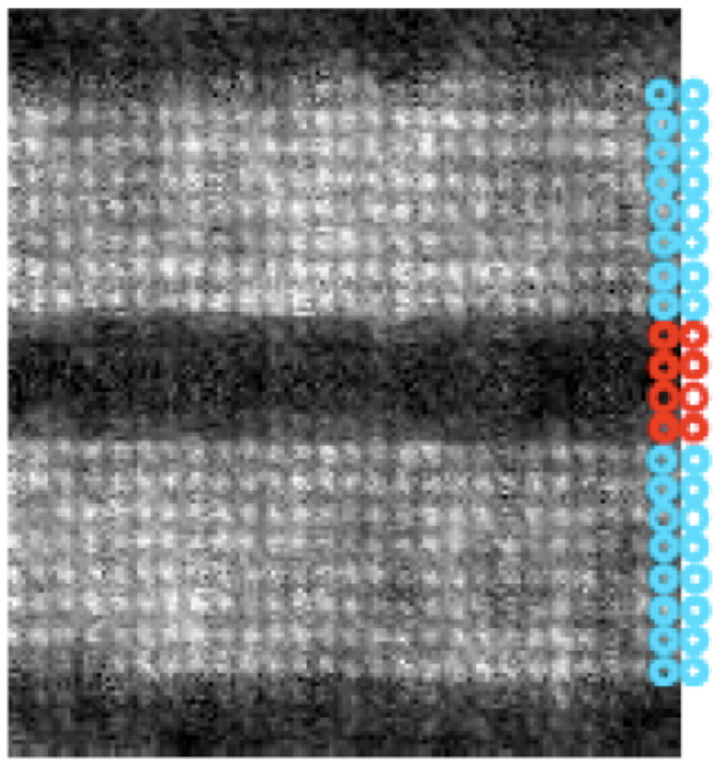
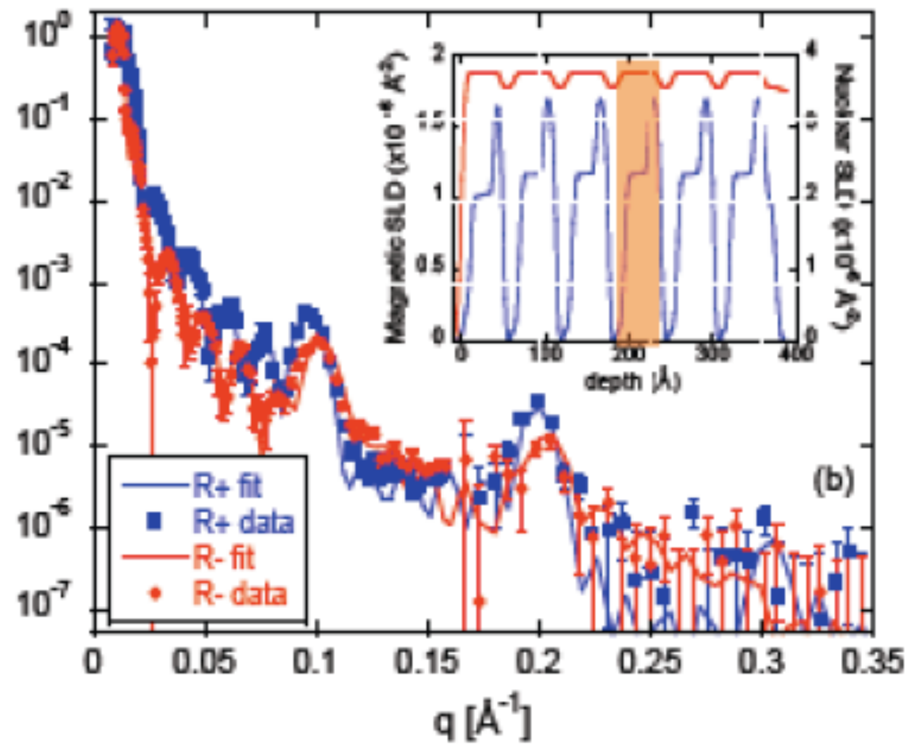
$(LaMnO_3)_n(SrMnO_3)_m$

Bhattacharya/Eckstein



n=5 m=10



Magnetization at the interface

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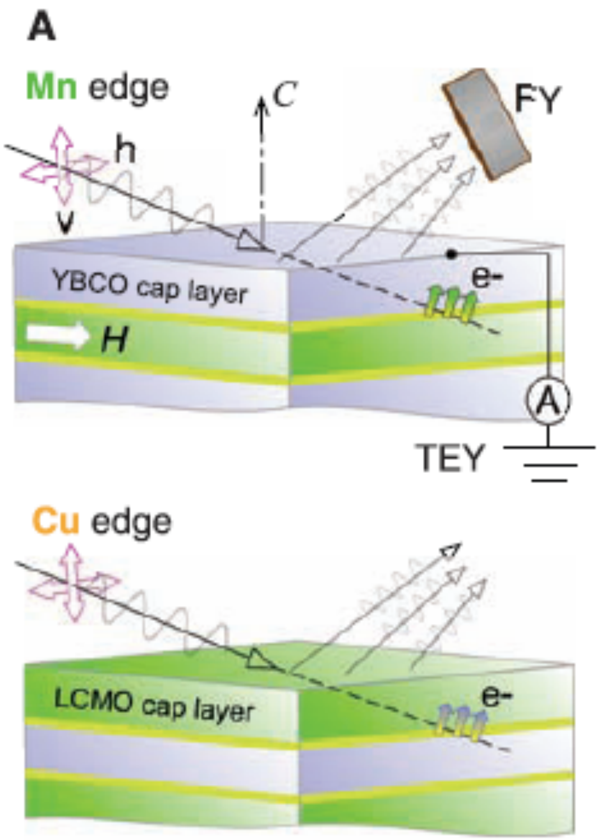
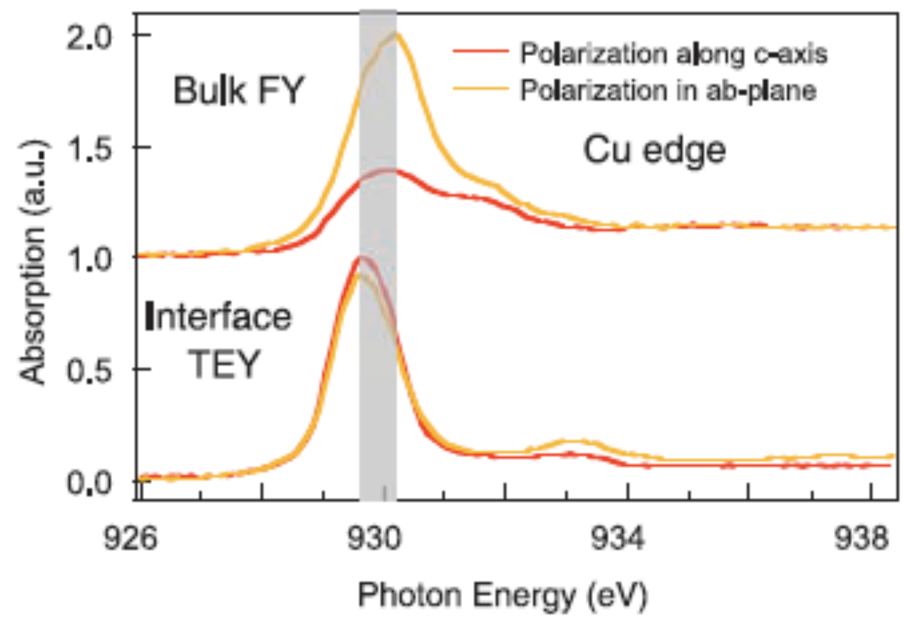
Heterometallic Interface:

$LaMnO_3/YBa_2Cu_3O_7$



Chakhalian, Science 08



Bulk: polarization => holes in x^2-y^2

Interface: holes also in $3z^2$-r^2

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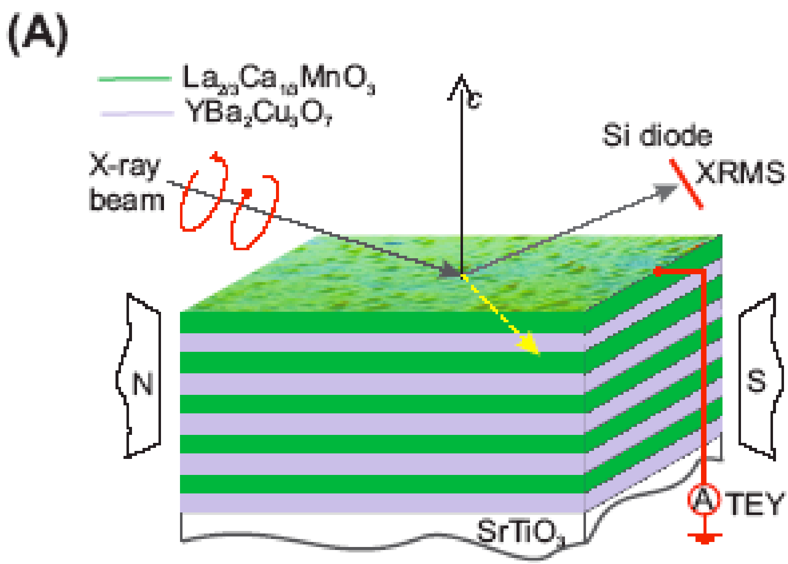
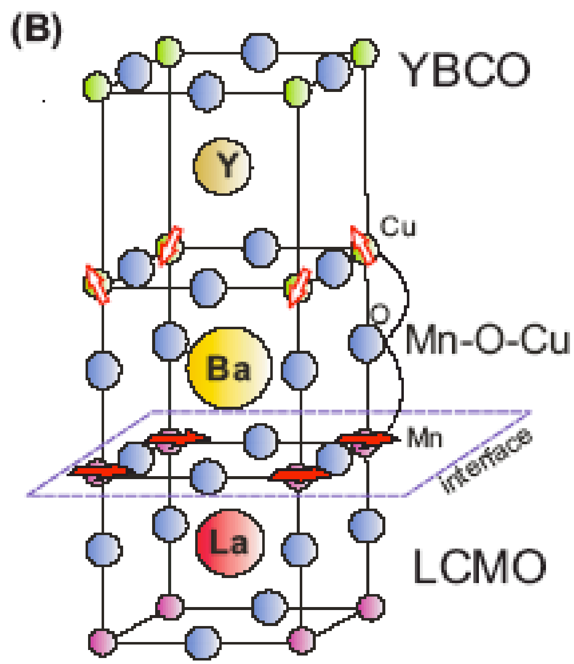
Example: penetration of magnetization into high-Tc superconductor
(Chakhalian/Keimer; Nature)

LCMO: Ferromagnet, high spin polarization
YBCO: high Tc superconductor



Each layer ~100A thick



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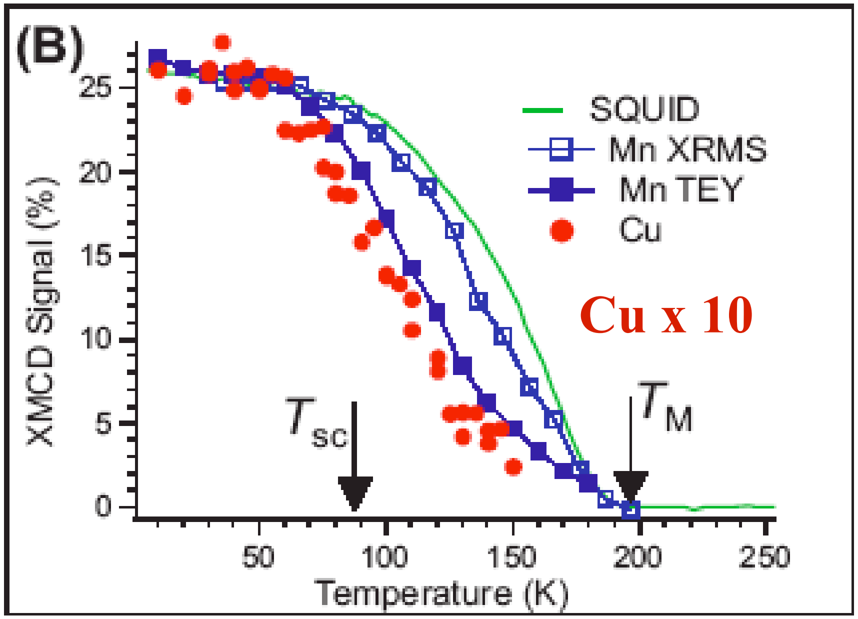
X-Ray Magnetic Circular Dichroism (element-specific)



XMCD signal combined with grazing-incidence neutron data (not shown) => Cu magnetization persists 20A (3 “bilayer” unit cells) away from interface.

TEY=”total electron yield” --more surface sensitive

XRMS: X-ray magnetic scattering: sees deeper into bulk

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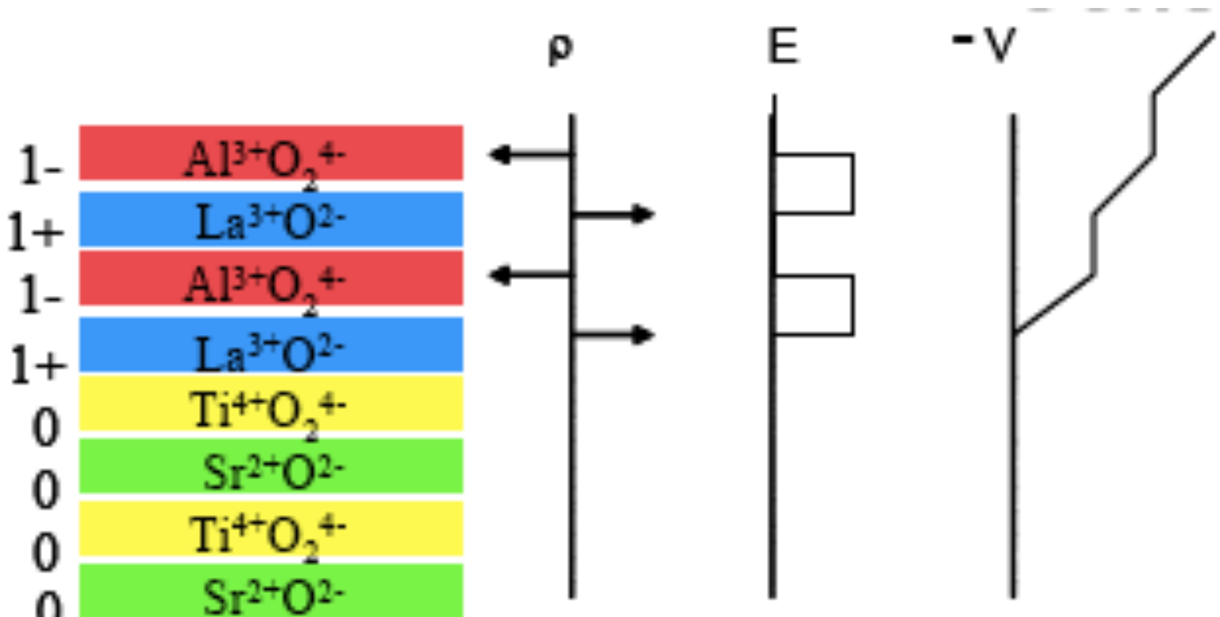
Simple terminations=>charge sheet: polarization ‘catastrophe’



Sawatzky 00; Reyren 06, Hwang 06....

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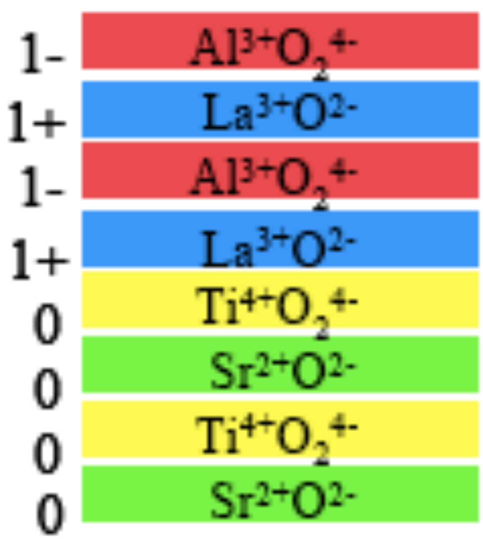
transfer electrons (or ions) eliminate polarization ‘catastrophe’

Before transfer



Figures Mannhart et al MRS Bulleting

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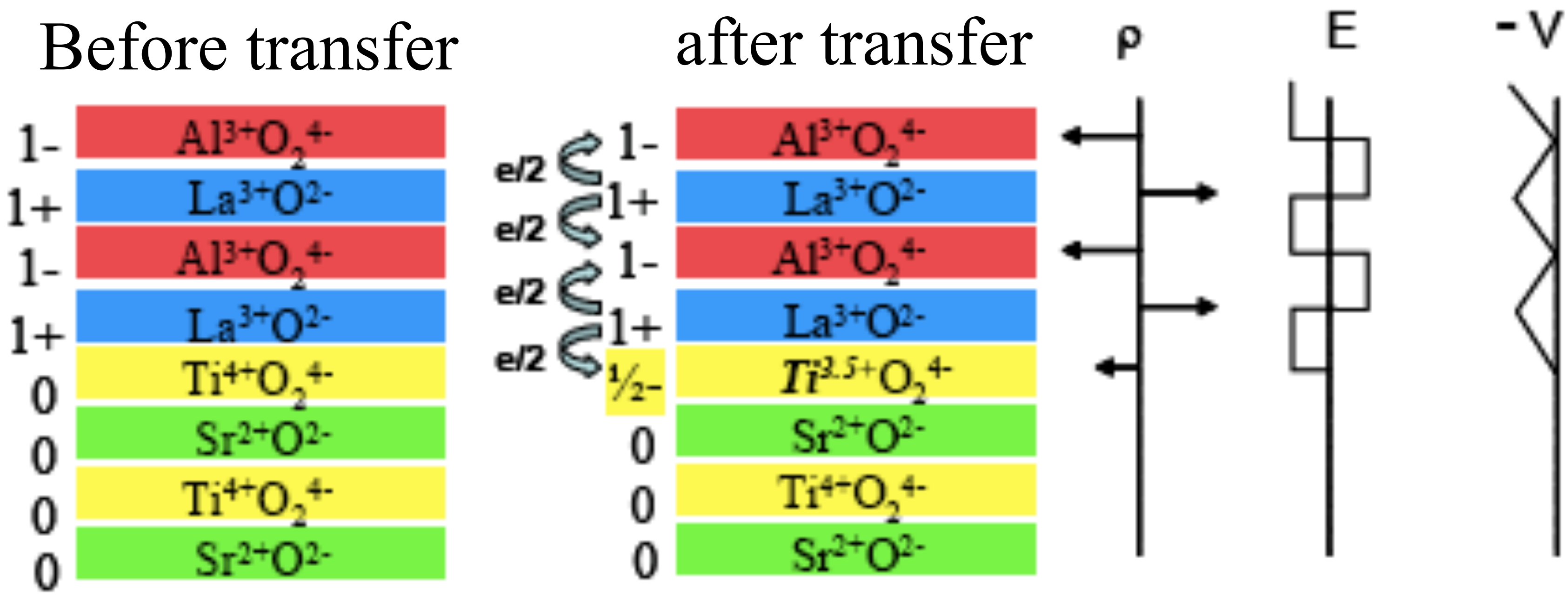
transfer electrons (or ions) eliminate polarization 'catastrophe'



Figures Mannhart et al MRS Bulleting

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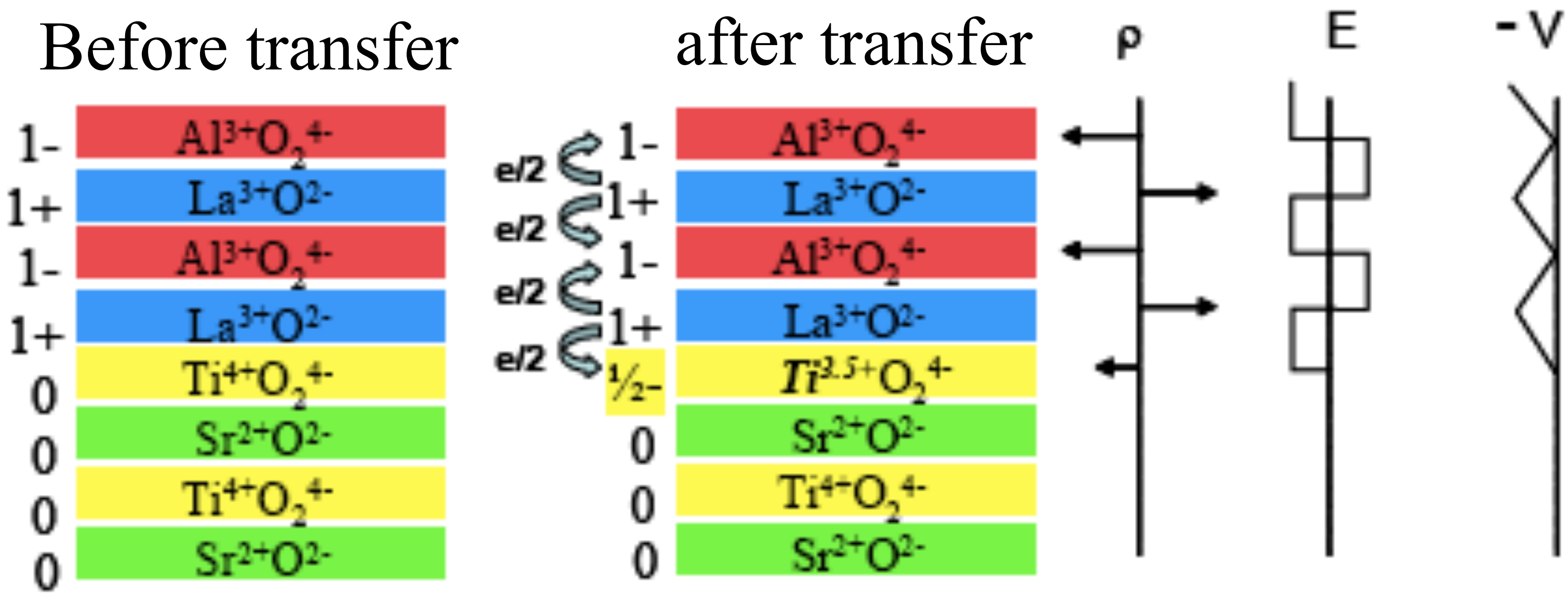
transfer electrons (or ions) eliminate polarization ‘catastrophe’



Electrostatics controls interface electronic charge density qn for expt: ?transfer ions (defects) or electrons?

Figures Mannhart et al MRS Bulleting

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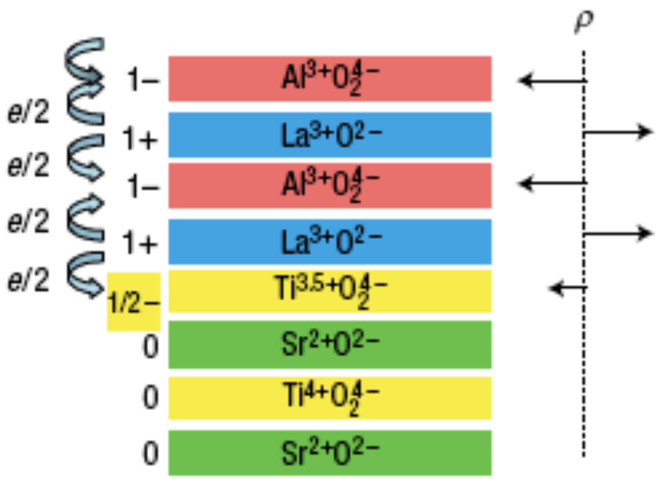
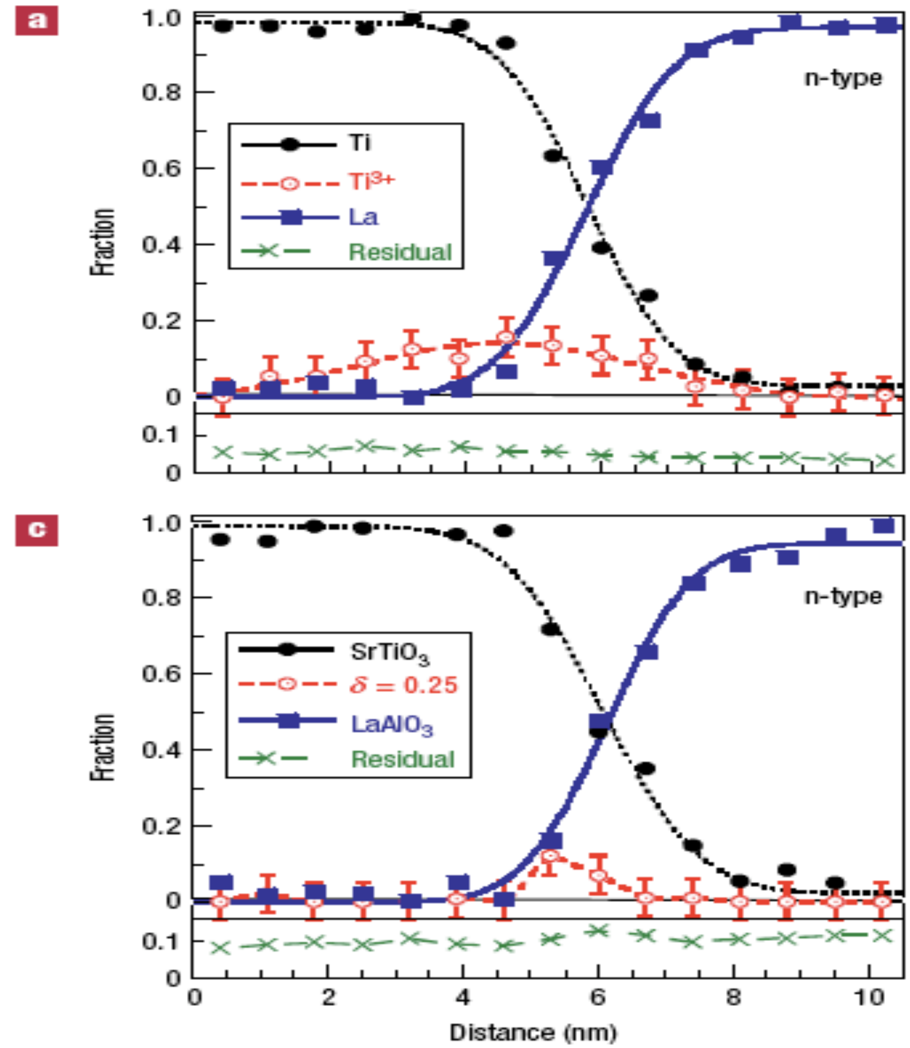
Hwang Nature Materials 2006

n-type





0.6 Ti 3+
0.15 O vacancies

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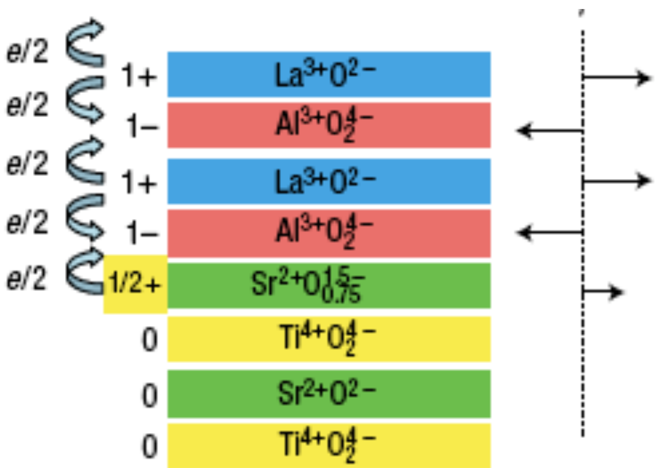
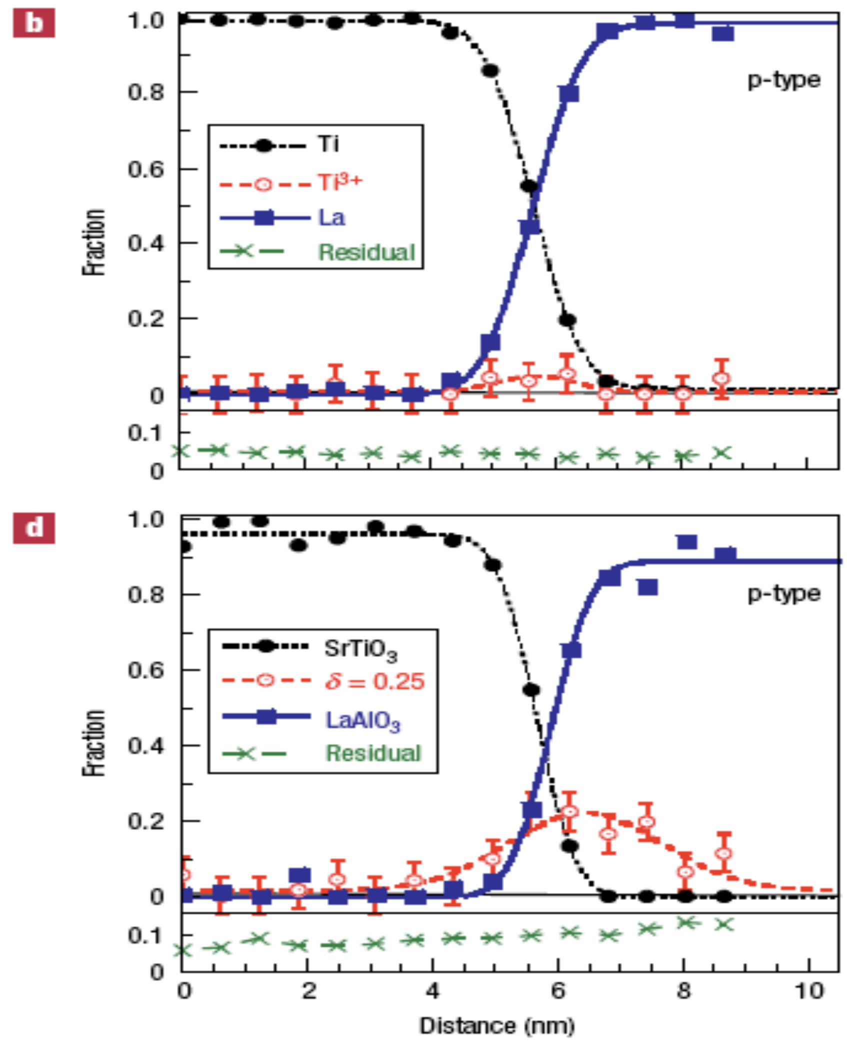
Hwang Nature Materials 2006

p-type





0. Ti 3+
0.3 O vacancies

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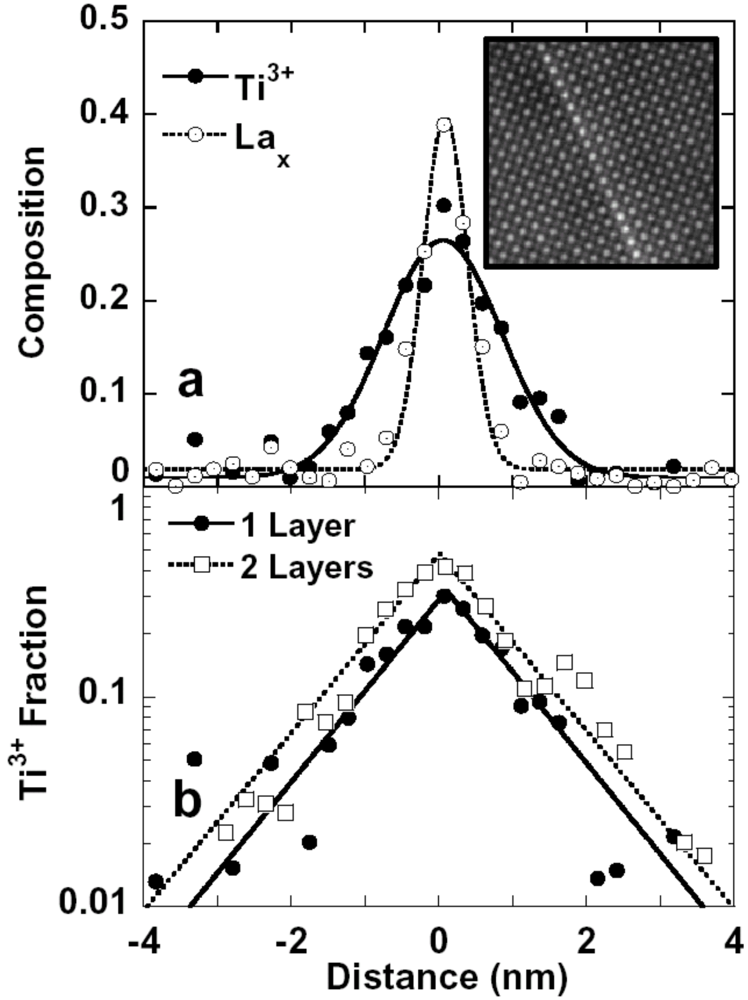
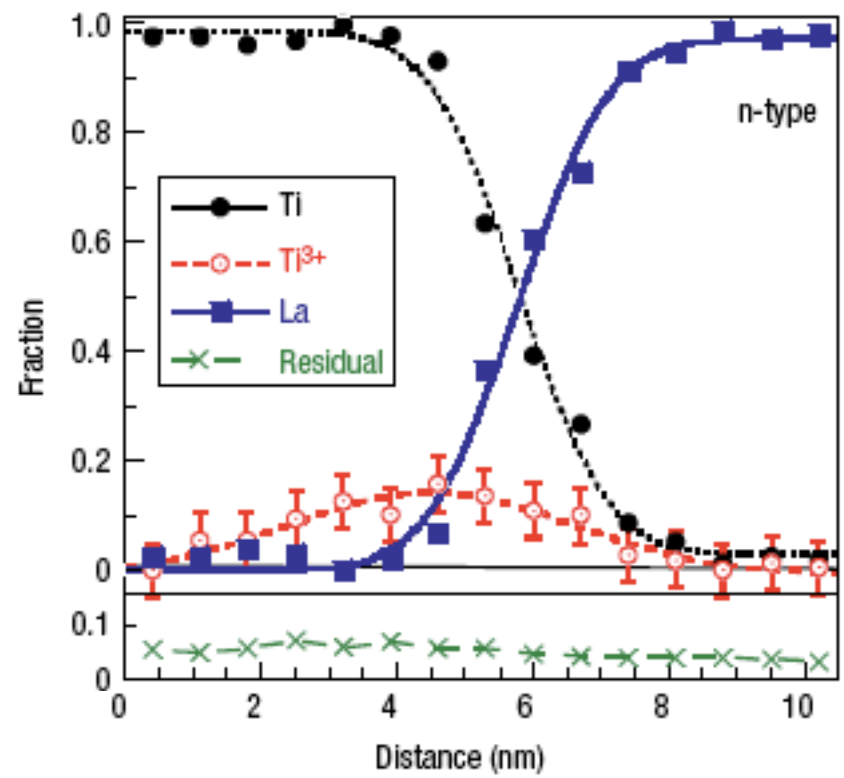
Heterometallic interface less sharp than homometallic





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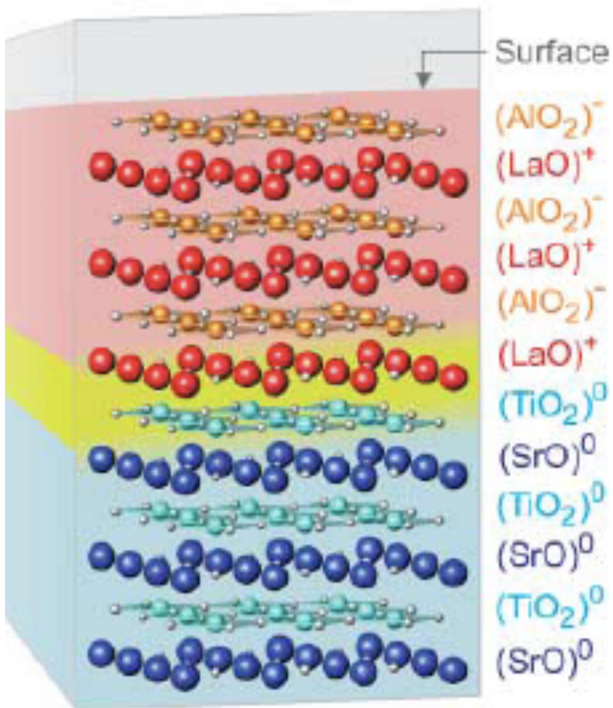
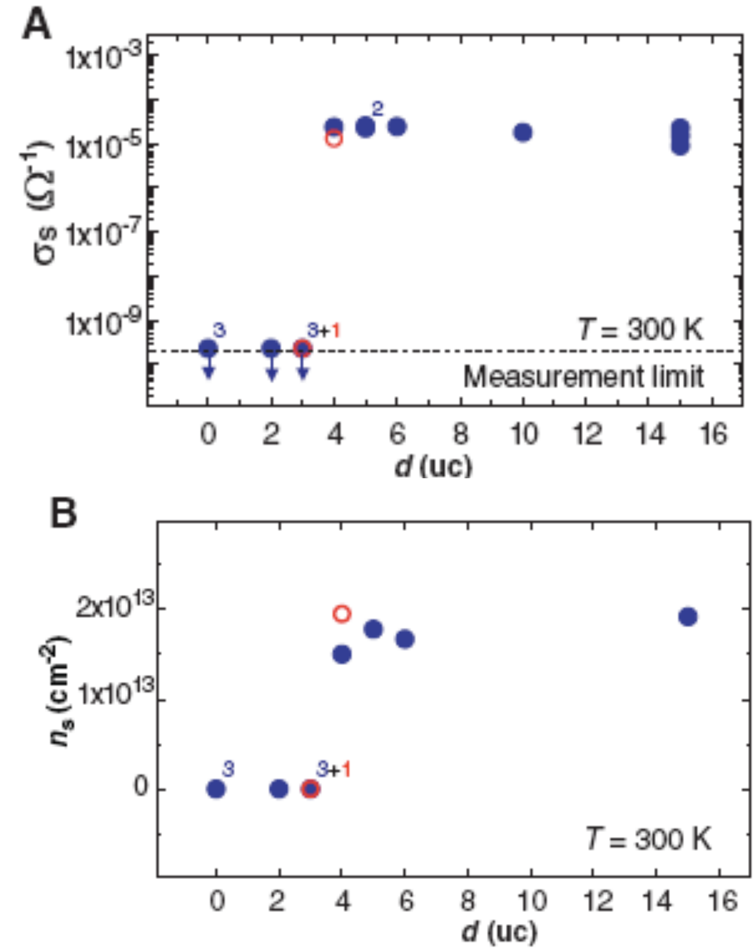
Thiel et. al.

SCIENCE VOL 313 29 SEPTEMBER 2006 1943





Note: n_{2d} ~0.03 /unit cell

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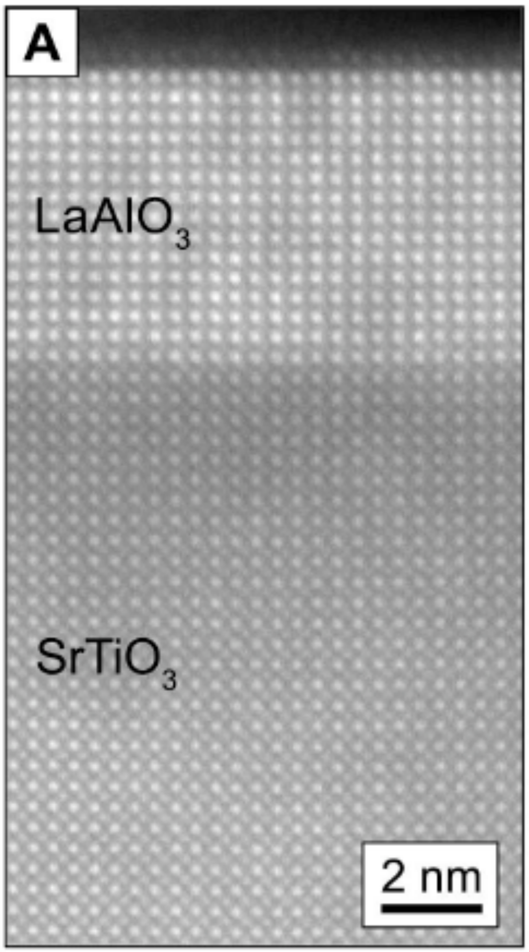
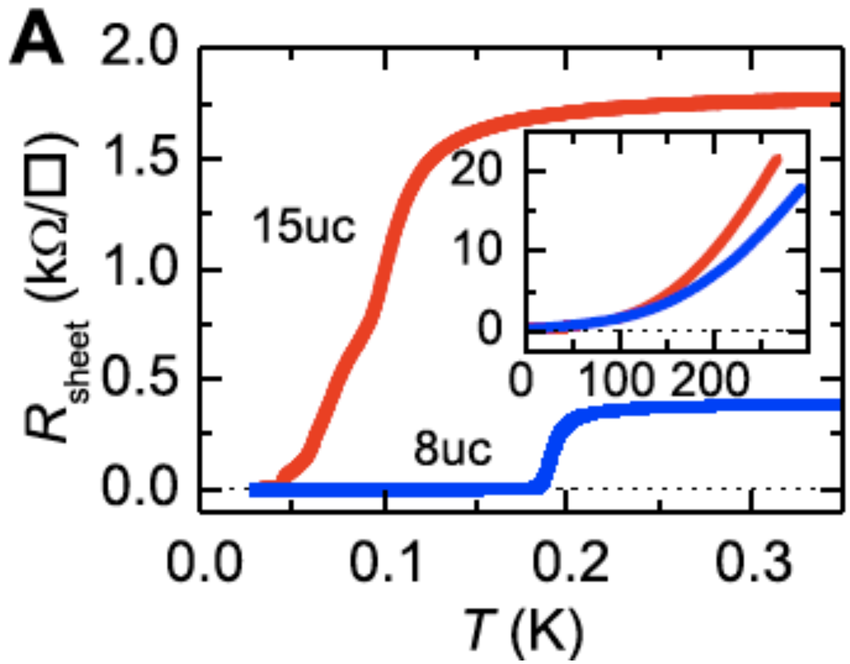
Superconductivity

Reyren et al. Science **317** 1196 (2007)





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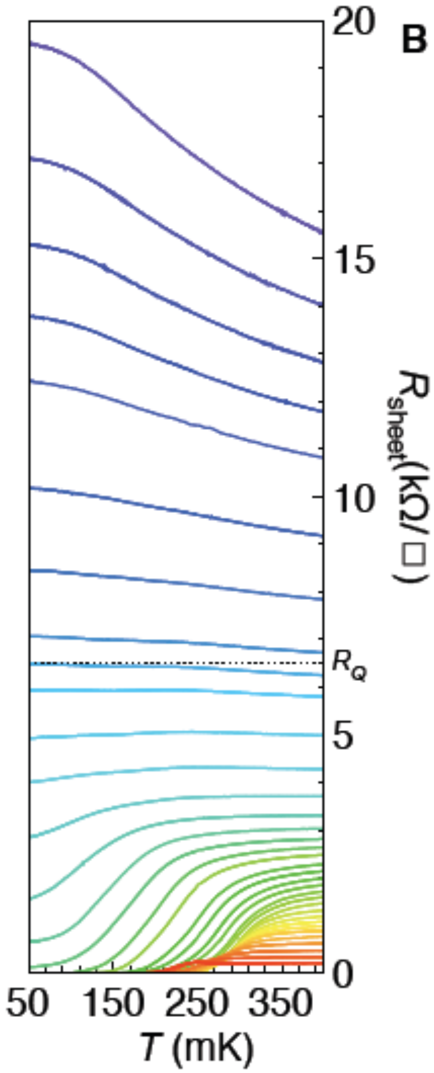
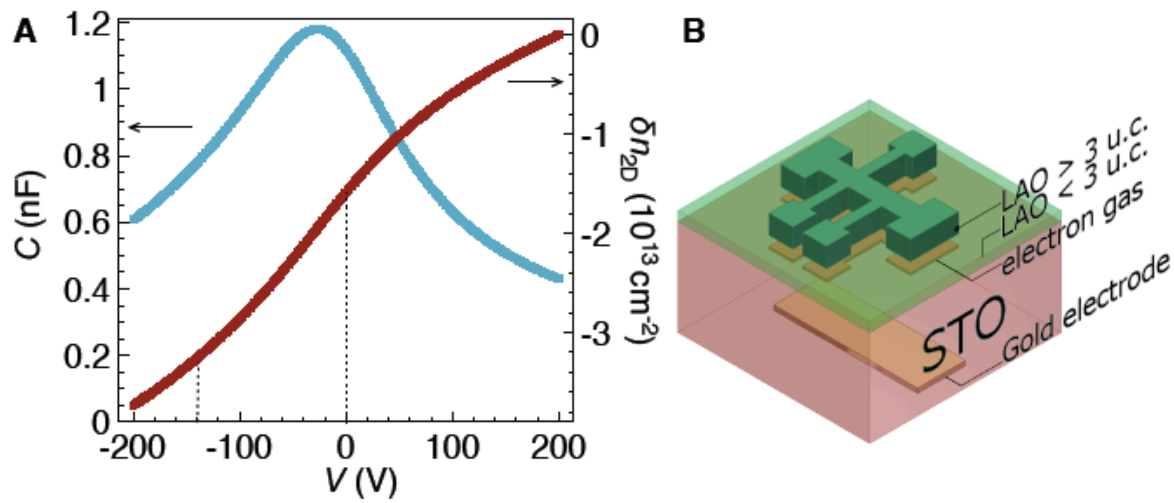
Superconductivity II

Caviglia et al preprint





At V=0 $\quad n_{2D} \simeq 4.5 \cdot 10^{13}\,\mathrm{cm}^2$

n_{max}=6 x 10^{13} cm^2 =**0.1 per cell**

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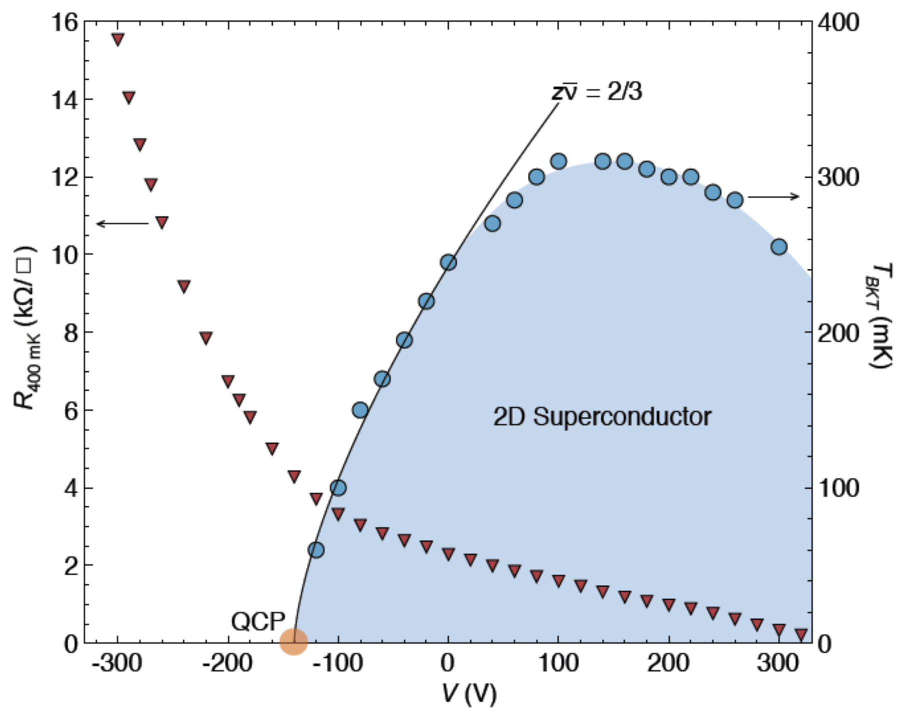
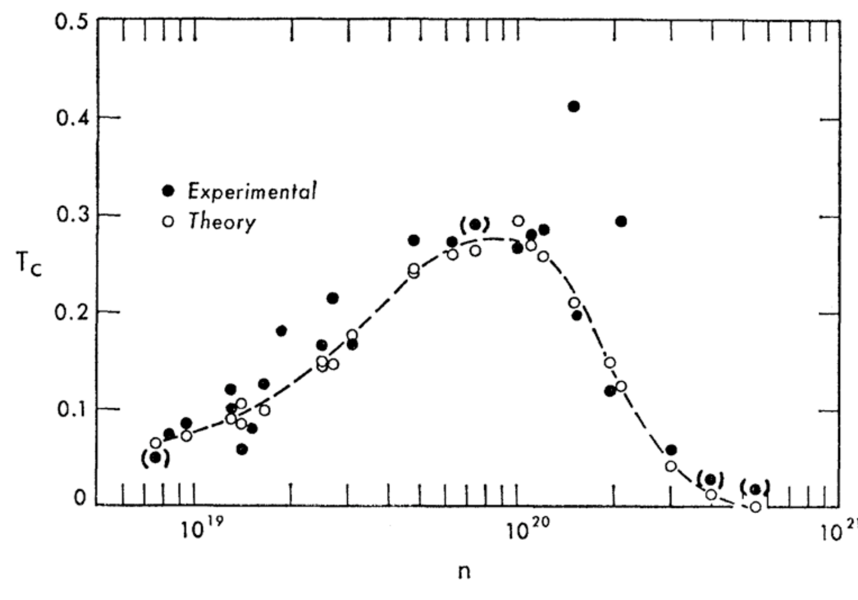
Interface vs bulk phase diagram



Bulk STO

Koonce et al PR 163 380 1967



Depth of SC region: 16 unit cells (from density of max Tc)

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Summary: Heterostructures

- **Structures can be grown**
- **Homometallic better quality than heterometallic**
- **Electrostatics controls charge density (modulo oxygen vacancies)**
- **consistency: transport and EELS?**

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