Oxide Multilayers

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Oxide Multilayers

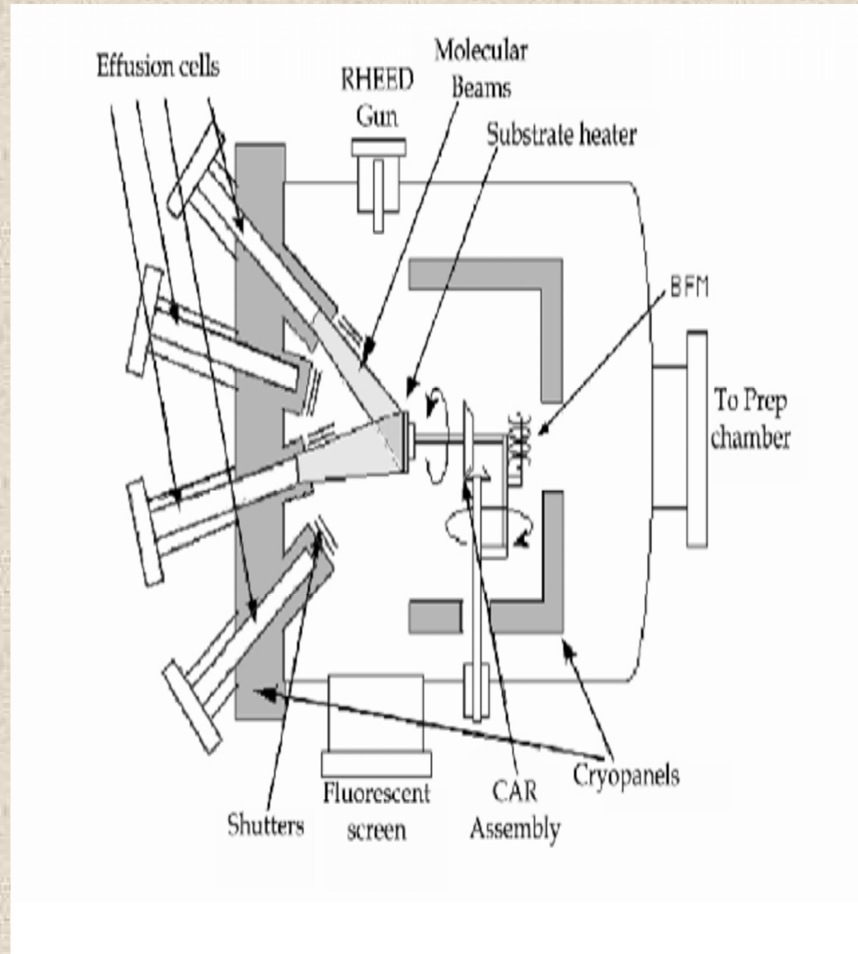
- Multilayer Thin Films
  - Wide range of applications (coating to Laser Diodes)
  - Developing deposition techniques
- Complex Oxides
  - Novel Properties

Outline

- Deposition Techniques
  - Molecular Beam Epitaxy
  - Pulsed-Laser Deposition
  - Reflection High-Energy Electron Diffraction
- Recent Studies
  - Perovskite Oxides
    - Lattice Structure and Electronic Structure
  - Superconductor-Ferroelectric Multilayers

Deposition Techniques

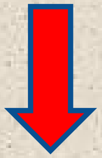
Molecular Beam Epitaxy



- MBE
  - can produce high-quality layers with very abrupt interfaces
  - Provides good control of thickness, doping, and composition
- 'Molecular Beams'
  - typically from thermally evaporated elemental sources
  - deposited onto a heated crystalline substrate to form thin epitaxial layers

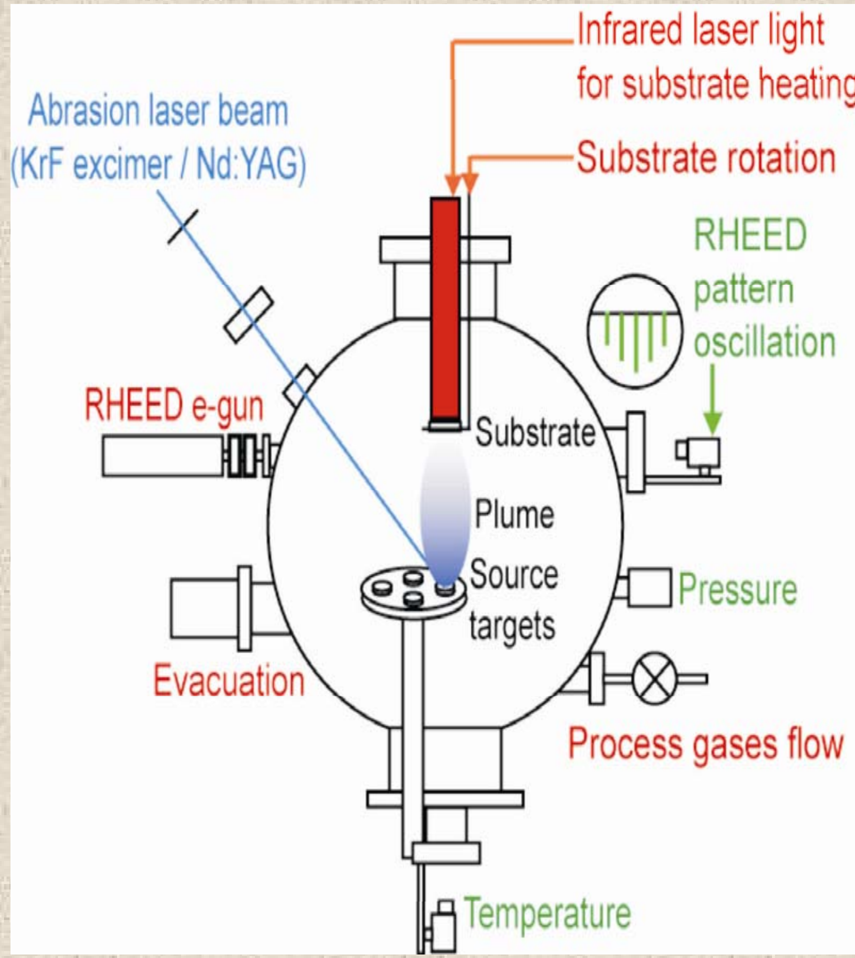
Molecular Beam Epitaxy

– To obtain high-purity layers
  - extremely pure material sources
  - ultra-high vacuum (10^{-8} Pa)
  - Very fast shutters
  - Very slow growth rates (1 nm/s)



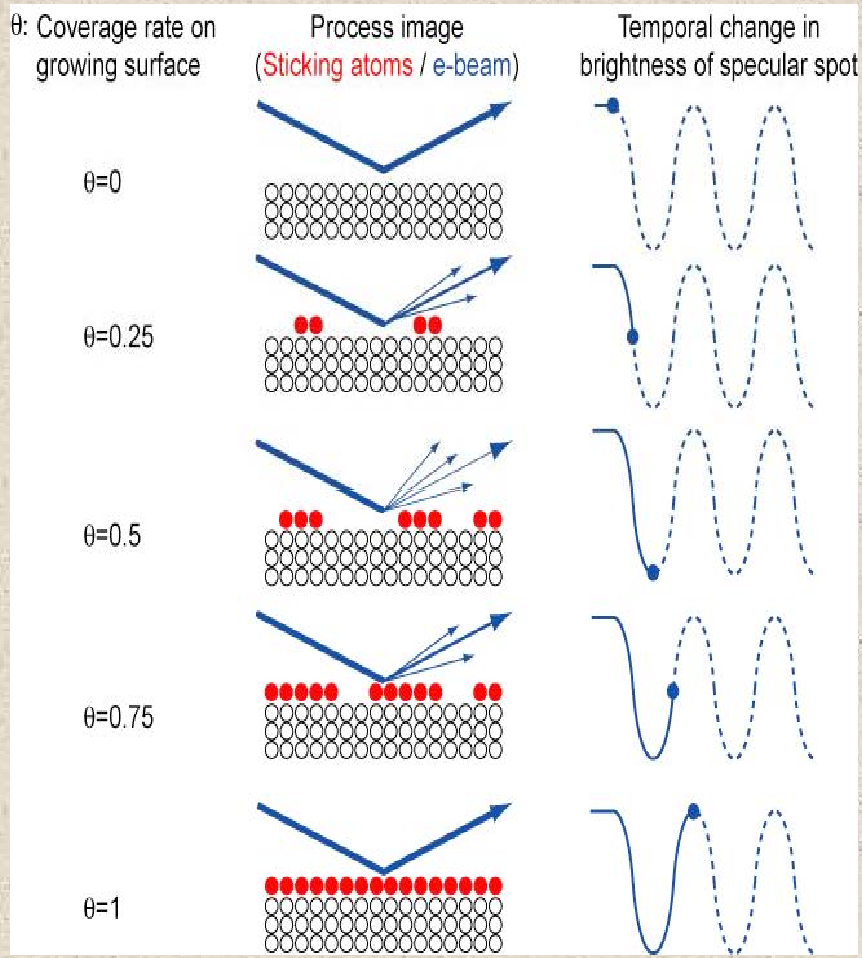
  - Very expensive process
  - Not suitable for mass production

Pulsed-Laser Deposition



– PLD
  - The laser-induced expulsion produces a plume of material with stoichiometry similar to the target
  - Allows the deposition of multi-element oxides

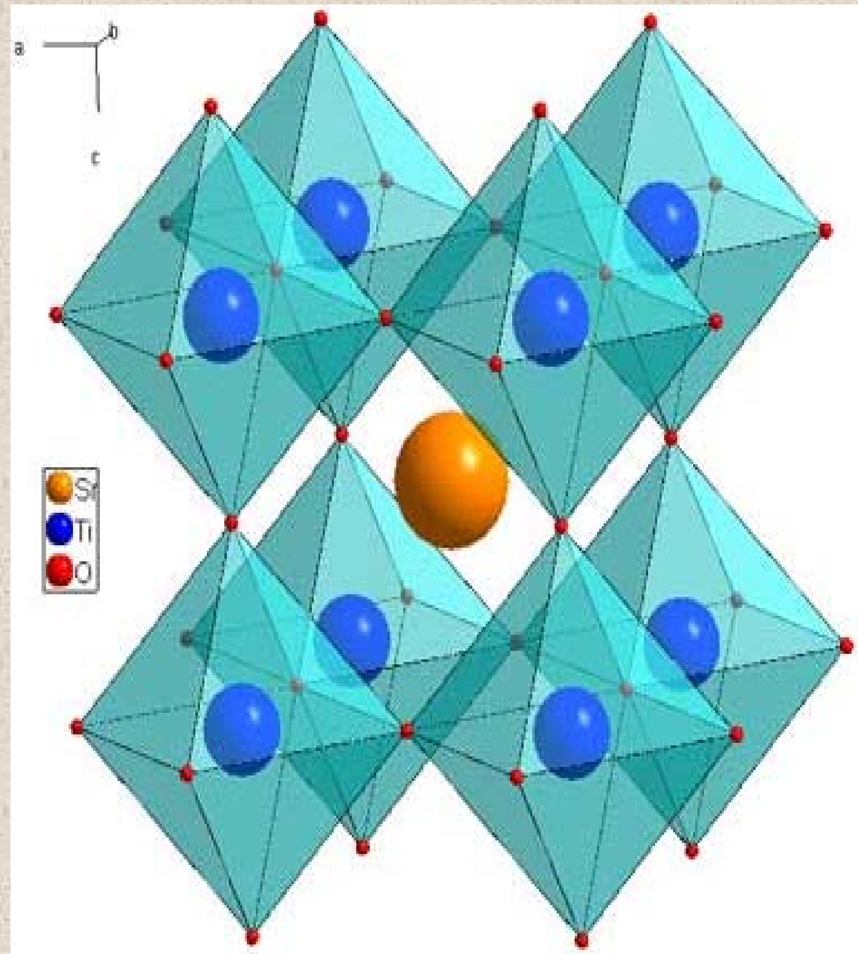
Reflection High-Energy Electron Diffraction



– RHEED
  - is based on the reflection of electrons
    With
      high kinetic energy (5-100 keV)
      low impact angle (less than 5^o)
  - **Intensity** depends on the film roughness
  - **Patterns** are used to determine the crystal structure

Recent Studies

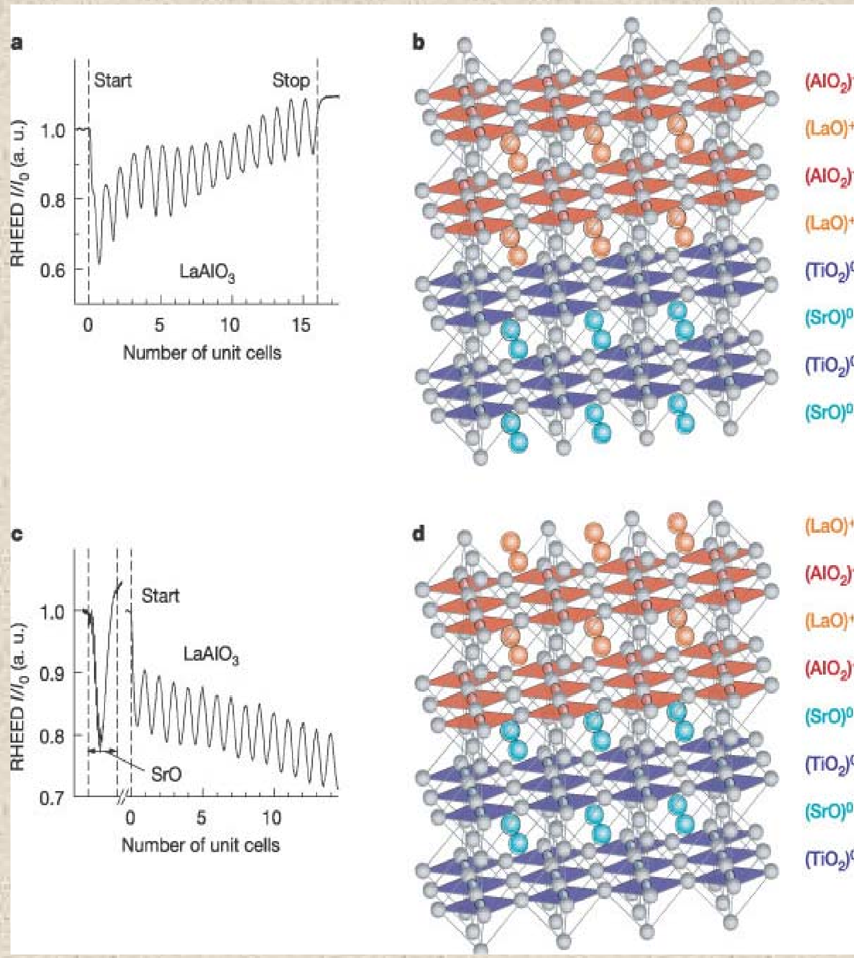
Perovskite Oxides



- *Lattice constants*
  - $LaAlO_3$ ~ 3.789Å
  - $SrTiO_3$ ~ 3.905Å
  - $LaTiO_3$ ~ 3.97Å
- Bandgap
  - $LaAlO_3$ ~ 5.6 eV
  - $SrTiO_3$ ~ 3.2 eV

Insulators

$LaAlO_3$/$SrTiO_3$ superlattice films



– dangling bonds and incomplete atomic coordination

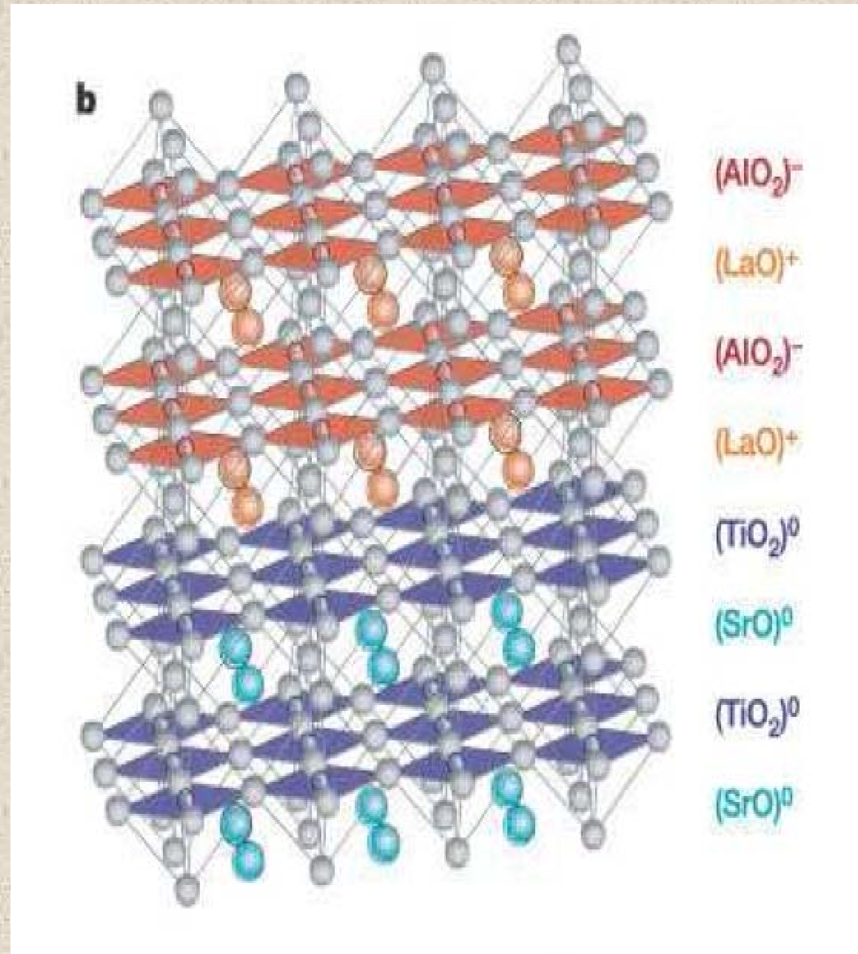
– nontrivial electronic structure at the interface

– Formal valance states

La^{3+}, Al^{3+}, O^{2-}, Sr^{2+}

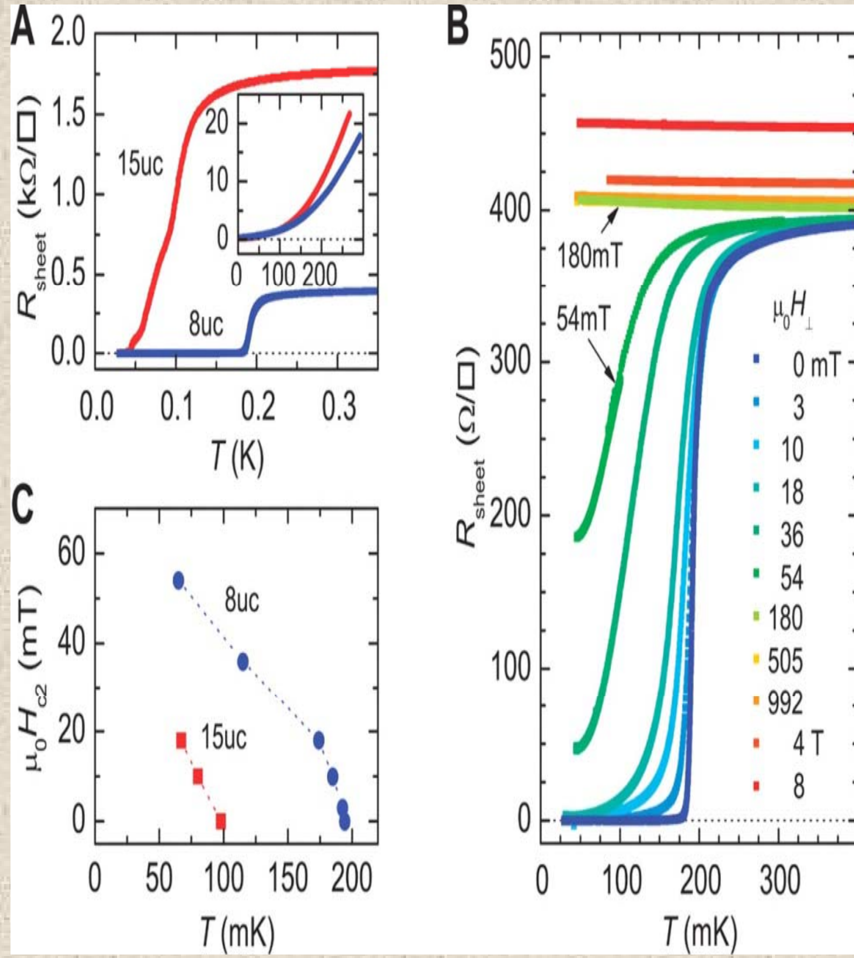
Ti^{4+}----> Ti^{3+}

$LaAlO_3$/$SrTiO_3$ superlattice films



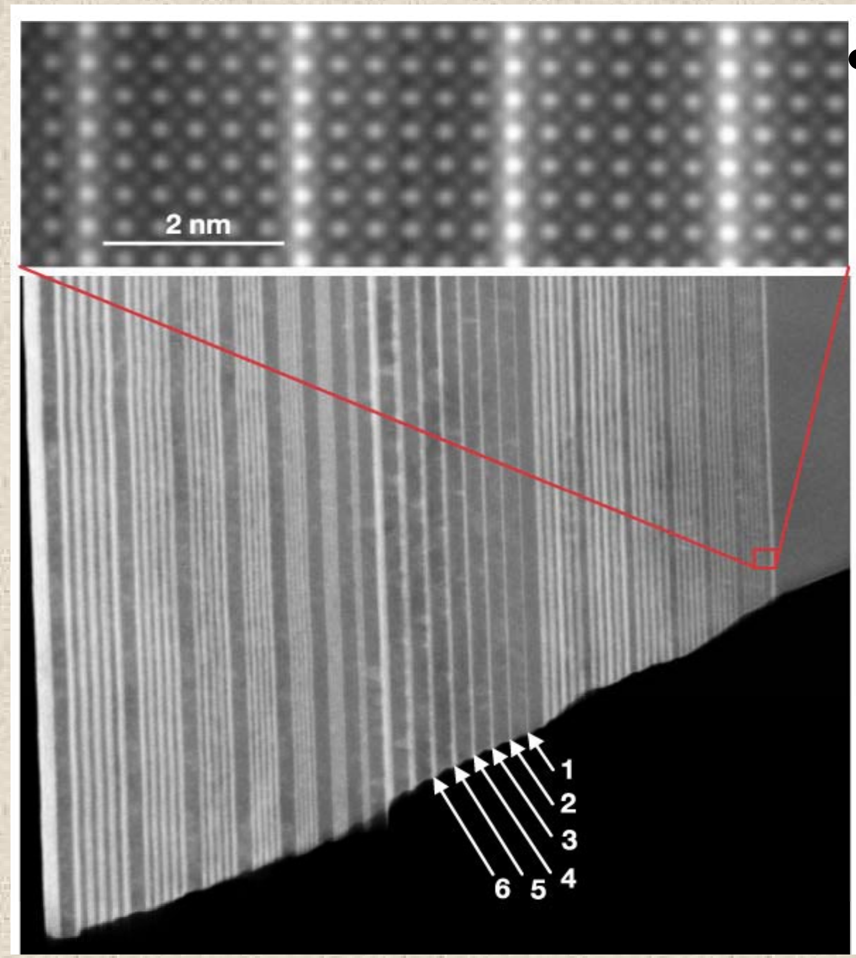
- *$SrTiO_3$*
  - is a sequence of charge neutral sheets
- *$LaAlO_3$*
  - alternates between *±e* charged sheets

$LaAlO_3/SrTiO_3$ superlattice films



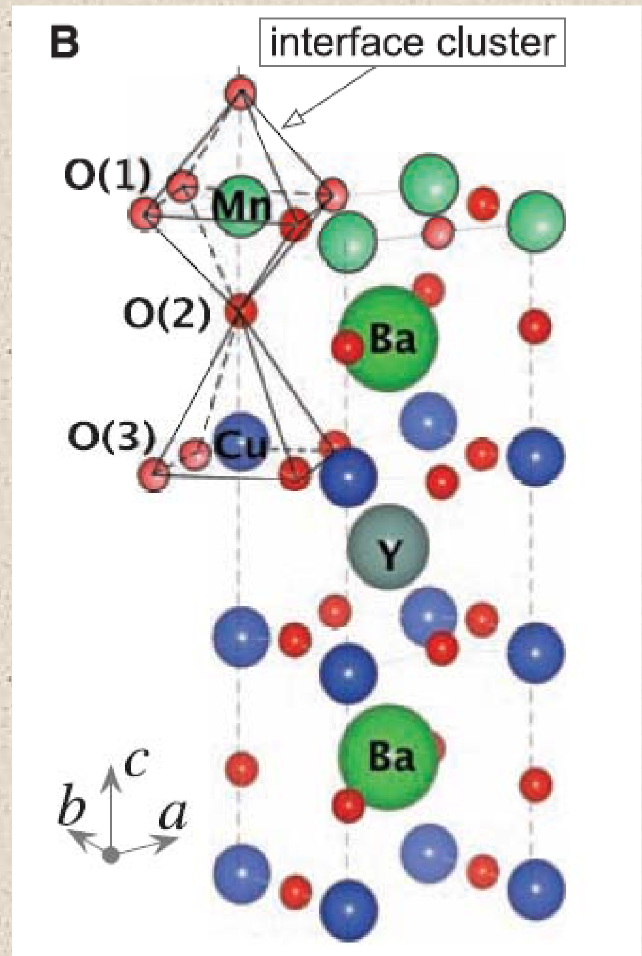
- Ohtomo et al.(2004)
  - interface has a very high carrier mobility exceeding 10,000 $cm^2V^{-1}s^{-1}$
- Thiel et al. (2006)
  - large electric-field response
- Reyren et al. (2007)
  - superconductivity in this electron gas with a transition temperature of 200mK

$LaAlO_3/SrTiO_3$ superlattice films



- Ohtomo et al. (2002)
  - spatial distribution of the extra electron in the titanium sites results in metallic conductivity in the interface
  - electron gas is confined within a ~ 2-nm thick layer

Superconductor-Ferroelectric Multilayers



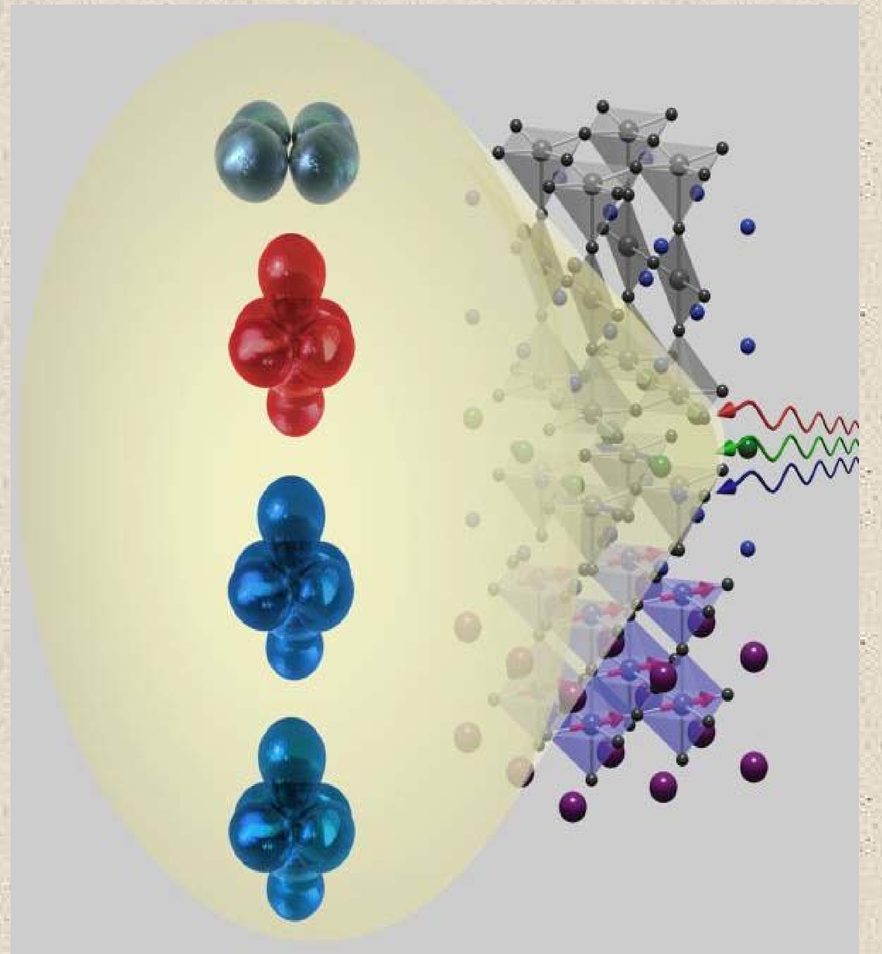
- Chakhalian et al. (2007)
  - $La_{0.67}Ca_{0.33}MnO_3$/ $(Y,Ca)Ba_2Cu_3O_7$
  - holes which are constrained to the

Cu $d_{x^2-y^2}$ orbital in the bulk, occupy the

$d_{3z^2-r^2}$ orbital at the interface

→ orbital reconstruction

Resonant x-ray spectroscopy



- synchrotron sources
  - can create x-rays with tunable energy and polarization
- intra-ionic transition
  - $2p^6 3d^9 \rightarrow 2p^5 3d^{10}$ (913eV)
  - polarizations parallel or perpendicular to the interface can be used to observe shifts in the absorption peak

Conclusion

- “Oxide Multilayers” is a relatively new and interesting field
- Since strongly correlated electron materials have very few common points compared to semiconductors their properties are material based and can not be generalized.
- Developing production and diagnostic methods can lead to new novel properties in these structures

References

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