Surface Phase Transitions of Layered Perovskite $Ca_{2-x}Sr_xRuO_4$

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What We Do…

Investigate the surface behavior of layered Calcium-Strontium Ruthenate Crystals, $Ca_{2-x}Sr_xRuO_4$, by a combination of electron spectroscopy and scanning probe microscopy techniques.

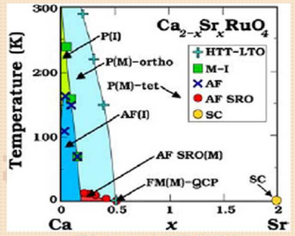
Why We Do It…

Strong coupling between electronic, lattice, orbital and spin degrees of freedom in transition metal oxides has attracted significant interest in exploiting their immense potential for oxide electronic devices with novel functionalities.

Doped transition metal oxides in general have a competition between ground states similar in energy creating materials with a wide array of exotic phases such as colossal magnetoresistance and superconductivity. In particular, substitution of isovalent Ca^{+2} for Sr^{+2} controls the bandwidth of the material allowing an opportunity to study the evolution from an unusual p-wave superconductor (x=2) to an Antiferromagnetic Mott-type insulator (x<0.2) with the Mott metal-insulator transition temperature strongly dependent on doping.

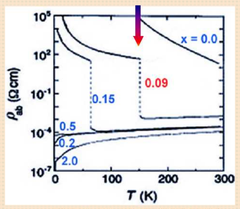
The layered perovskite structure is amenable to cleaving. Breaking translation symmetry by the creation of a surface in strongly coupled systems is a controlled way to study the coupling between the various degrees of freedom and the possible creation of new phases.

Understanding the fundamental physics of reduced dimensionality involved in surface/interface properties is vital for the realization of materials with desired transport properties necessary for the next generation of electronic devices.



Nakatsuji et al, PRL 84, 2666

T_c ~ 150 K for Bulk $Ca_{1.9}Sr_{0.1}RuO_4$



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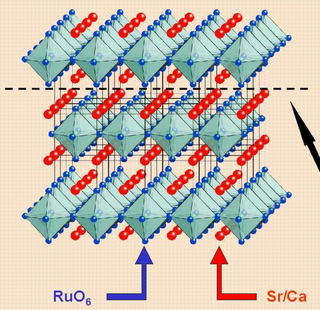
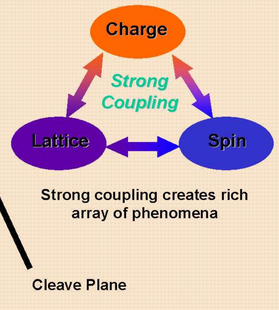
$Ca_{2-x}Sr_xRuO_4$ layered perovskite structure





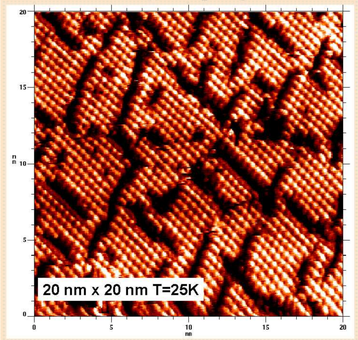
Strong coupling creates rich array of phenomena

Cleave Plane

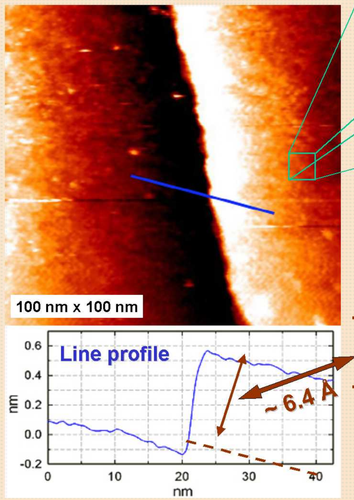
How We Do It…

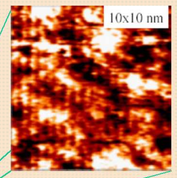
Surface Electronic Structure – STM

Defect Ordering on Sr_2RuO_4 Surface

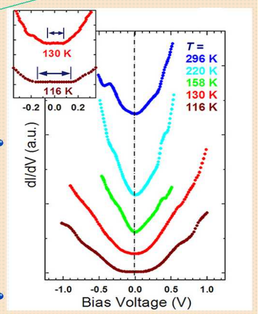


Step Edge on $Ca_{1.9}Sr_{0.1}RuO_4$ Surface





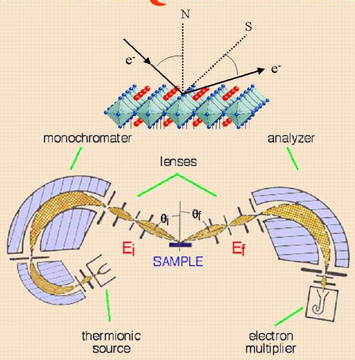
Surface electronic inhomogenities existent in many doped TMOs

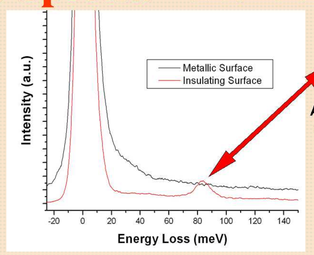


STS shows electronic gap open up at ~130K for $Ca_{1.9}Sr_{0.1}RuO_4$

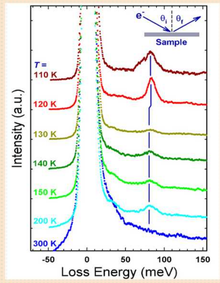
STM reveals the local electronic density of states near the Fermi Energy. STM and STS are used to study the structure and electronic properties of the surface.

Surface Quasi-Particle Spectra – HREELS



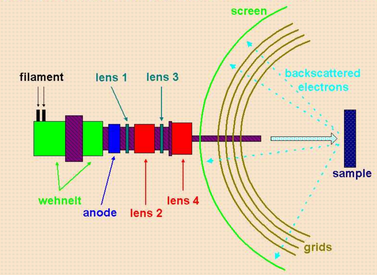


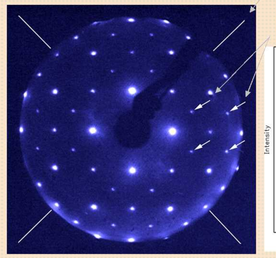
A_{1g} dipole active vibration mode



High Resolution Electron Energy Loss Spectroscopy (HREELS) uses low energy monochromatic electrons to study the dielectric response of a surface through quasi-particle excitations. HREELS reveals metal-insulator transition is synchronized with phonon dynamics for $Ca_{1.9}Sr_{0.1}RuO_4$.

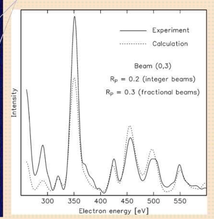
Surface Structure – LEED

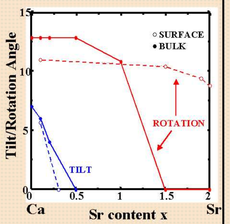




Glide planes show RuO_6 Tilt exists only for x < 0.3

Fractional spots show surface reconstruction

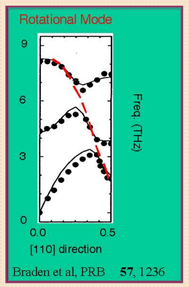


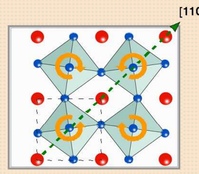


Low Energy Electron Diffraction (LEED) reveals the surface structure of the crystals. By tracking diffraction spots as a function of incident electron beam energy (LEED-IV), surface reconstruction can be calculated to determine the rotation and tilt of the RuO_6 octahedra.

What We Have Found…So Far

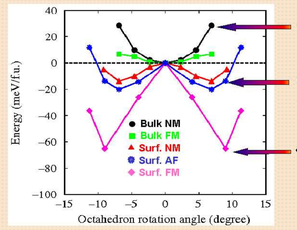
Sr_2RuO_4





RuO_6 octahedra rotated by ≈ 9º

Bulk Sr_2RuO_4 has a bulk phonon which freezes into a structural distortion as temperature is lowered. Creation of surface freezes the soft phonon resulting in surface reconstruction with RuO_6 octahedra rotated by ~9º producing ferromagnetic ordering.



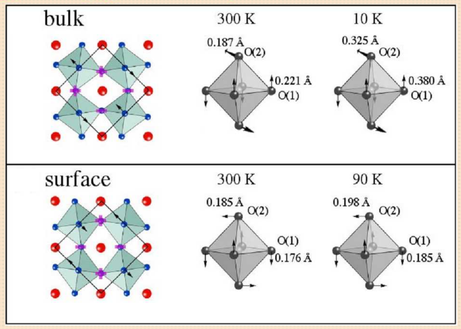
• No rotation in the bulk

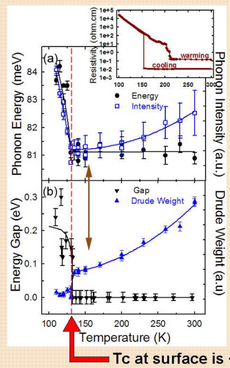
• Reconstruction at Surface
→ energy reduction 14 meV

• FM stabilizes reconstruction
→ energy reduction 65 meV

Matzdorf et al., Science 289, 746

$Ca_{1.9}Sr_{0.1}RuO_4$





Doping creates an orthorhombic bulk structure altering the bandwidth and electron-electron (e-e) correlations resulting in Mott metal-insulator transition (MIT). Creation of a surface is expected to increase e-e correlations causing higher MIT transition temperature at the surface. However, surface reconstruction distorts the RuO_6 octahedra resulting in a LOWER transition temperature.

Tc at surface is ~20K lower than bulk

To Be Continued…