Tuning the electronic structure of High Temperature Superconducting films by field-induced oxygen diffusion

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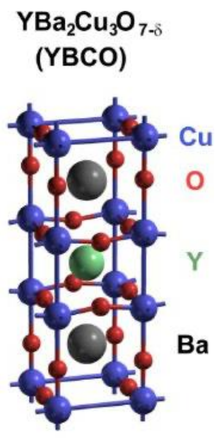
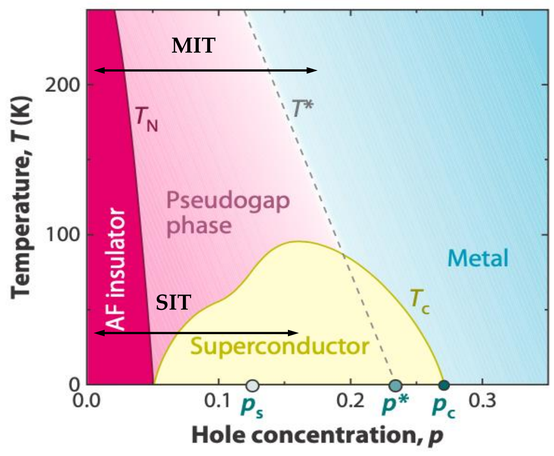
Motivation

Modulation of carrier concentration in strongly correlated oxides offers the unique opportunity to induce different phases in the same material, which dramatically change their physical properties. Specially, the possibility to reversibly modify the metal-insulator transition (MIT) in perovskite oxides, by means of an electric field, as the external control parameter, is a very active area of research in condensed matter physics, and a promising technique to generate new solid-state devices with exciting functionalities. In this contribution we will show the electric manipulation of the superconducting to insulator phase transition (SIT) in high temperature superconductor $YBa_2Cu_3O_{7-\delta}$ films by field-induced oxygen doping. We demonstrate that non-volatile volume phase transitions can be locally modulated to generate transistor-like devices, with free-resistance channels, in which the electric field magnitude and direction, temperature, and anisotropic oxygen mobility determine their characteristics.



Phase diagram of strongly correlated cuprates and multilevel states

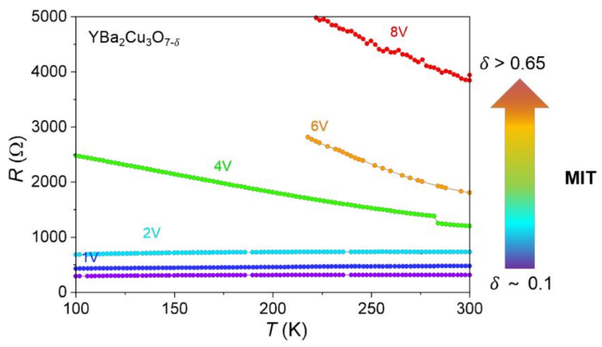
- **Field Induced MIT / SIT:** Non volatile Reversible Metal (Superconductor) - Insulator transitions through an optimal modulation of their carrier concentration.



*Taillefer , **Annu. Rev. Condens. Matter Phys.** 1, 51–70 (2010)*

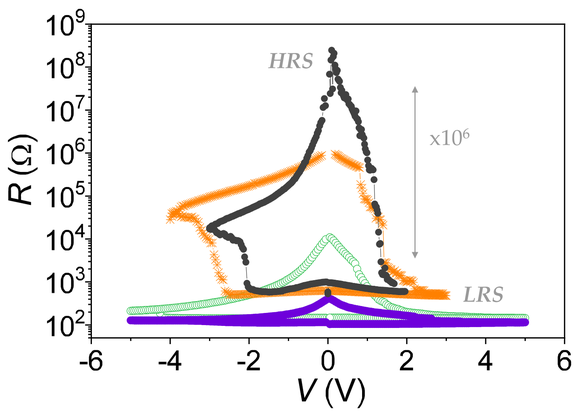
- Field-induced reversible robust volume Metallic to Insulator Transition (MIT) through oxygen doping:

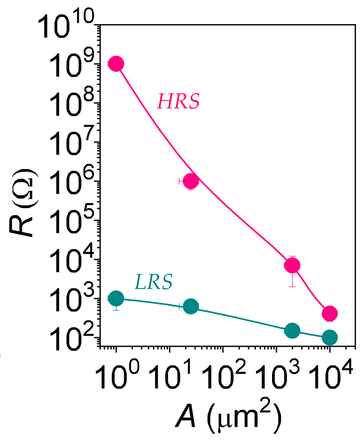
→ Fabrication of gate-tuneable transistor-like devices (operating at RT or below T_c)

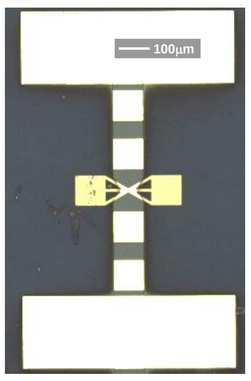


*Palau et al. **ACS Mat. & Interf.** 10, 30522 (2018), Fernandez-Rodriguez et al. **Materials** 13, 281 (2020)*

High temperature MIT

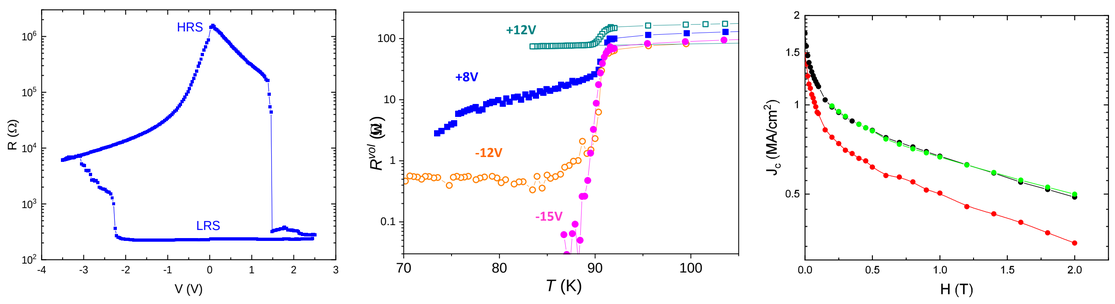






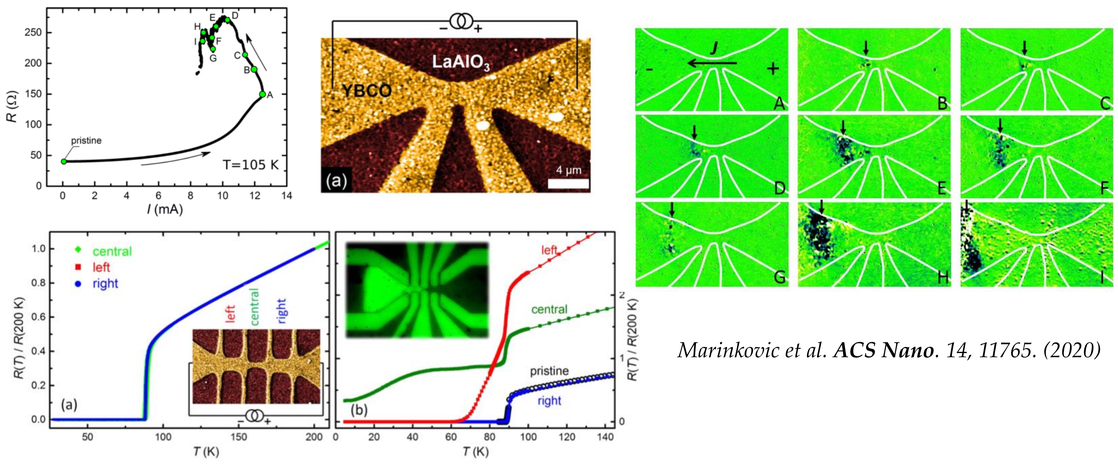
- **Area dependent resistance values** consistent with a switching effect homogeneously distributed underneath the electrode.
- Very large switching ratios obtained with moderate low V pulses by using micrometric contacts.

Switching Superconducting parameters



- **Ionic carriers move anisotropically**, creating a lateral oxygen diffusion of hundreds of microns away from the contacts.
- Locally modulate the superconducting order parameter by using a micrometric contacts → reconfigurable pinning potentials
- Reversible changes in the J_c(H) dependence → reconfigurable pinning landscape

Direct visualization of current induced O migration



*Marinkovic et al. **ACS Nano**. 14, 11765. (2020)*

- Area with oxygen vacancies clearly visible as a bright region in microscope images. Clear modulation of Tc (hence oxygen doping) at different regions of the YBCO constriction.
- Tuning the oxygen content by current induced oxygen migration in YBCO thin films (Electromigration).
- Oxygen vacancy displacement towards the cathode (−) visible by optical microscopy.

Conclusions

We have shown the resistive switching in metallic oxide perovskites that corresponds to a field-induced modulation of the carrier concentration. Volumic robust effect with High R ratios and also multilevel, reversible and non-volatile states with long retention times. Experimental evidence through Hall measurements, micro-Raman, and optical microscopy that the electromigration process allows a selective displacement of oxygen atoms. Powerful alternative to locally fine-tune the charge carrier density in cuprates and study of the phases appearing in their doping phase diagram.

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