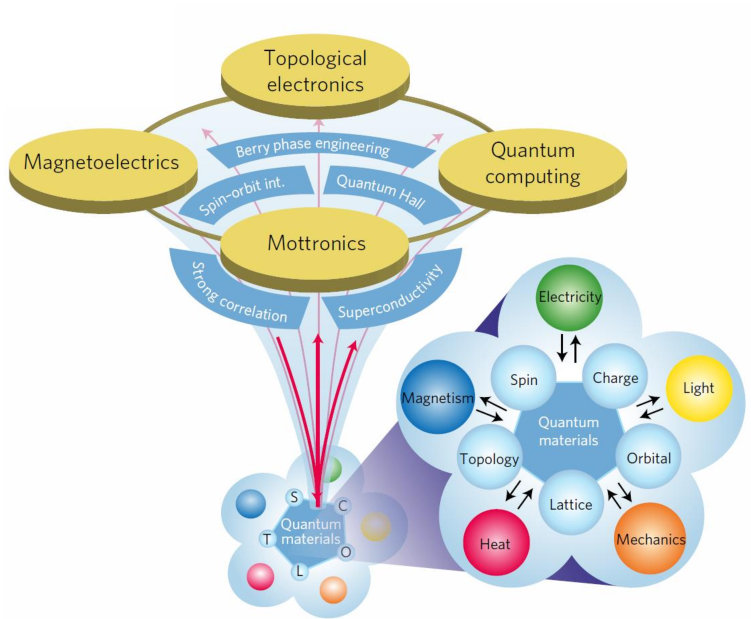
Carrier-doping control of metal-insulator transition in SrIrO3 ultrathin films

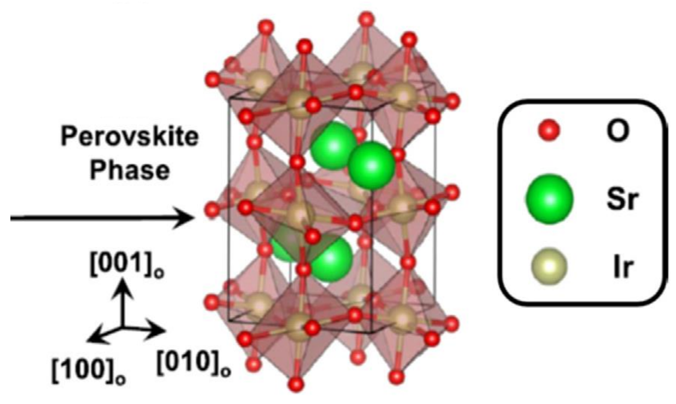
F. Gallego[1,3], J. Tornos[1], *A. Rivera-Calzada*[1,2], *F. J. Mompean*[2,3], *M. Garcia-Hernandez*[2,3], *C. Leon*[1,2] *and J. Santamaria*[1,2].

[1]*GFMC Universidad Complutense de Madrid, Dpto. Fisica de Materiales, 28040 Madrid, Spain*
[2] Unidad Asociada ICMM-CSIC "Laboratorio de Heteroestructuras con Aplicación en Espintrónica" UCM, CSIC, 28049 Madrid
[3]*Instituto de Ciencia de Materiales de Madrid, ICMM- CSIC, 28049 Cantoblanco, Spain*

Quantum materials include a vast collection of different compounds such transition metal oxides, high Tc superconductors, topological insulators or two-dimensional van der Waals crystals [1]. Their study is not just providing the discoveries of new states of matter, which stimulate disruptive advances in physics, but bring us the possibility of exploit their anomalously strong response to weak stimuli, creating new device concepts for the next-generation quantum-technologies [1,2]. The 5d transition metal oxide $SrIrO_3$ (SIO) is a good candidate to explore these new emergent phenomena, because it combines electron correlations and strong Spin Orbit Coupling. This system is also generating a considerable interest in terms of its proximity to a Mott transition [3] and a ferromagnetic instability [4]. In this work we have explored metal-insulator-transition in SIO ultrathin-layers by using Electric Double Layer techniques. This technique is used to modify the carrier up to extremely high concentrations, at the level of an electron per formula unit, what can stabilize novel phases in strongly-correlated systems. We have simultaneously measured longitudinal (magneto) resistance and Hall effect across this transition. Increasing the doping, we are not only able to modify the transition temperature, but also to reach an insulating state which exhibits hysteretic-magnetoresistance and anomalous Hall effect at low temperature, suggesting ferromagnetic order.

Quantum Materials: SrIrO3

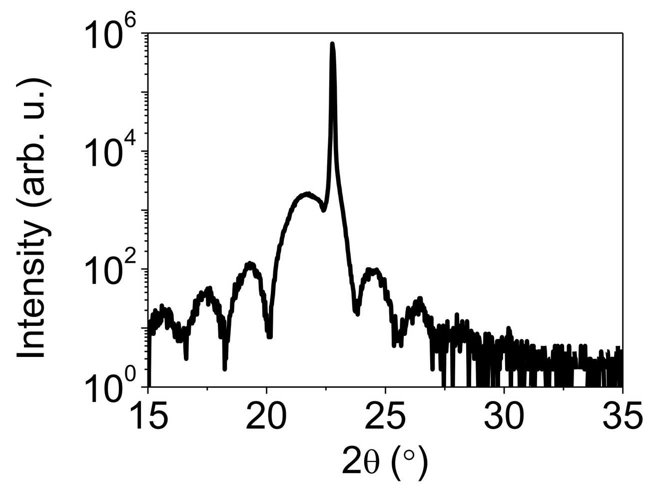


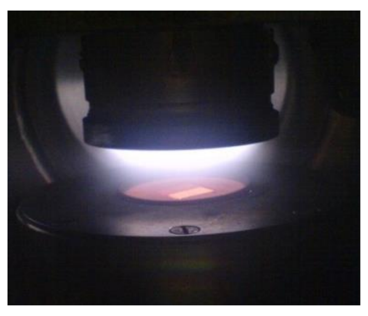


$SrIrO_3$:
- **Electronic correlations**
- **Strong Spin Orbit Coupling**

Ultrathin-film Growth

High pressure pure O_2 sputtering deposition (2.8 mbar, T=650°C, annealing 1h@650°C, 900 mbar



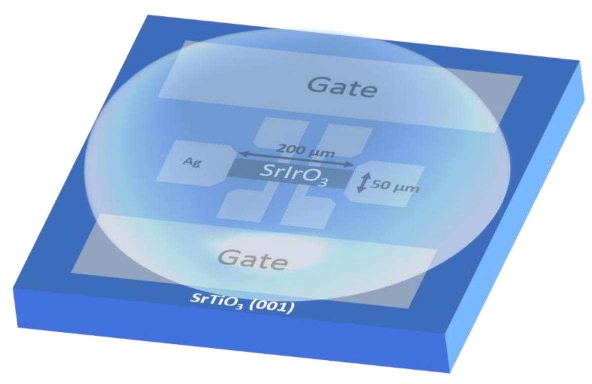


Fully epitaxial sample
Smooth surface

$SrTiO_3(001)$ // $SrIrO_3$ (2.4nm)

Electric Double Layer Ionic Liquid Gating

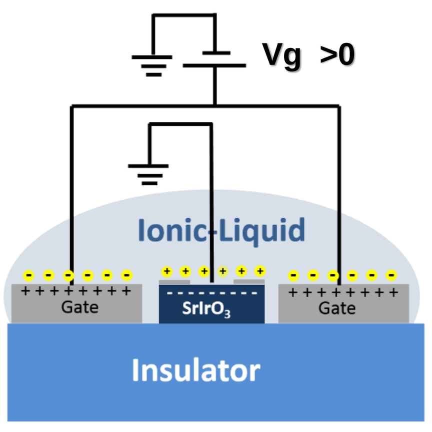
Device Concept



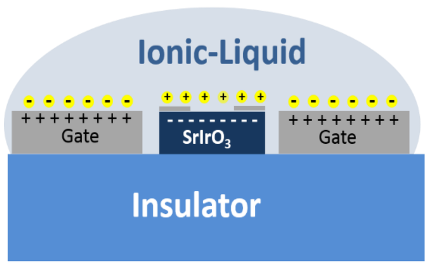
Hall Bar (200 μm x 50 μm):
Optical Litography
+
Ar Ion Milling

Carrier density:
Gate Oxide: ~10^{13} cm^{-2}
Ferroelectric Gate: ~10^{14} cm^{-2}
Ionic Liquid Gating: ~10^{15} cm^{-2}

Vg > 0
Electron dopping
Vg < 0
Hole dopping



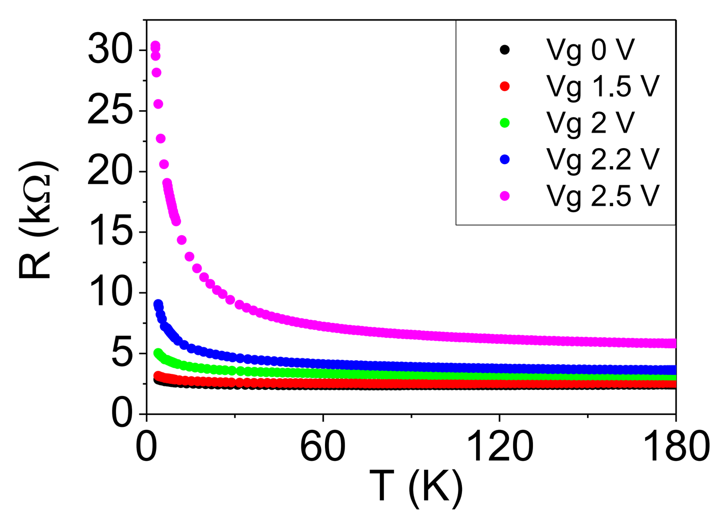
T = 230 K
Ions → Mobile

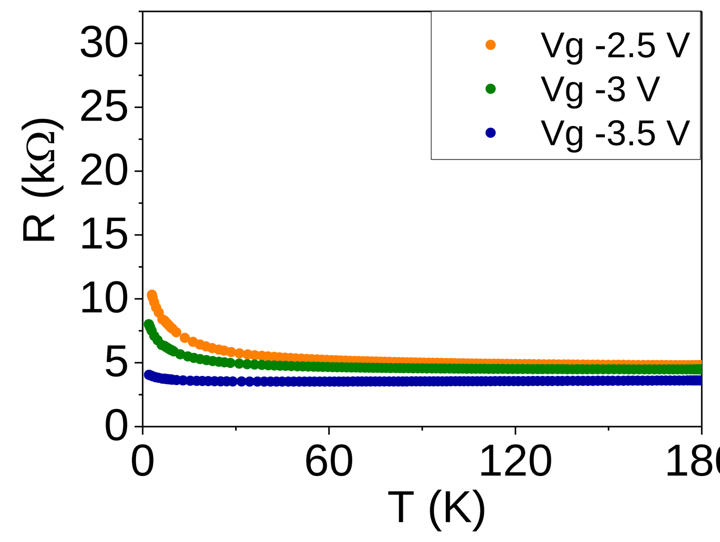


T = 180 K
Ions → Blocked

Metal Insulator Transition

Resistance Versus Temperature

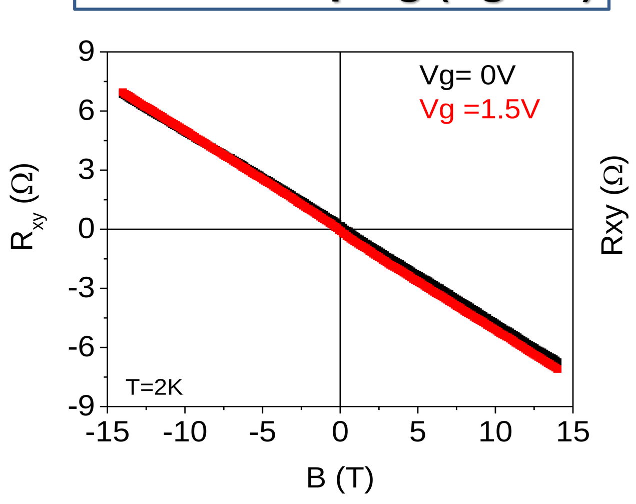


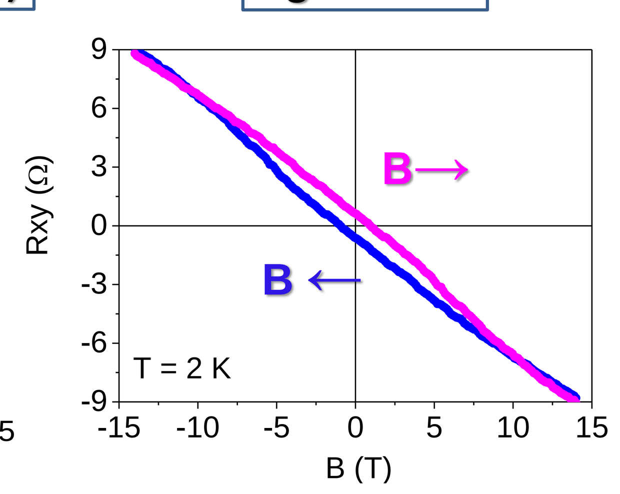


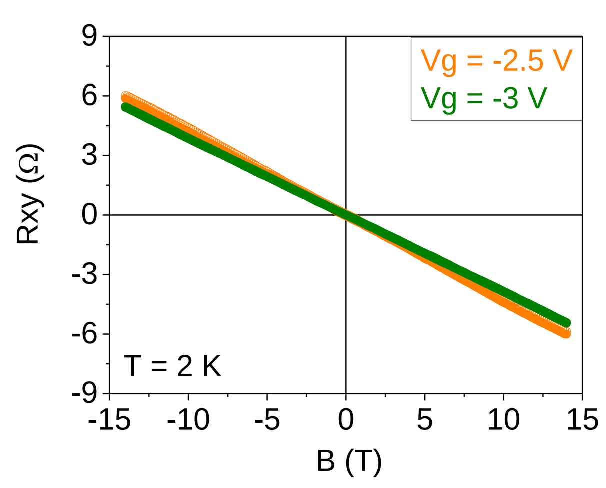
Electron doping increases resistivity
Semimetal (SM) → Insulating state (MIT)
Hole doping → SM ground-state can be recovered

Hall Effect Measurements

R_{xy} Magnetic cycles at low temperature

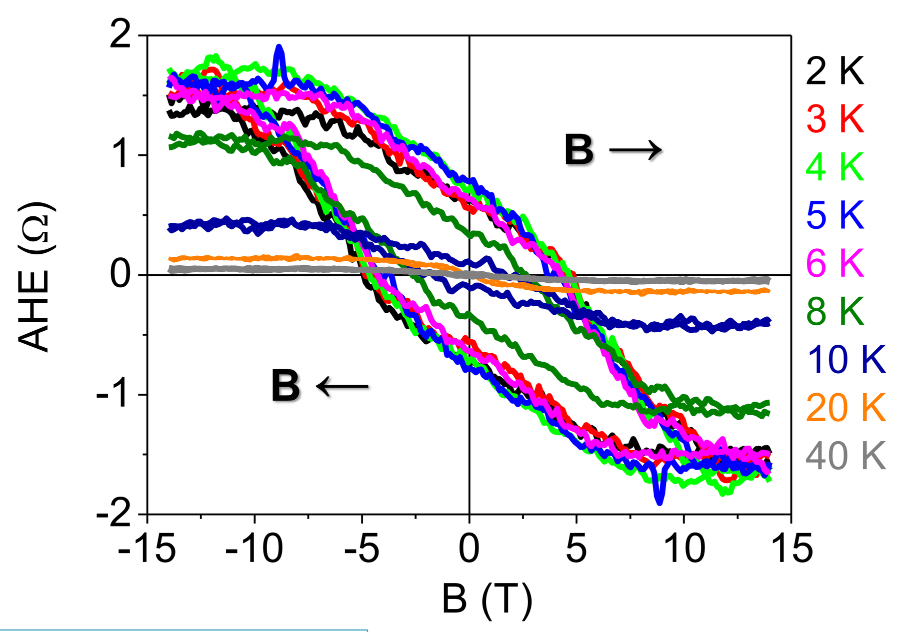






Rxy linear at low temperature.
Vg = 2.5 V Hysteretic Rxy
Non hysteretic Rxy can be also recovered

Anomalous Hall Effect at different temperatures



Rxy Hysteresis up to 10 K
Indication of FM-I state
OOP Magnetization

Ruddlesen Popper $Sr_{n+1}Ir_nO_{3n+1}$ series:
(n = 1) Sr_2IrO_4: spin-canted-AF-I
(n = 2) $Sr_3Ir_2O_7$: AF-I
(n = ∞) $SrIrO_3$: SM close to a FM instability
FM & MIT should be related

SWITCHABLE FM-I STATE

Summary

We have conducted ionic liquid doping of $SrIrO_3$ ultra-thin films. Doping with electrons turns the system insulating. Applying higher (positive) voltages it yields a strongly insulating state where the Hall resistance is hysteretic, indicating a ferromagnetic instability in the system. Applying negative voltages (hole doping) it is possible to recover the paramagnetic semimetal ground-state of the $SrIrO_3$. We have demonstrated a switchable ferromagnetic-insulating state in $SrIrO_3$ controlled by doping. This work opens the possibility to control new emergent magnetic state and eventually topological phenomena in 5d transition metal oxides modifying SOC and electron correlation by carrier doping.

[1] D. N. Basov, R. D. Averitt and D. Hsieh, Nature Materials, 16, 1077-1088, (2017)
[2] Y. Tokura, M. Kawasaki and N. Nagaosa, Nature Physics, 13(11), pp.1056-1068 (2017)
[3] Y. F. Nie, P. D. C. King, C. H. Kim, M. Uchida, H. I. Wei, B. D. Faeth, J. P. Ruf, J. P. C. Ruff, L. Xie, X. Pan et al., Phys. Rev. Lett. 114, 016401 (2015)
[4] G. Cao, V. Durairaj, S. Chikara, L. E. DeLong, S. Parkin, and P. Schlottmann Phys. Rev. B 76, 100402(R) (2007)