Emergent Phenomena in Manganites under Spatial Confinement

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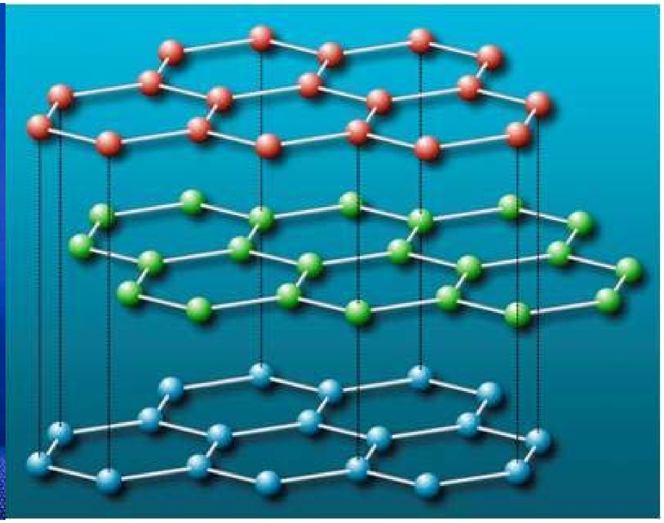
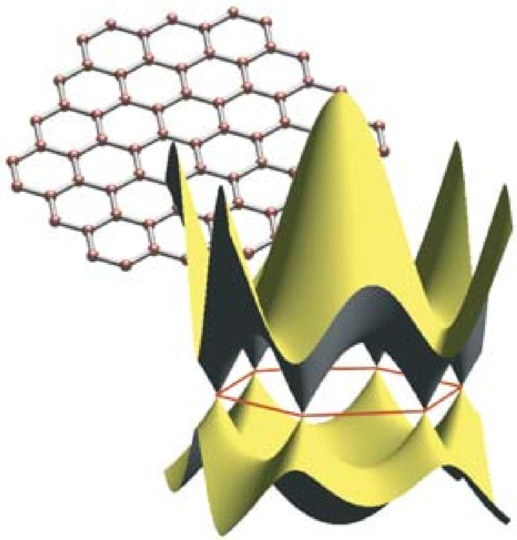
The Excitement in Nanoscale Physics

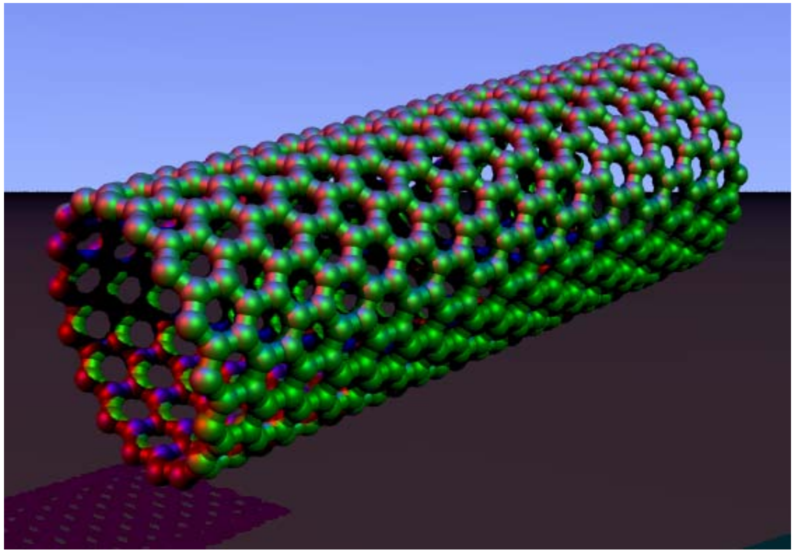
Carbon



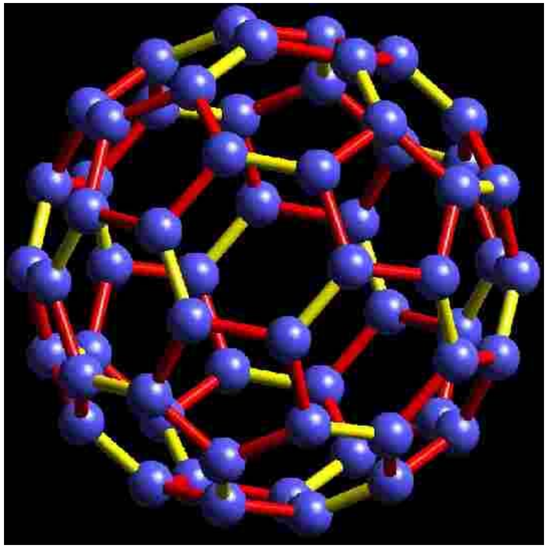
Graphene



Carbon nanotube

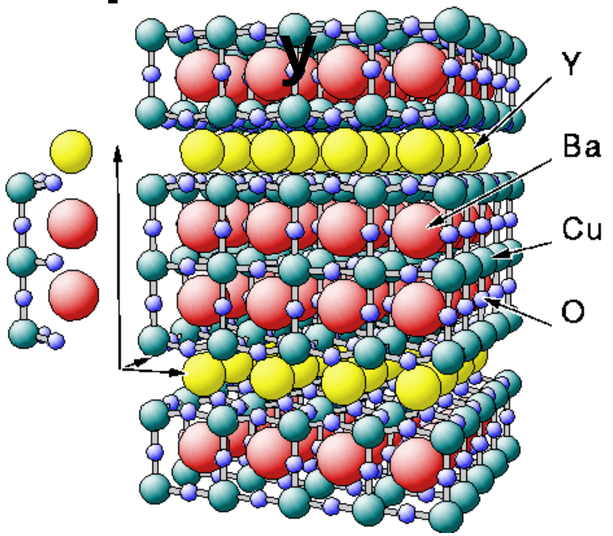


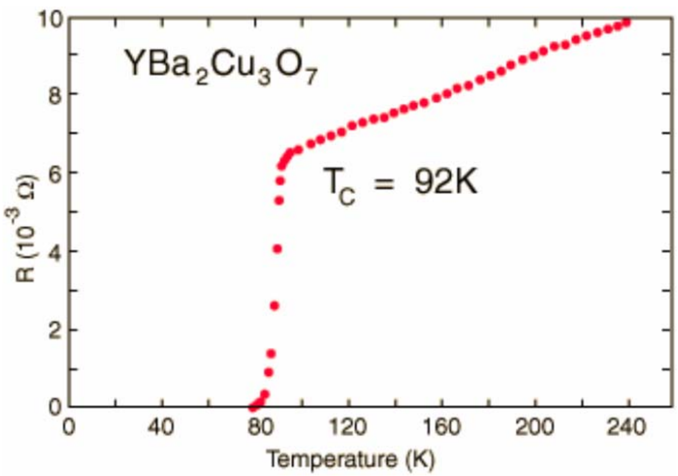
Bucky ball



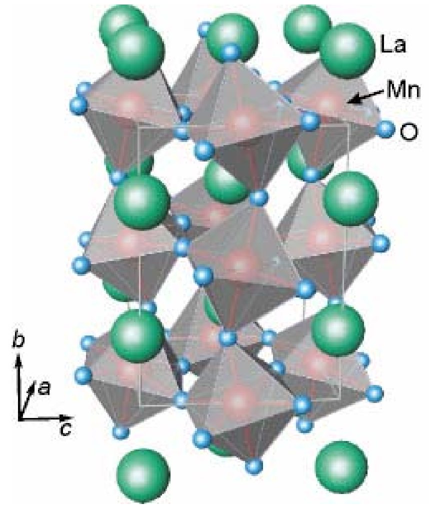
Complexity in Strongly Correlated Systems

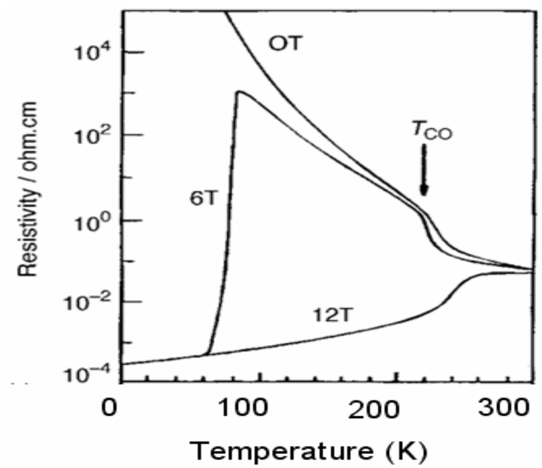
High-Tc Superconductivity



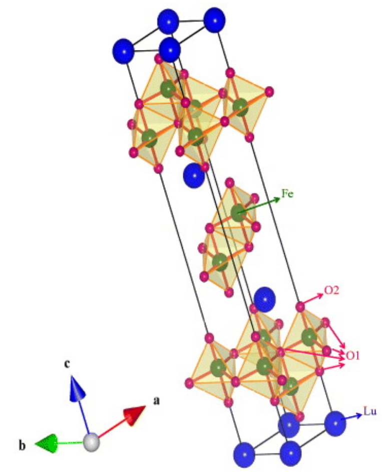


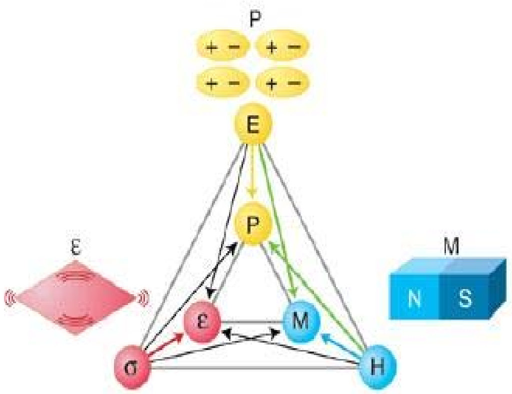
Colossal Magnetoresistance



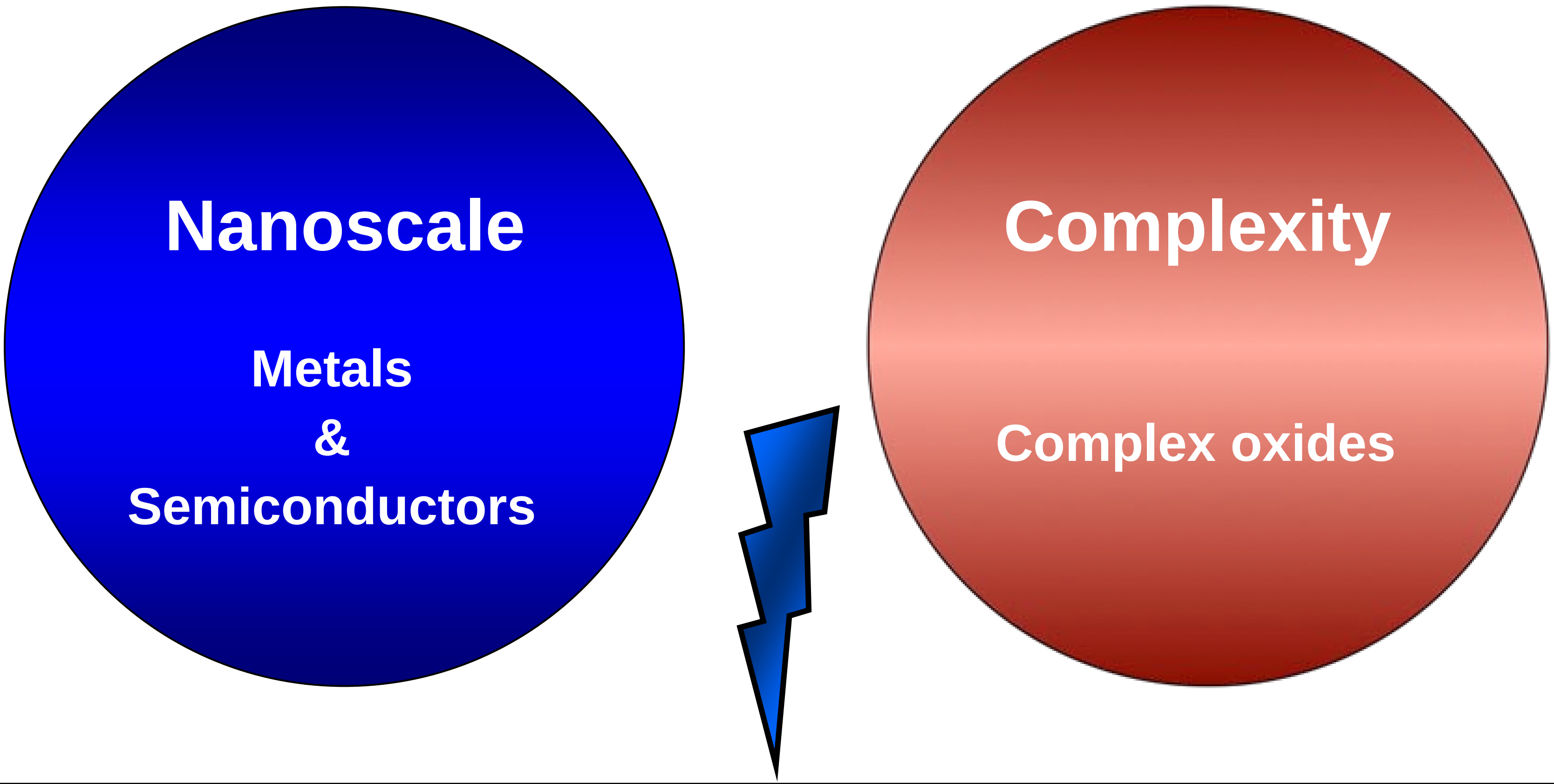


Multiferroicity



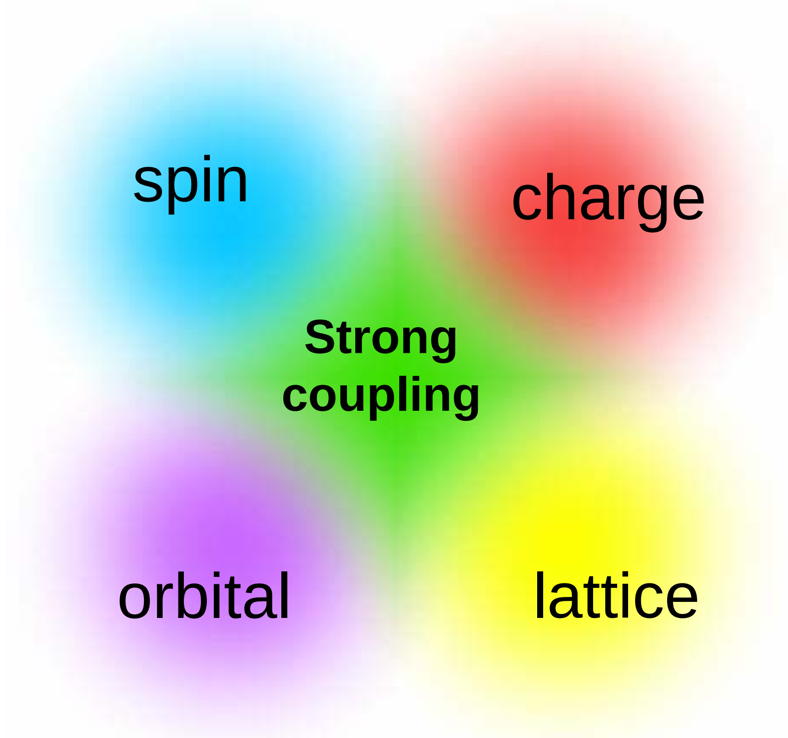


Complexity under Spatial Confinement

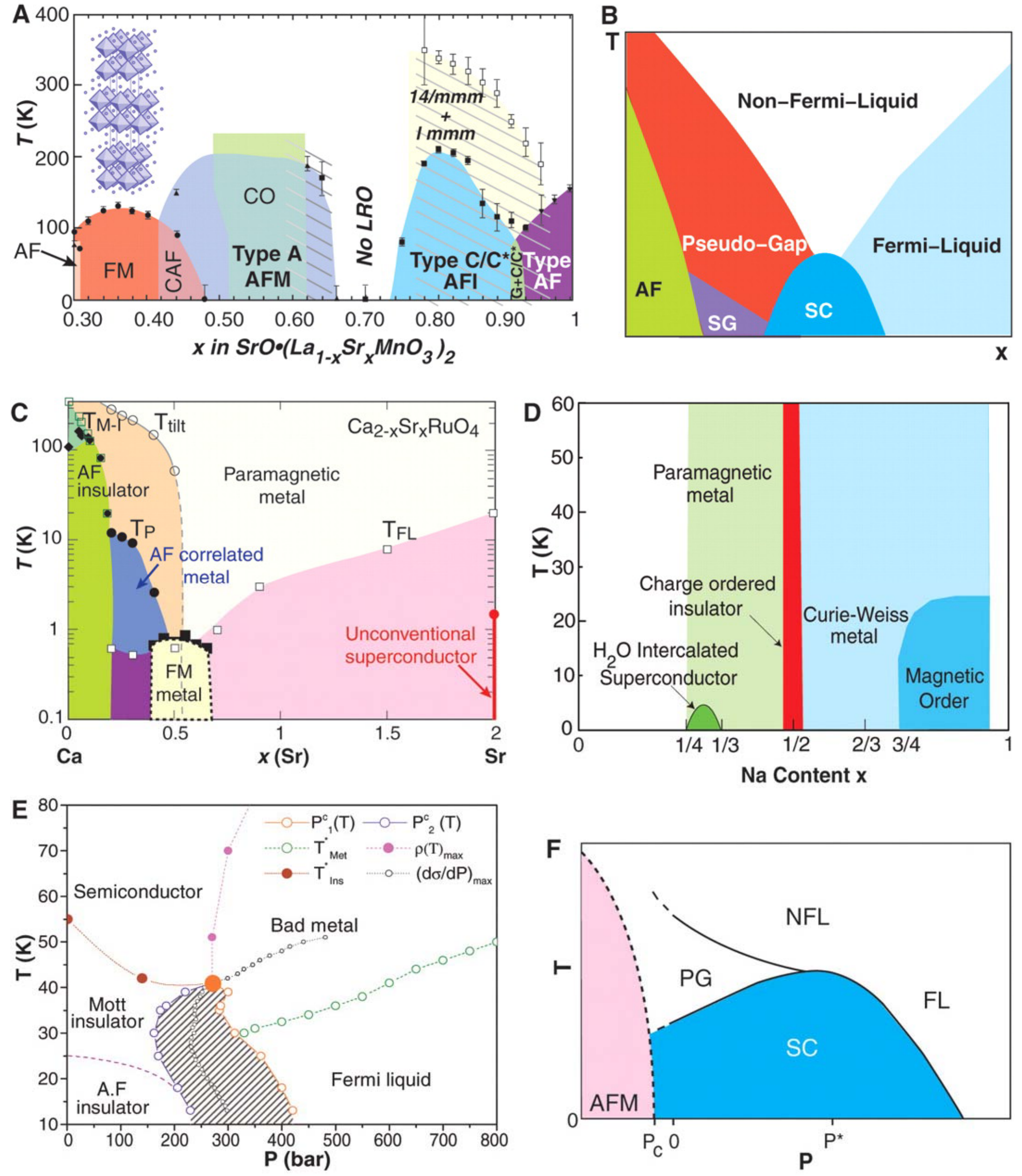


What exciting phenomena can we observe?

Transition metal oxides



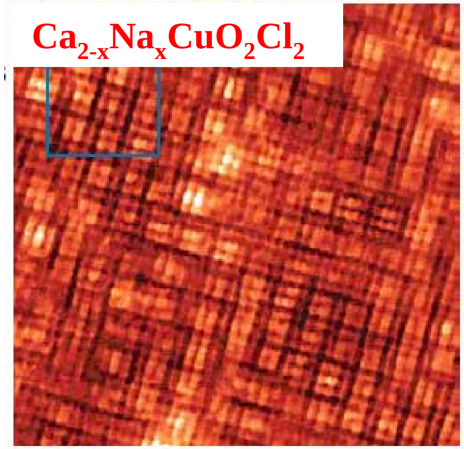
Electronic Phase Separation



E. Dagotto, Science 309, 257 (2005)

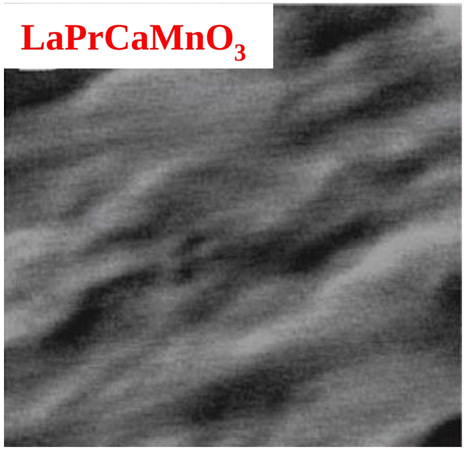
Electronic Phase Separation in Complex Oxides

STM



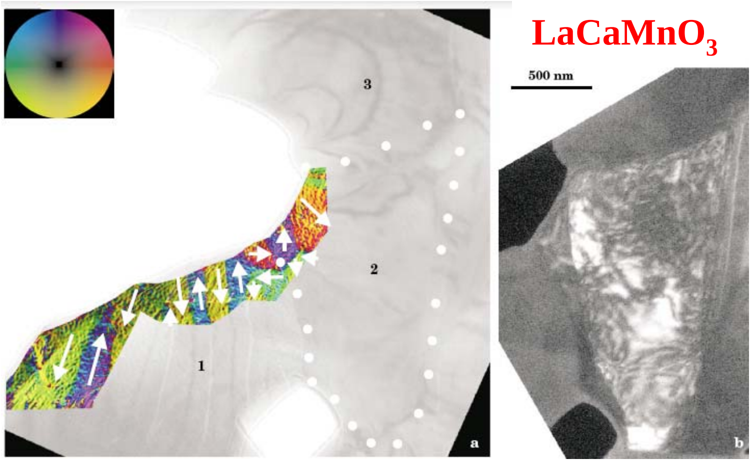
Nature 430, 1001 (2004)

MFM



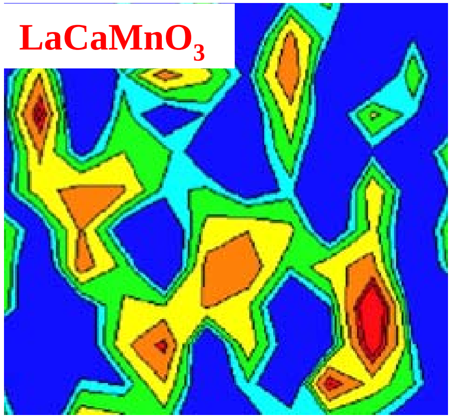
Nature 415, 412 (2002)

TEM



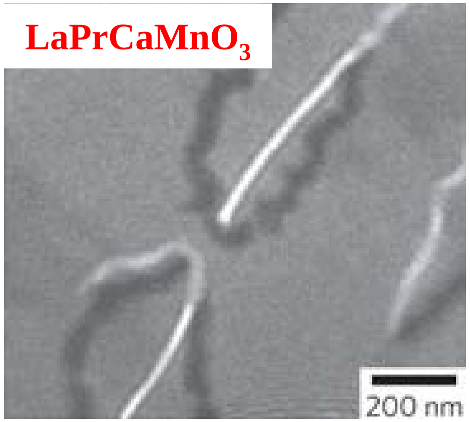
Nature 420, 797 (2002)

TEM



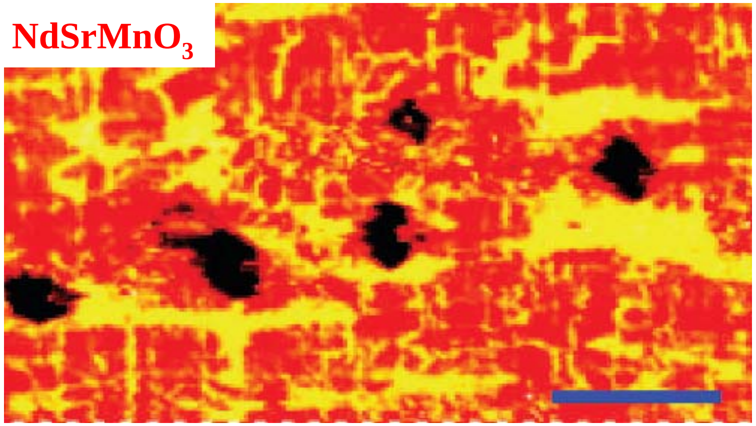
PRL 103, 097202 (2009)

Lorentz Microscope



Nat. Nanotech. 8, 37 (2010)

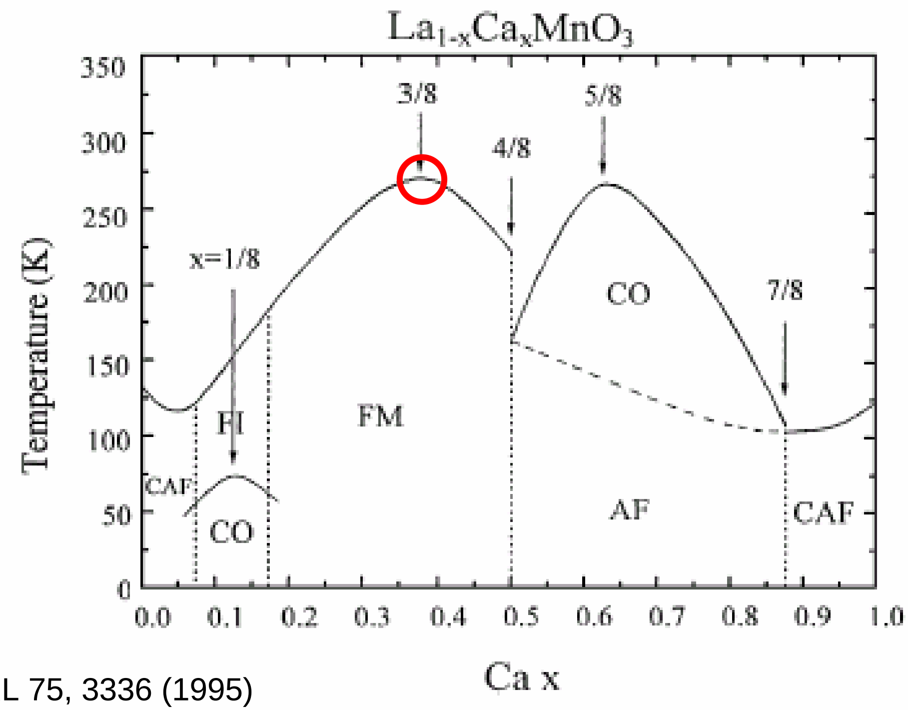
Microwave Impedance Imaging



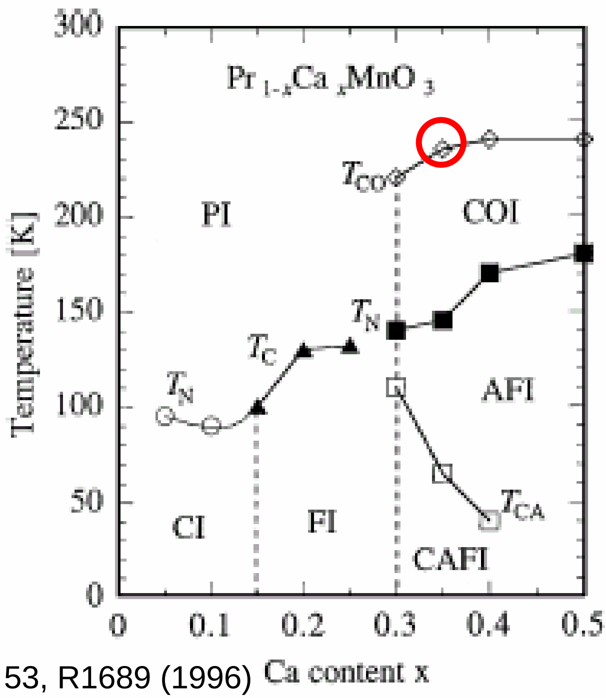
Science 329, 190 (2010)

Model System: $La_{5/8-y}Pr_yCa_{3/8}MnO_3$

Ferromagnetic metal **Charge-ordered Insulator**



PRL 75, 3336 (1995)



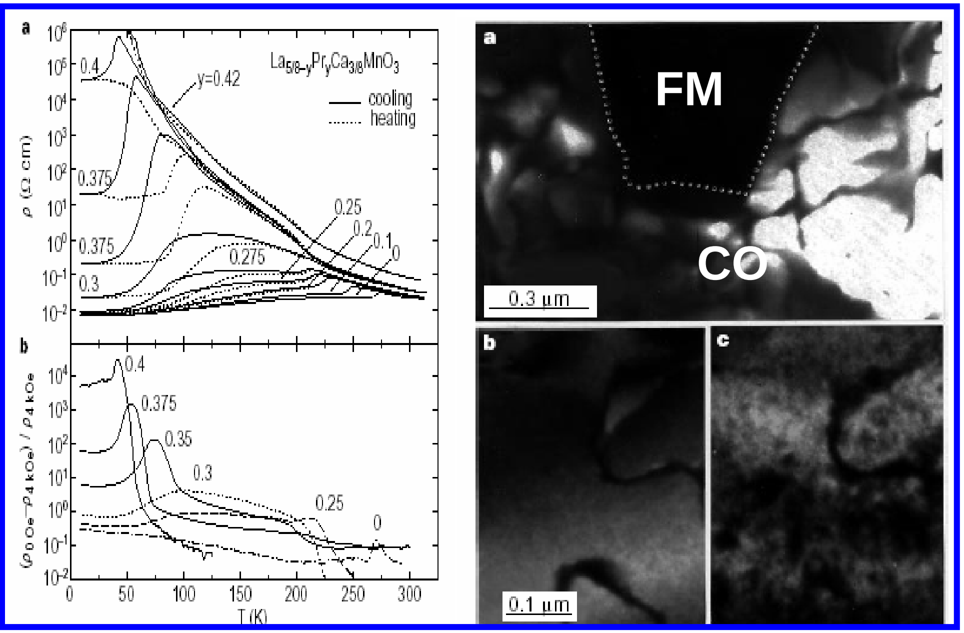
PRB 53, R1689 (1996)

$La_{5/8}Ca_{3/8}MnO_3$ T_c=275 K

$Pr_{5/8}Ca_{3/8}MnO_3$ T_{co}=220 K

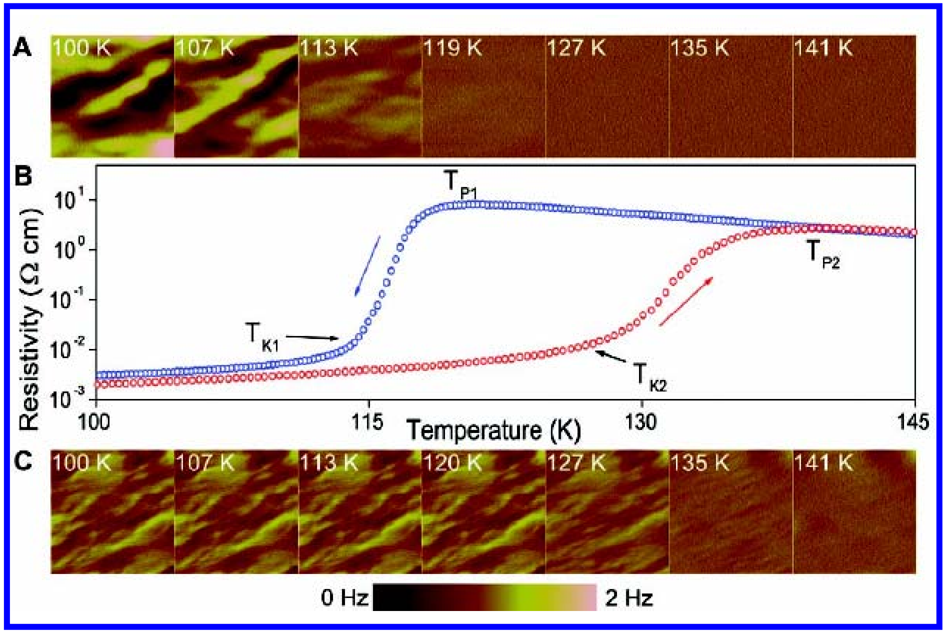
Large-scale (Micron) Phase Separation in LPCMO

TEM



Uehara et al, Nature 399, 560 (1999)

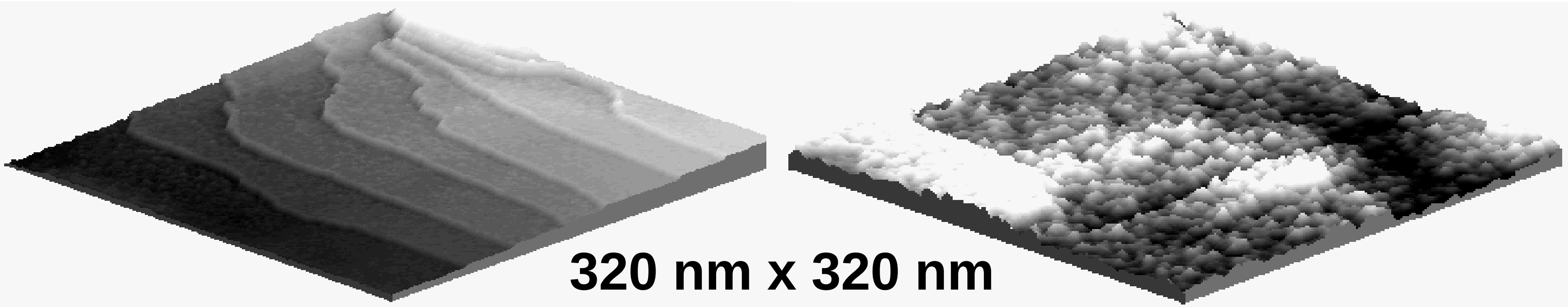
MFM



Zhang et al, Science 298, 805 (2002)

Electronic Phase Separation in LPCMO Film

Morphology **Spectroscopy**



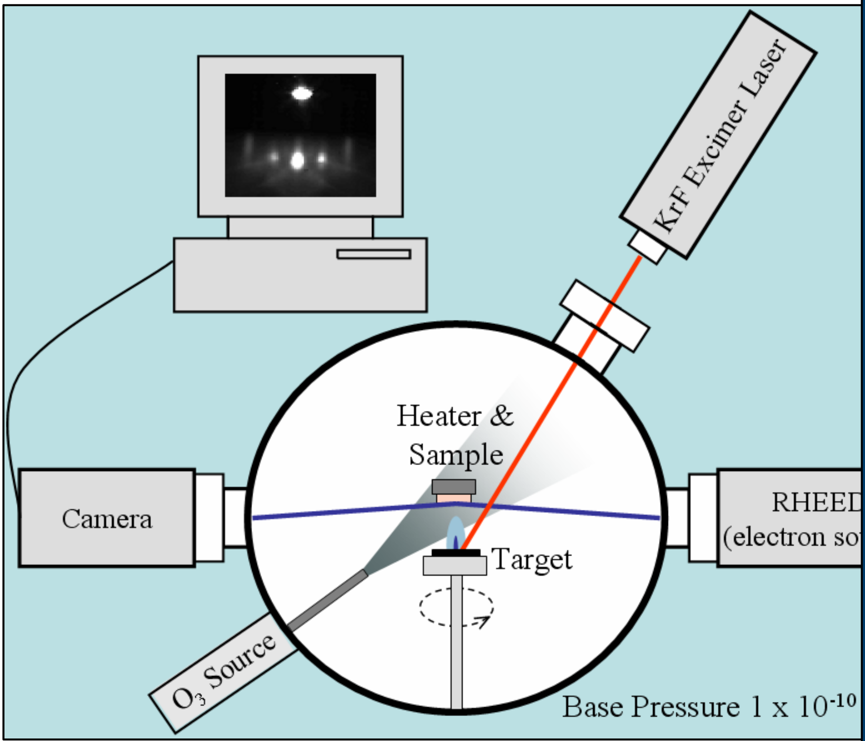
Phys. Rev. Lett. 95, 237210 (05)

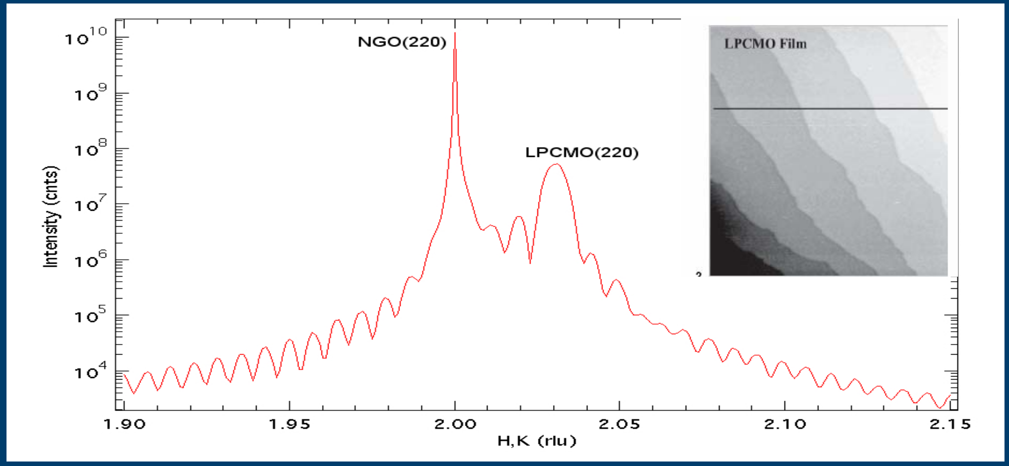
I. Using spatial confinement to “see” electronic phase separation and their dynamic behavior

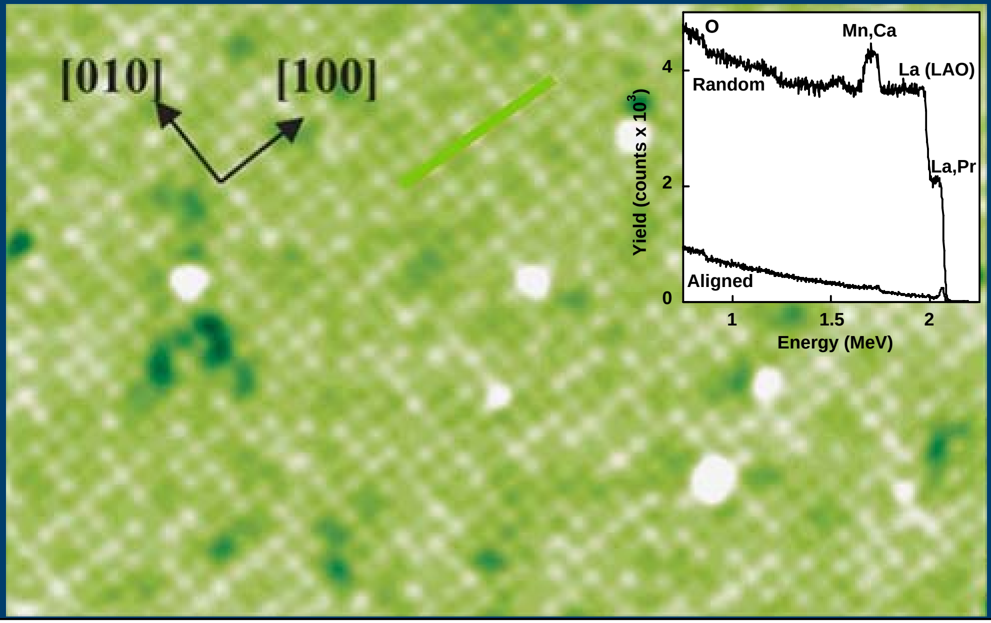
II. Electronic Nanofabrication

I. Using spatial confinement to “see” electronic phase separation and their dynamic behavior

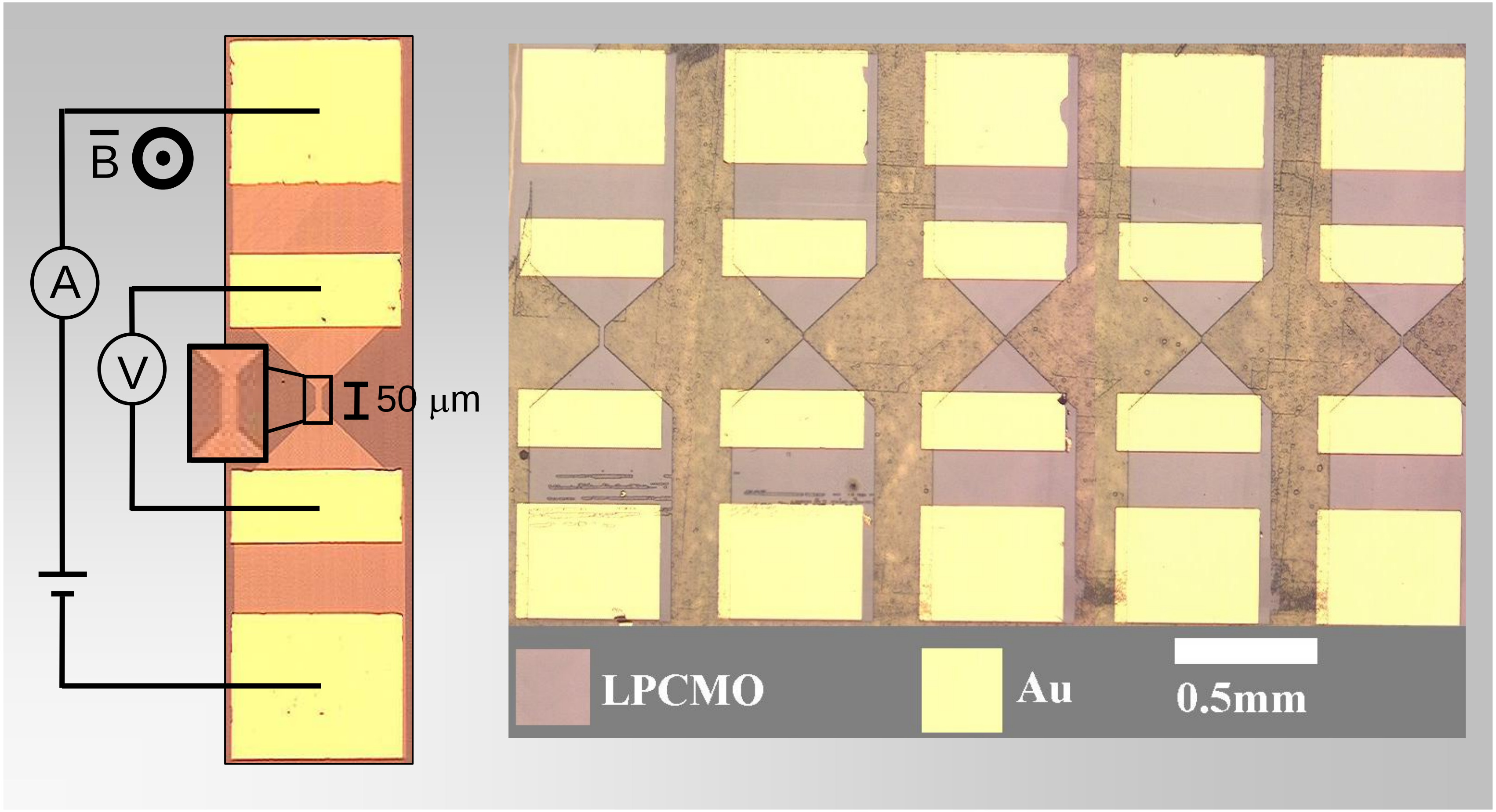
LPCMO Wire Fabrication Starts from High Quality Thin Film Growth





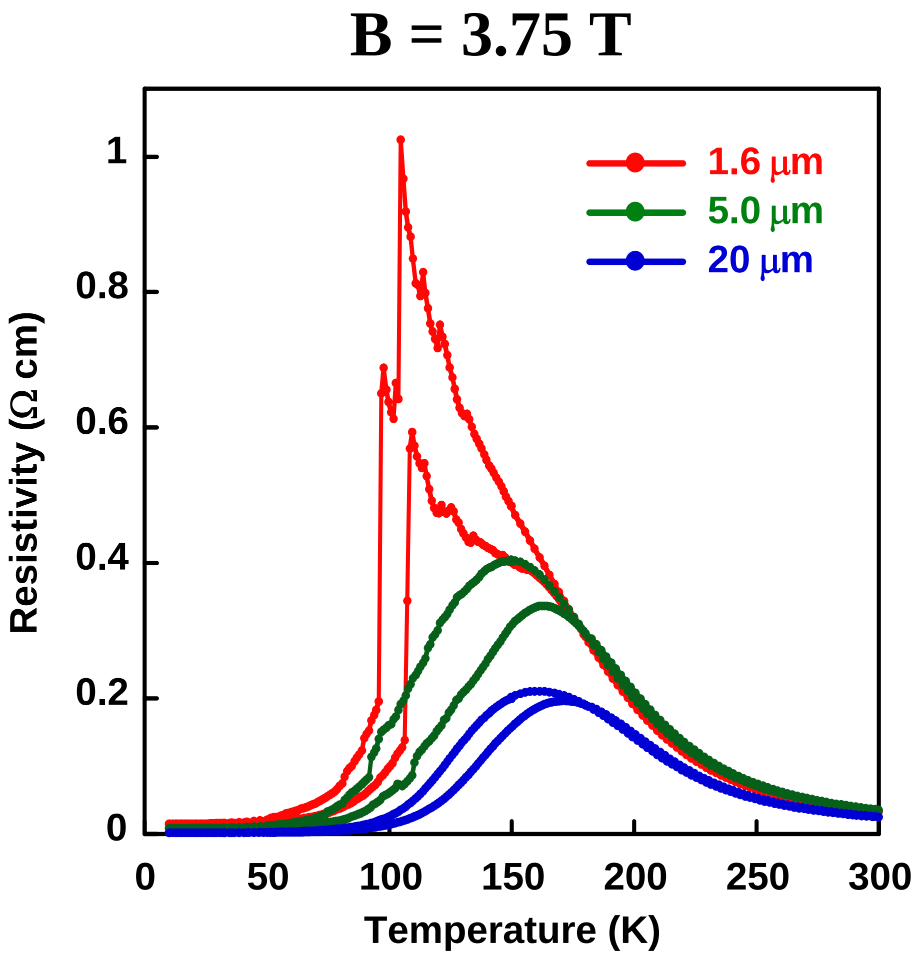


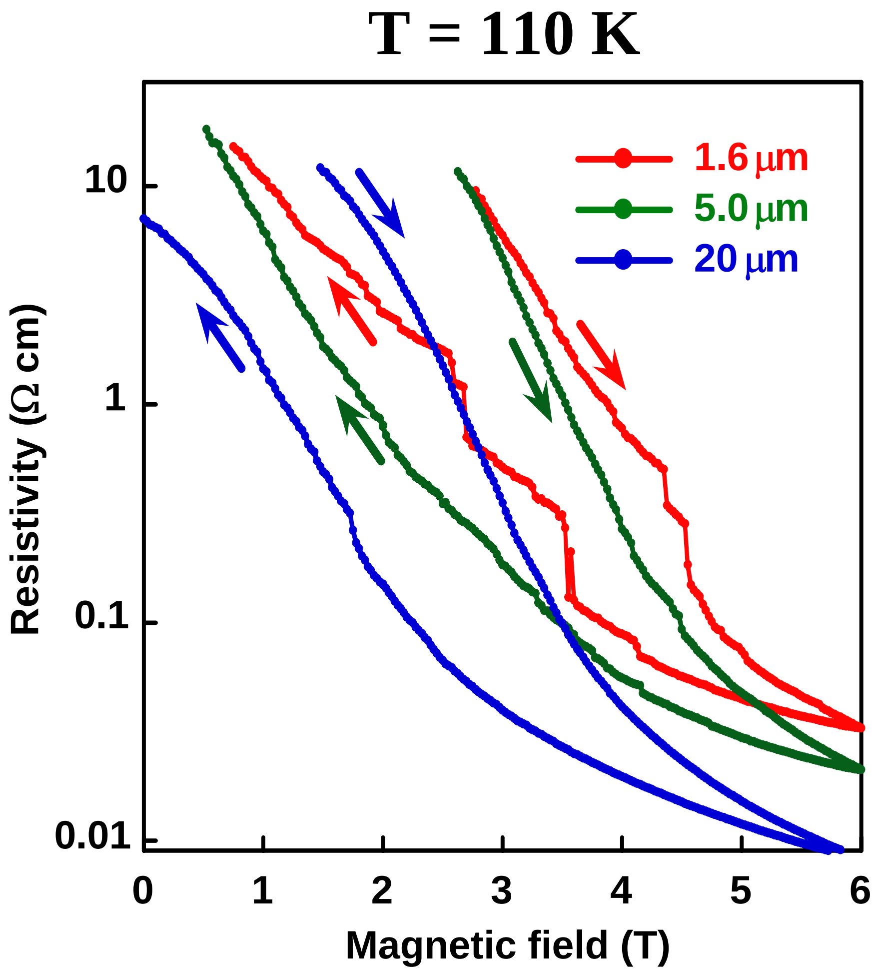
LPCMO Wires



Smallest structure ~ 50 nm

Giant and Discrete Steps in Metal-insulator Transition in LPCMO Wires on $LaAlO_3$

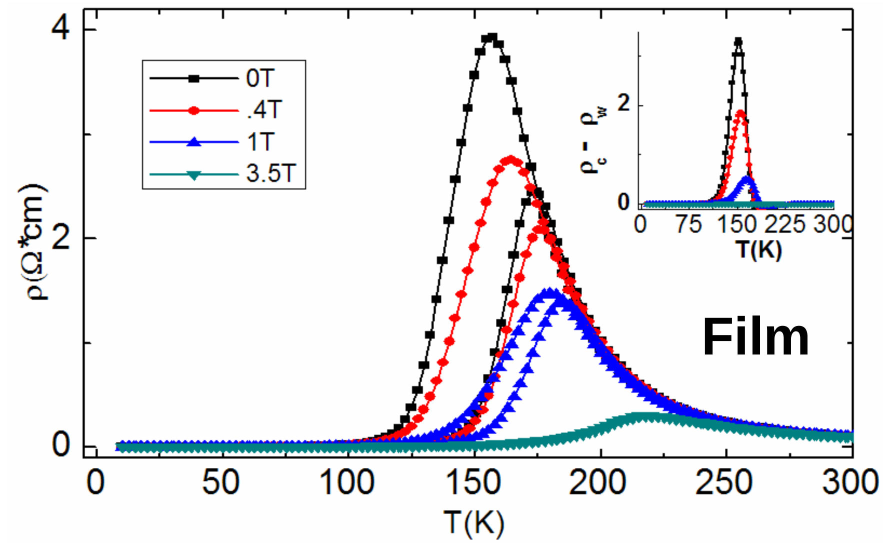




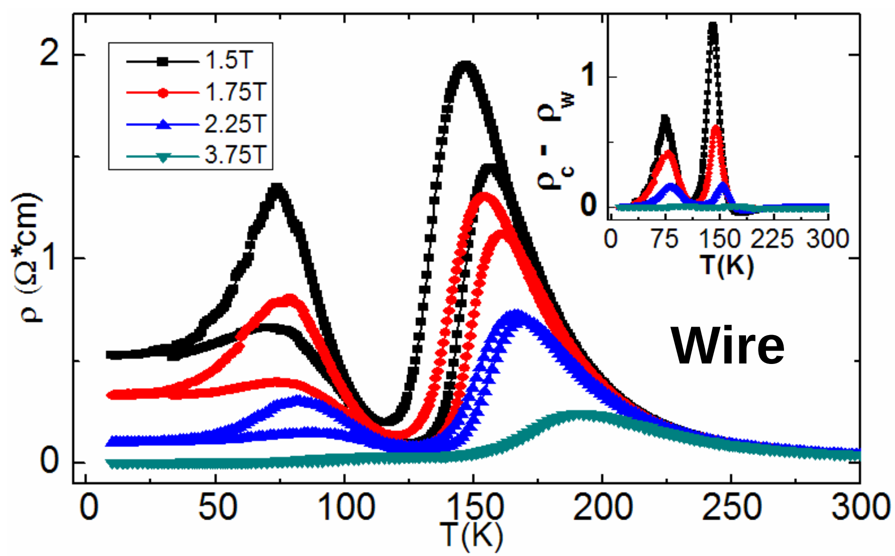
Phys. Rev. Lett 97, 167201 (2006)

Dramatic Effect of Spatial Confinement

70 nm LPCMO
Film on $SrLaGaO_3$

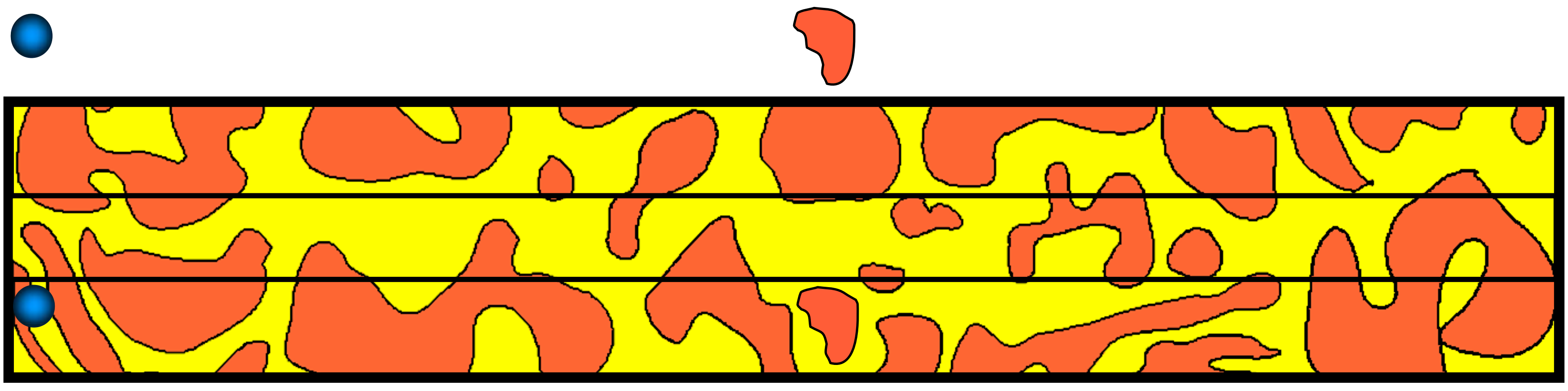


70 nm LPCMO
10μm wires on $SrLaGaO_3$



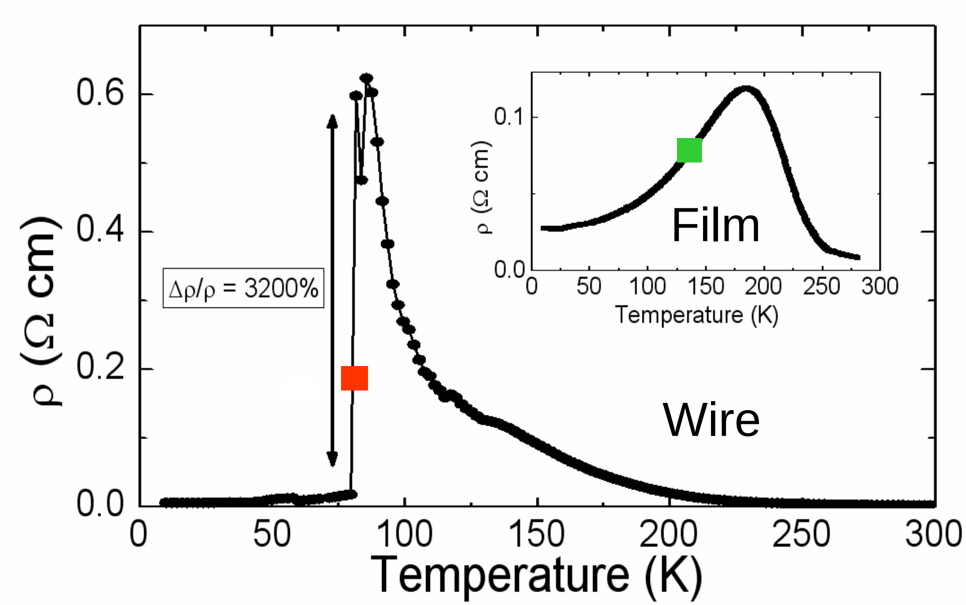
Phys. Rev. Lett. 100, 247204 (2008)

Spatial Confinement Effect of Electronic Phase Separation

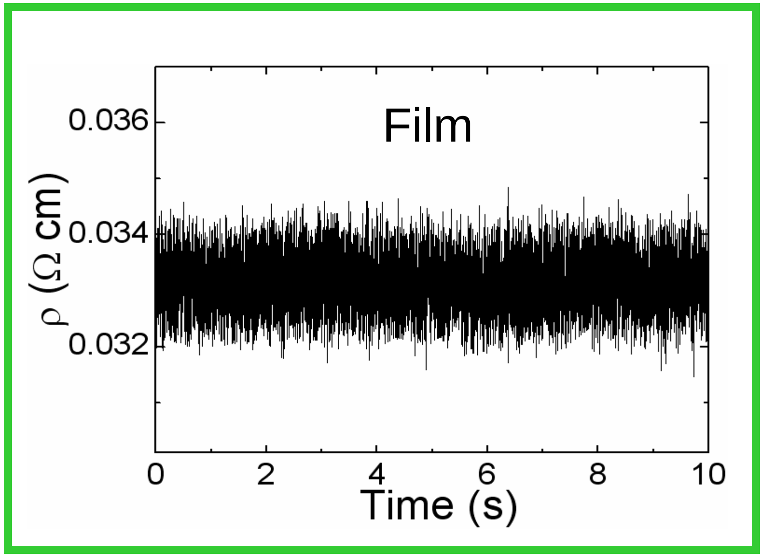


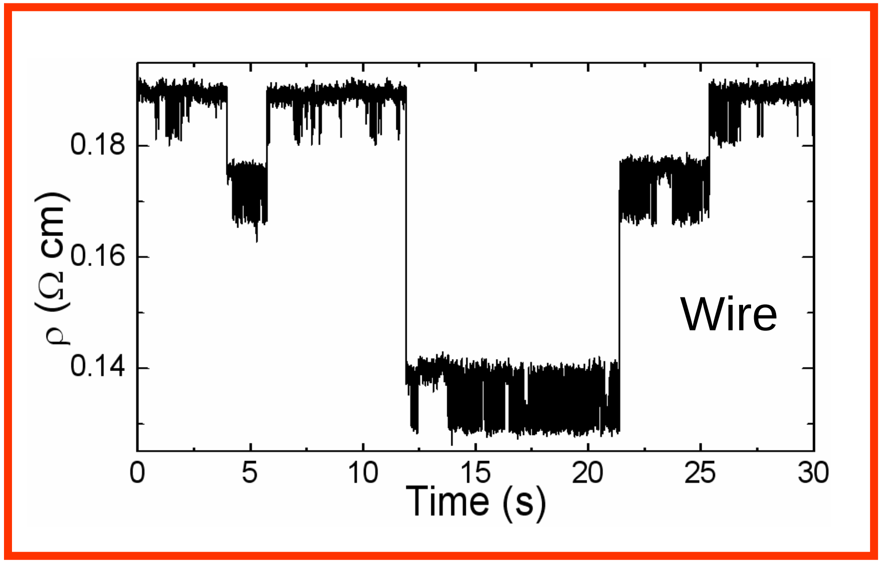
Dynamics of Domain Transitions

Field cooled 3.75 T
warming ρ vs T

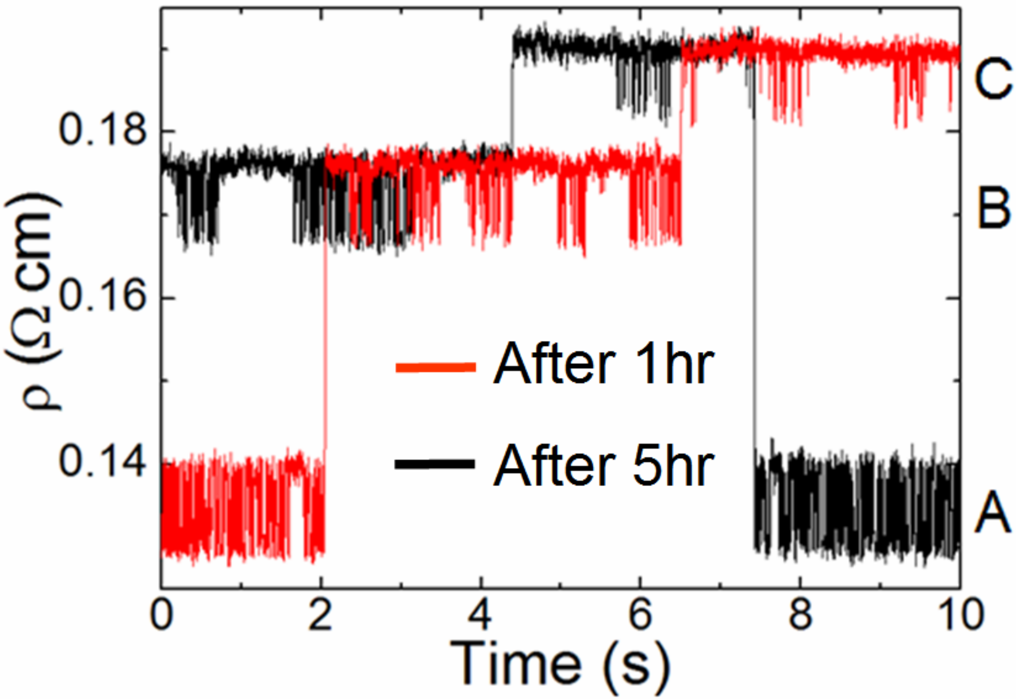


Phys. Rev. Lett. **102**, 087201 (2009)

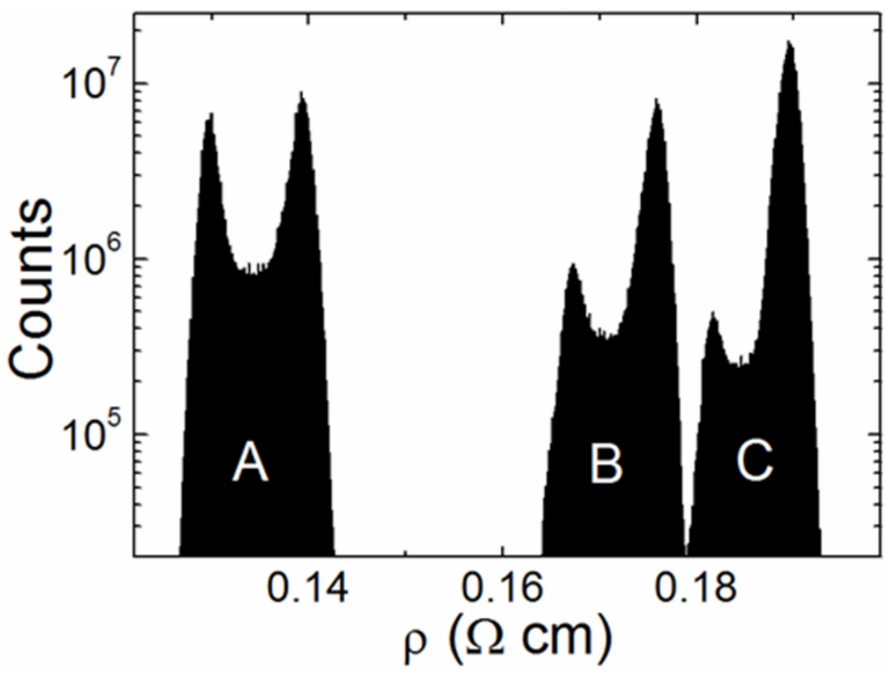




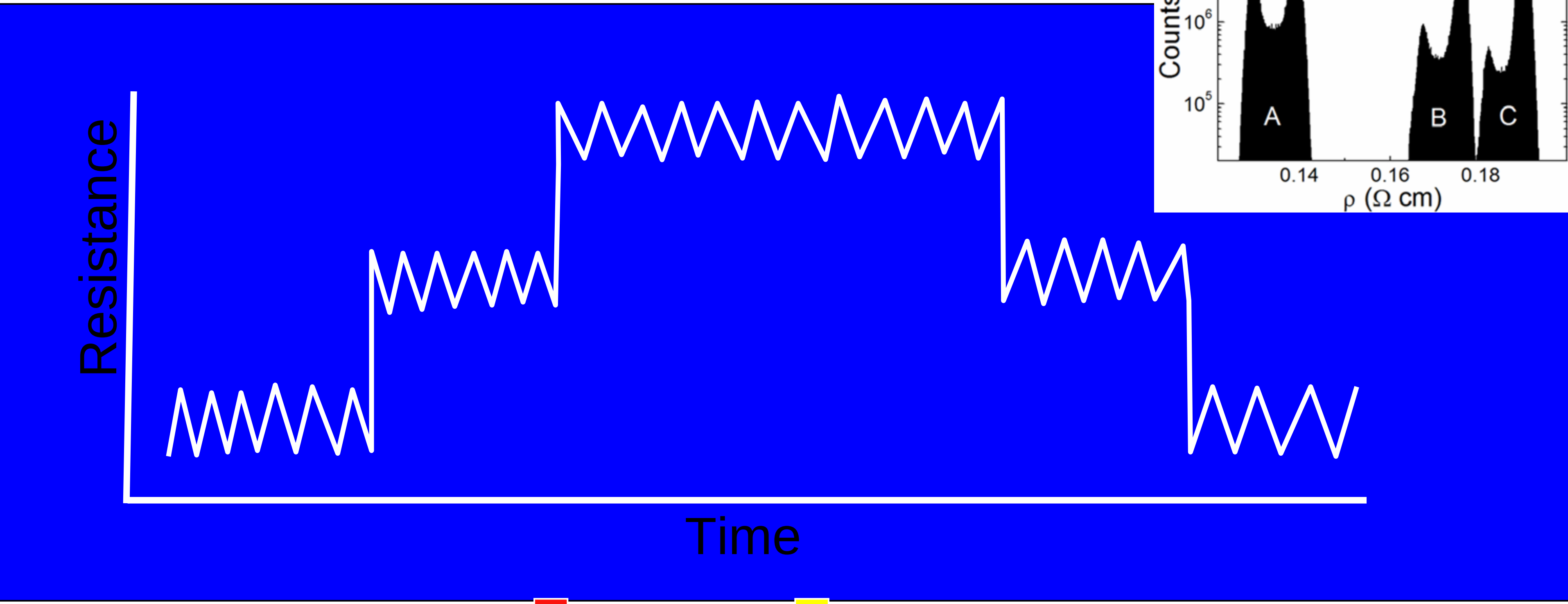
Phase Transition Dynamics

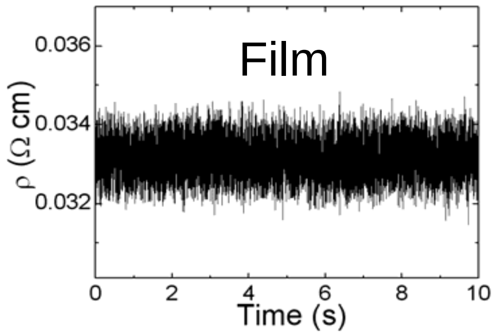


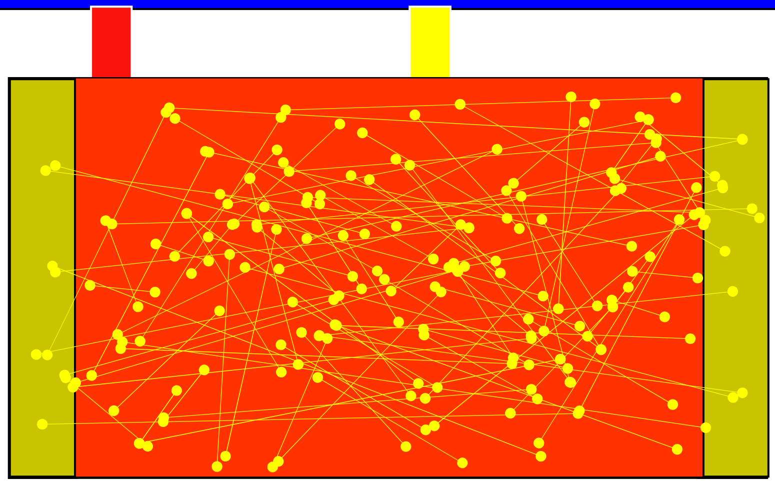
Binned data for 6 hours

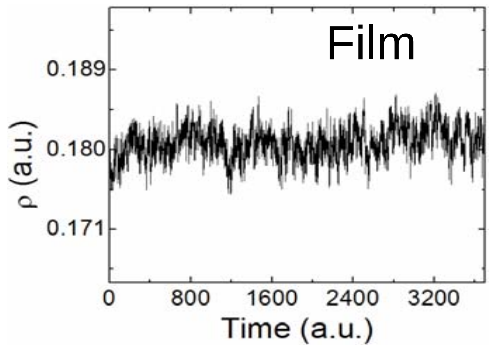


Percolative Switching Network

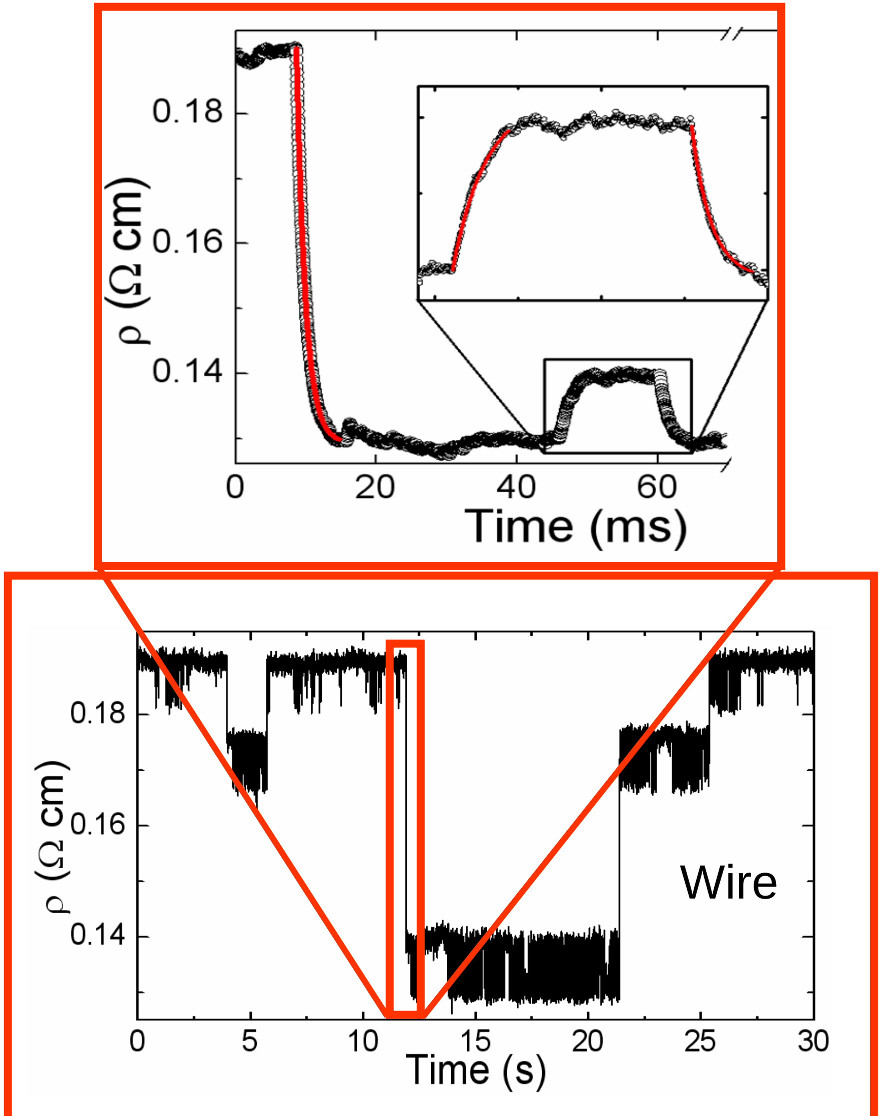




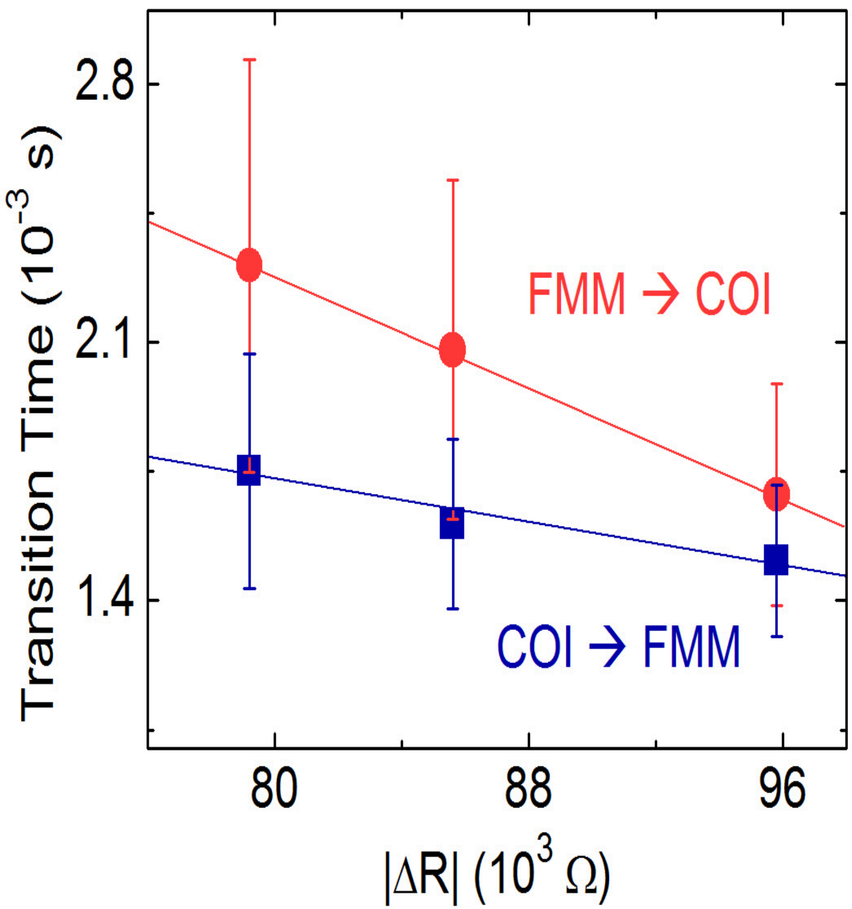




Time Scale of FM - COI Transition

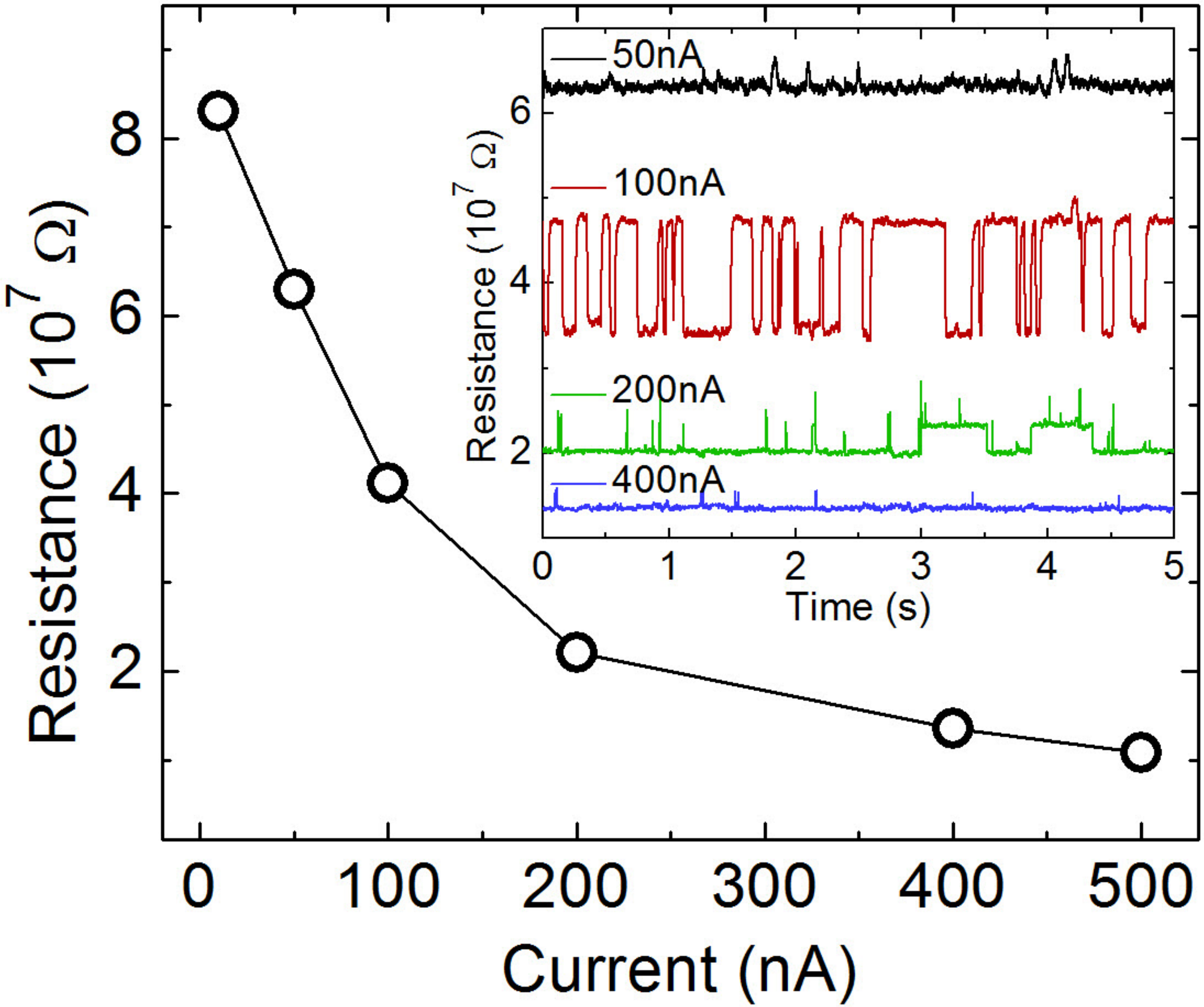


$y = A*e^{-t/\tau}$, τ = lifetime

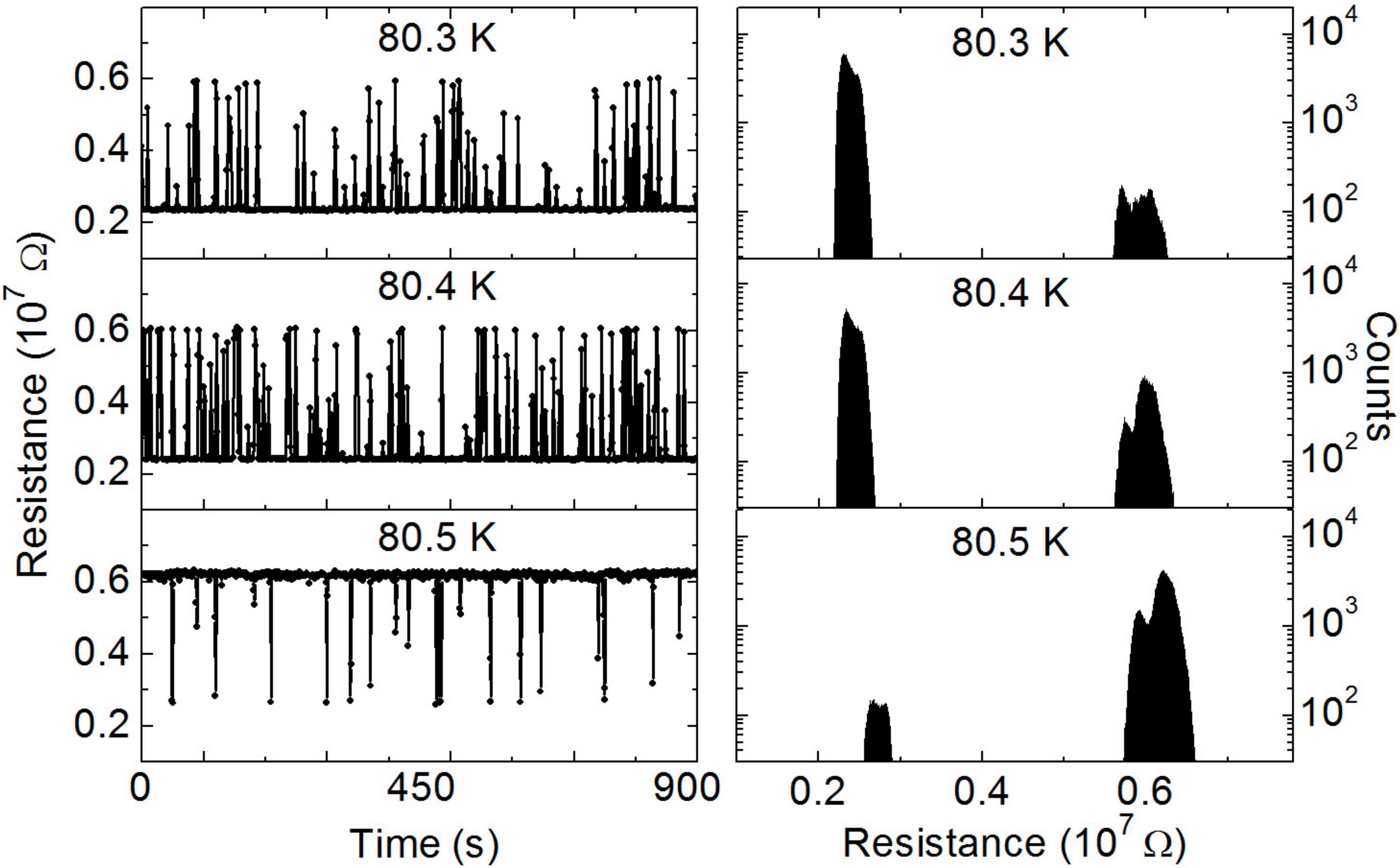


PRB 83, 125125 (2011)

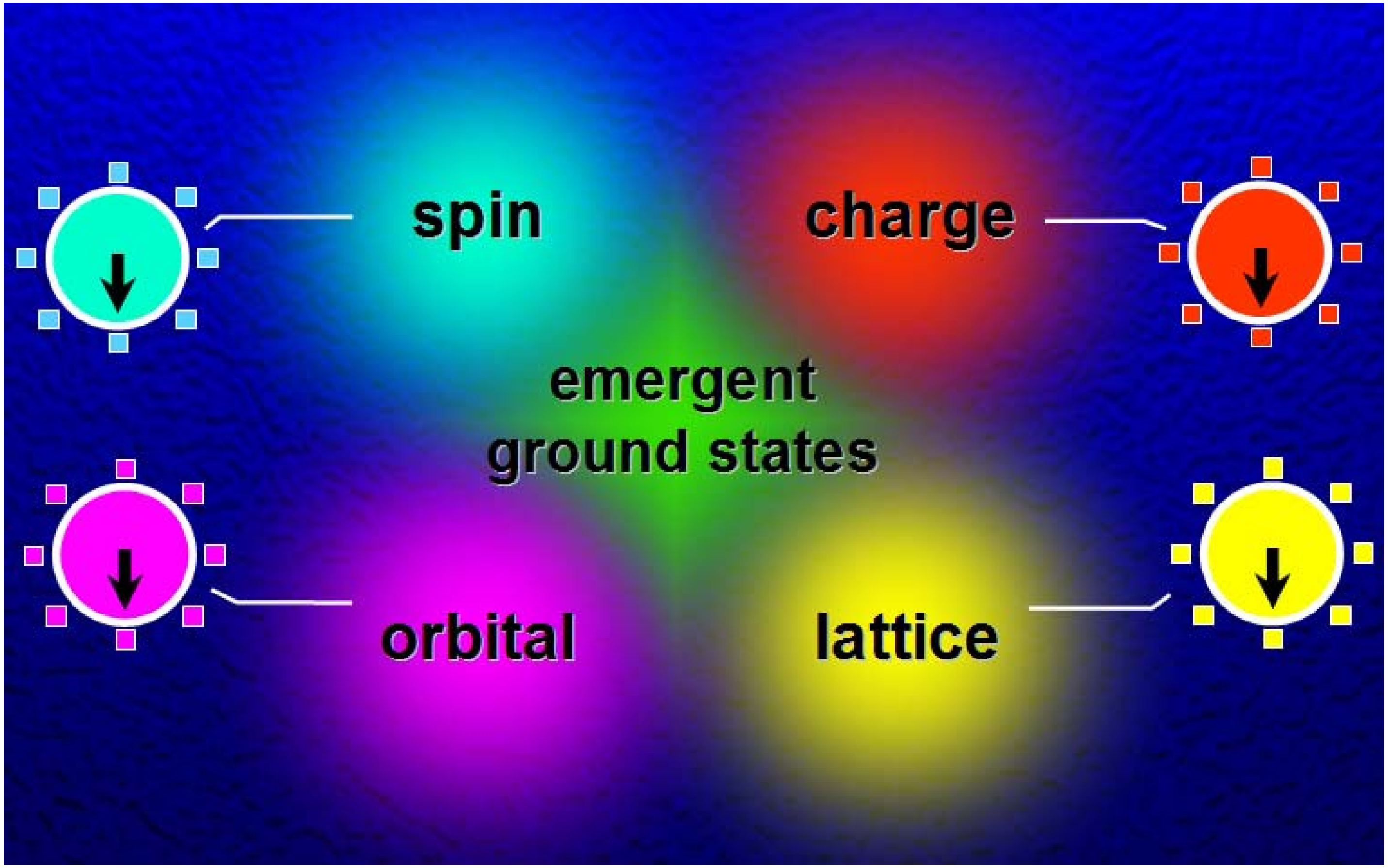
Effect of Measuring Current



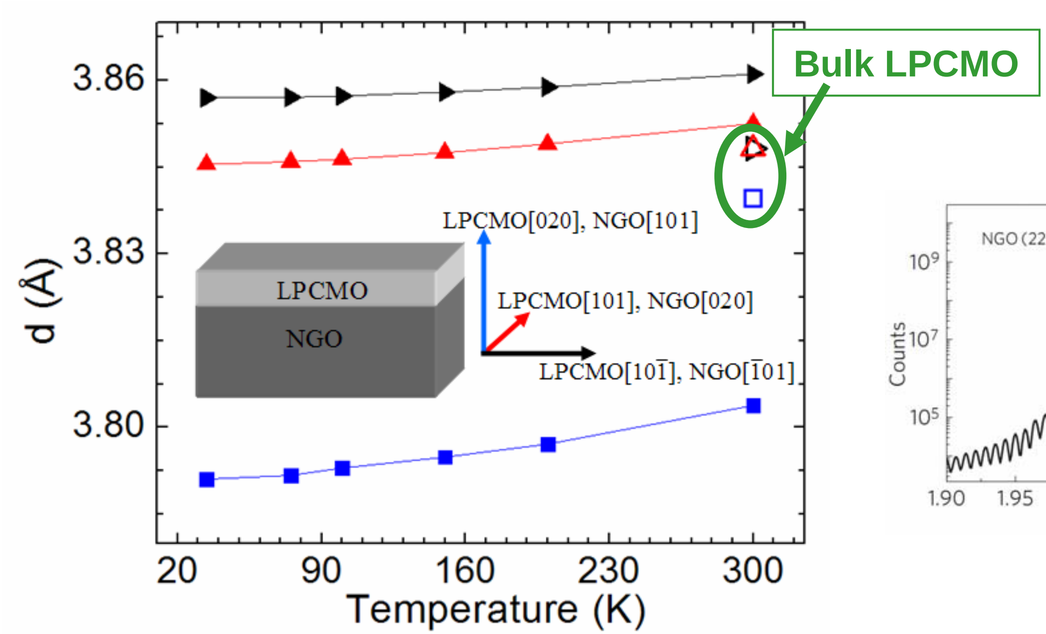
Effect of Measuring Temperature

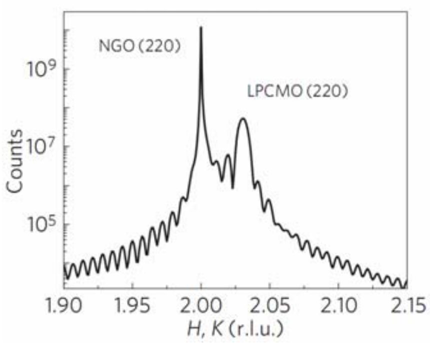


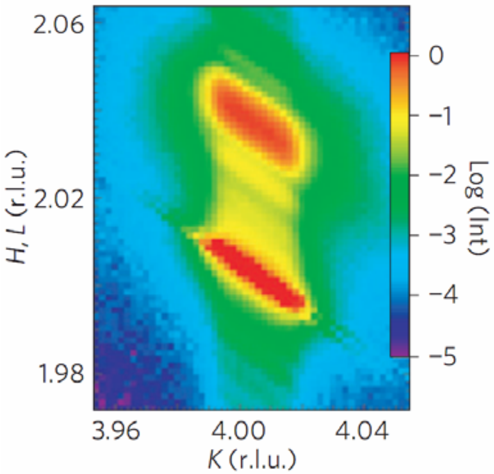
II. Electronic Nanofabrication



Application of Anisotropic Strain Field in LPCMO Films





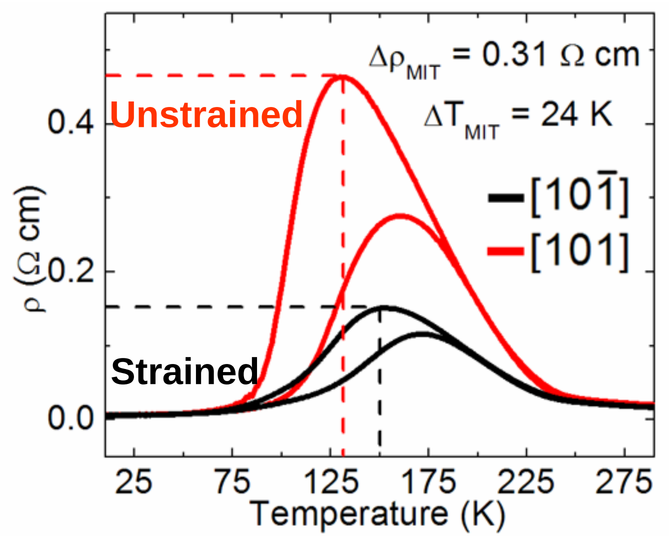


- Film and Substrate commensurate across full temperature spectrum

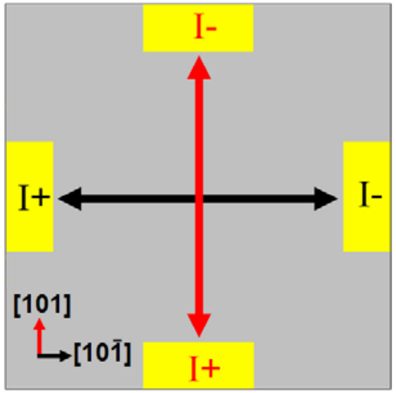
- Pseudo-cubic film locked to orthorhombic NdGaO3 (110) substrate
- Drives in-plane anisotropic strain field

Strain Field Effects on Transport

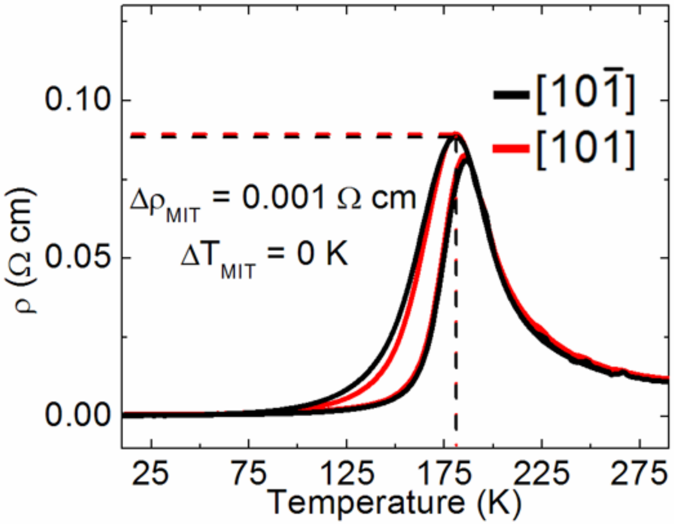
Anisotropic Strain



50nm LPCMO on NGO



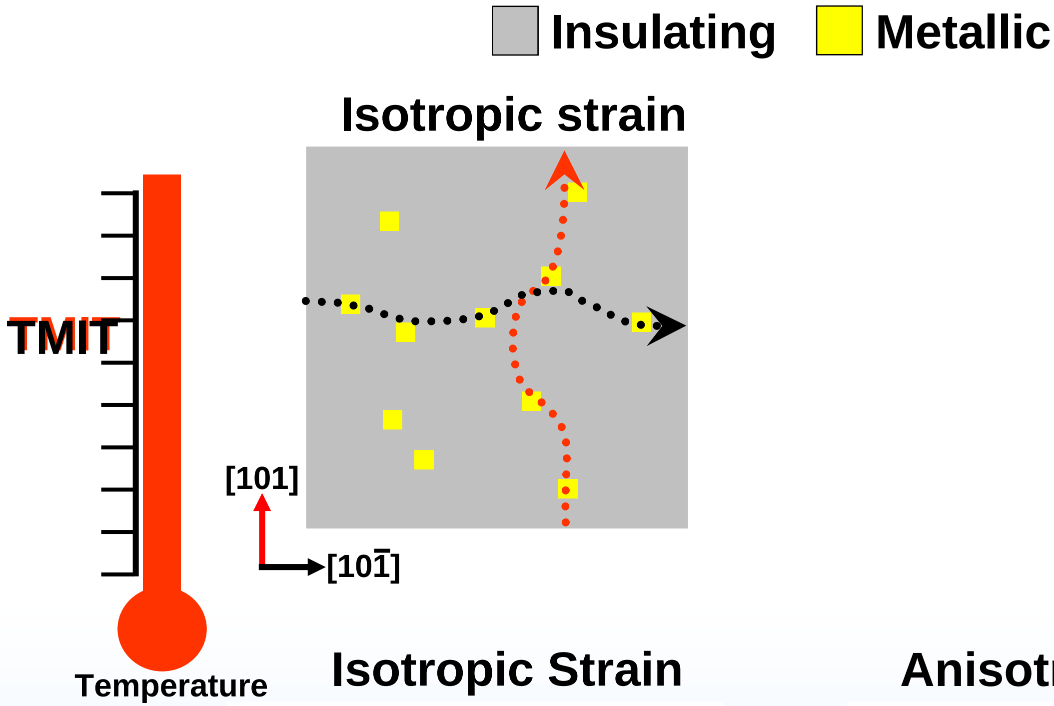
Isotropic Strain

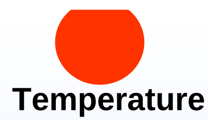


50nm LPCMO on SrLaGaO3

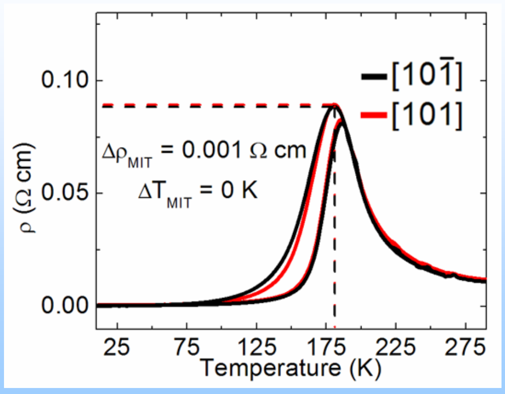
Nature Phys. 5, 885 (2009)

Anisotropic Percolation Model

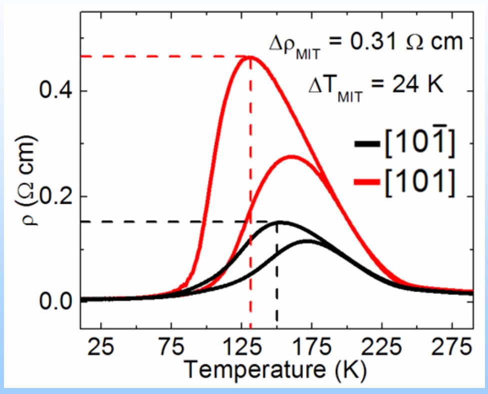




Isotropic Strain

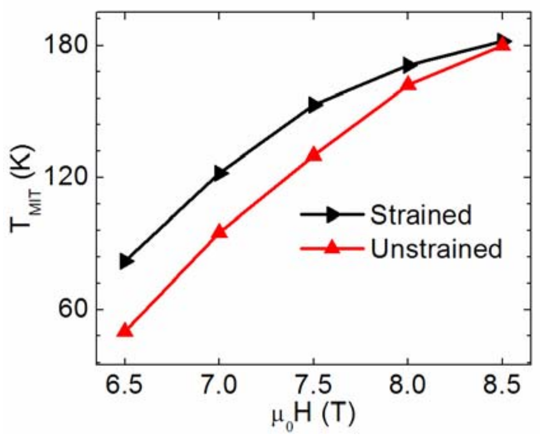


Anisotropic Strain

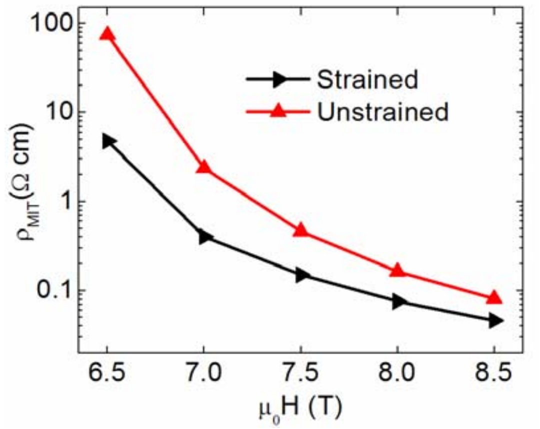


Magnetic Field Effects

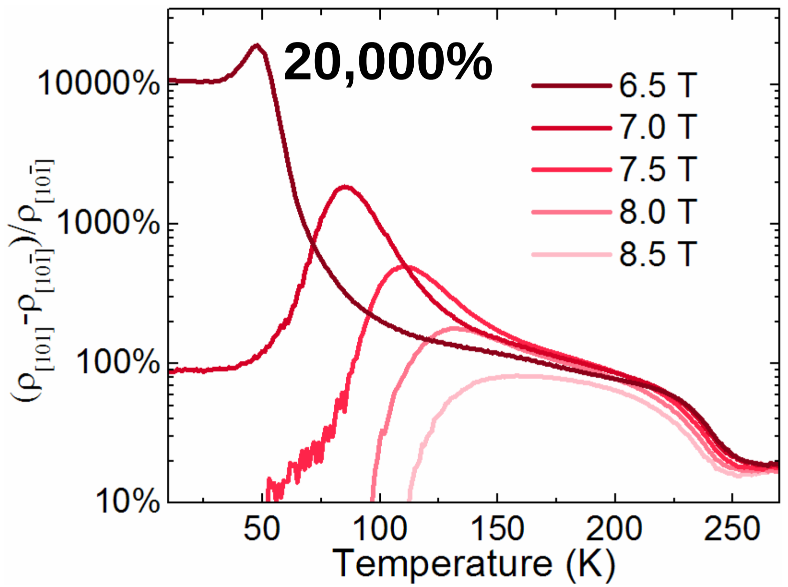
Metal-insulator transition temperature



Resistivity at metal-insulator transition

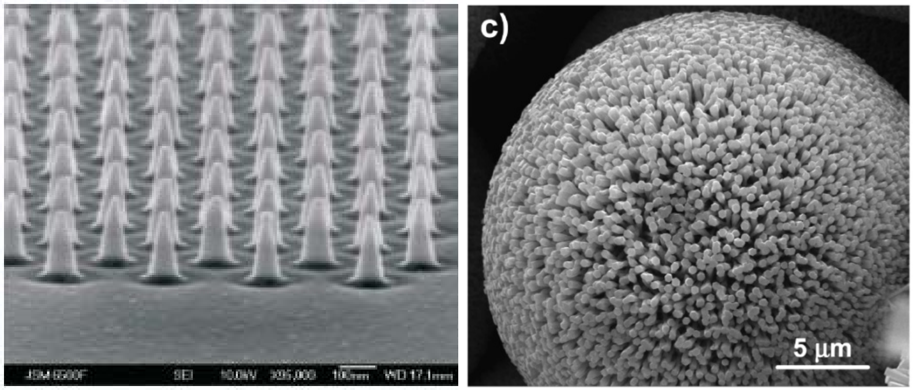


Difference in ρ along two in-plane directions

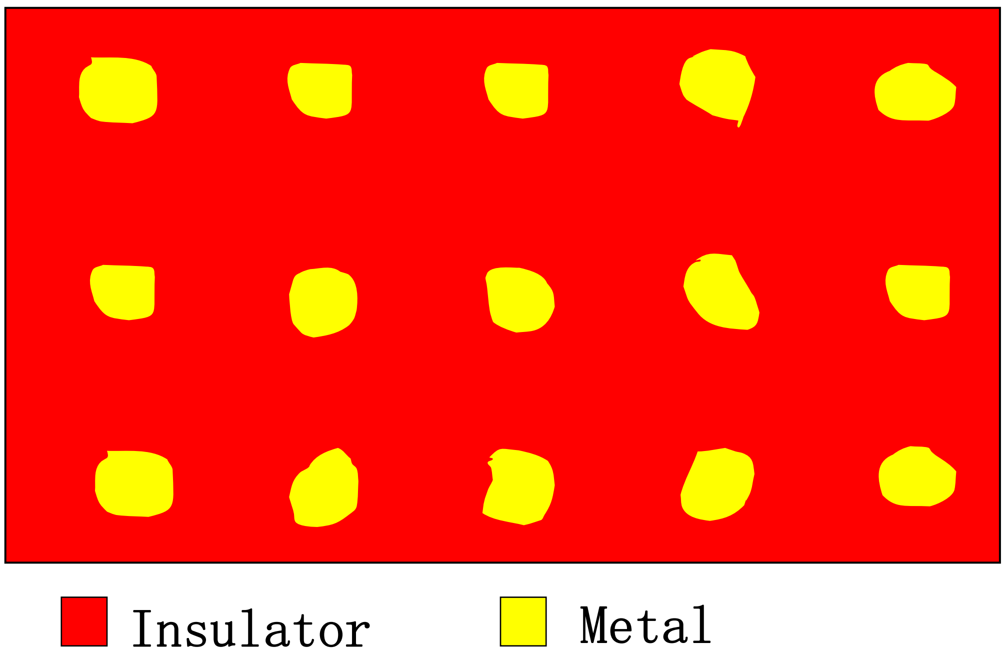


- **High B-field melts insulating phase and leads to isotropic behavior**
- **Low B-field shows strong anisotropic resistivity of over 20,000%**

Electronic Nanofabrication

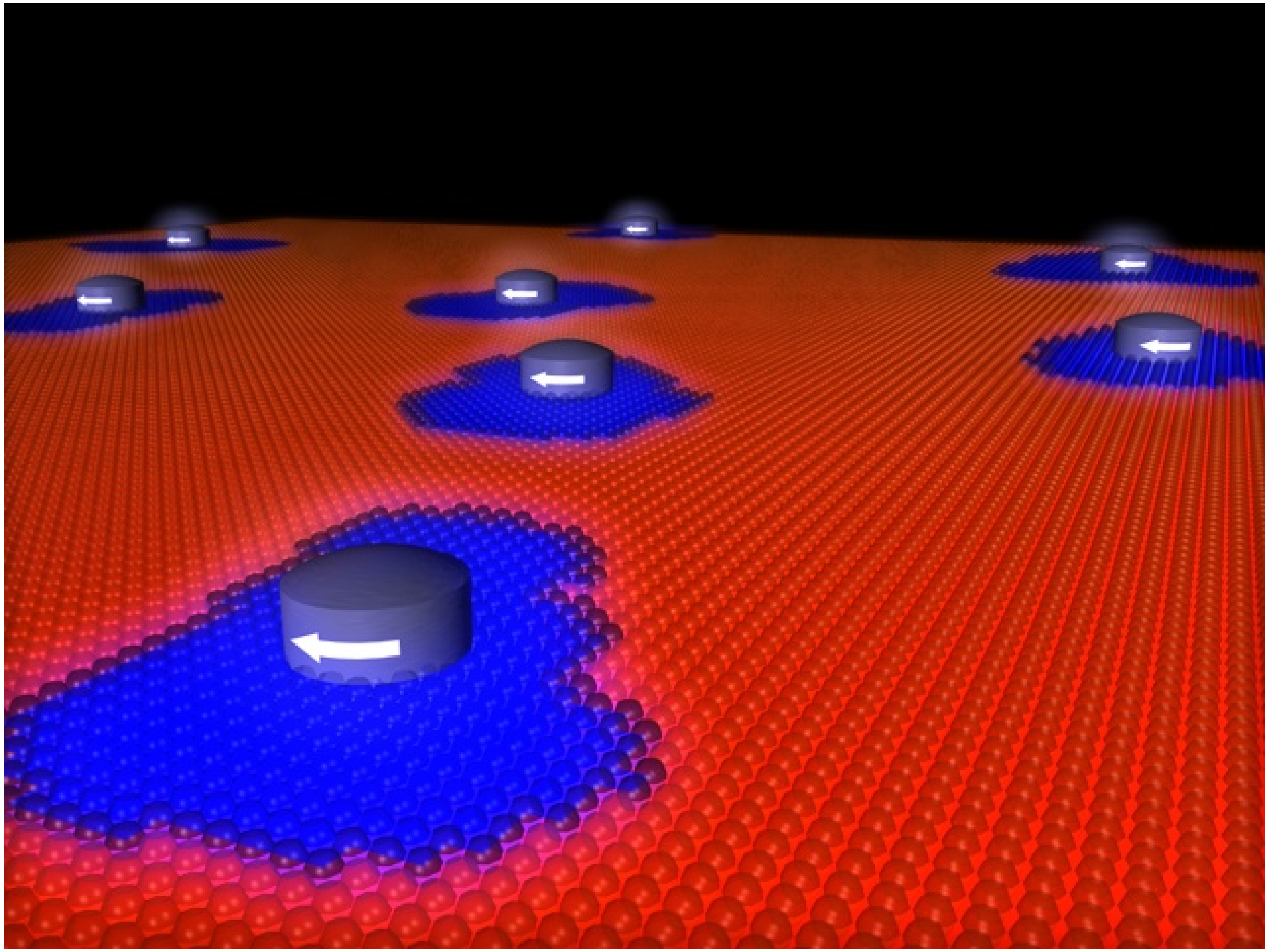


Conventional

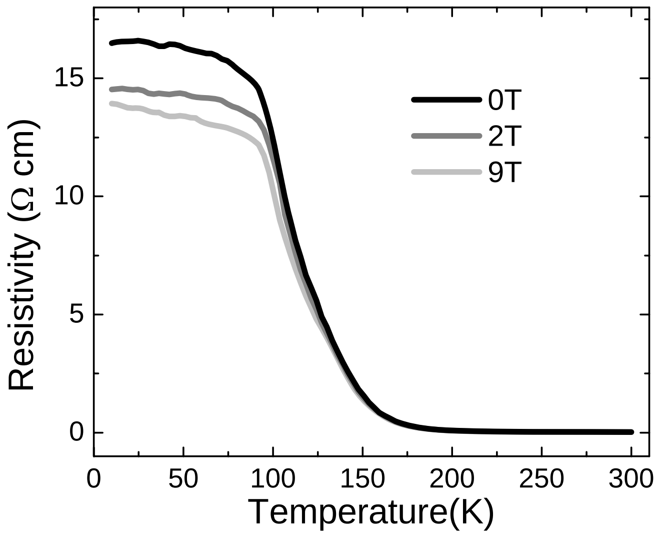


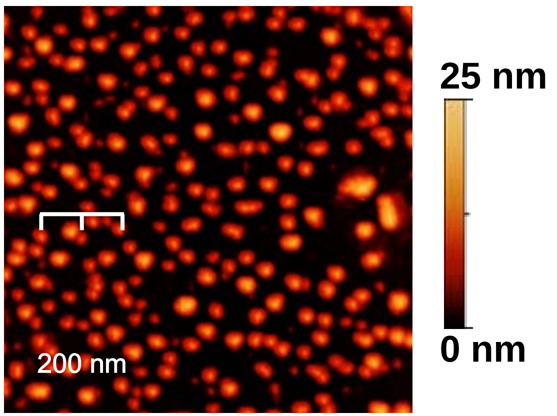
Electronic

Application of Local Magnetic Fields on Manganites Thin Films

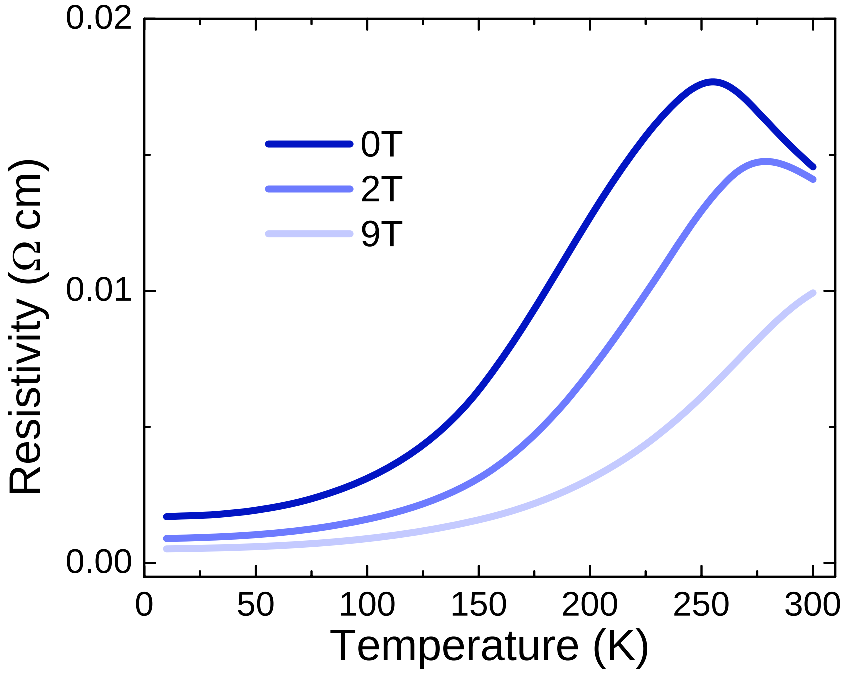


Fe Nanodots on 20nm $La_{0.7}Ca_{0.3}MnO_3$ Thin Film Grown on $LaAlO_3$(001)

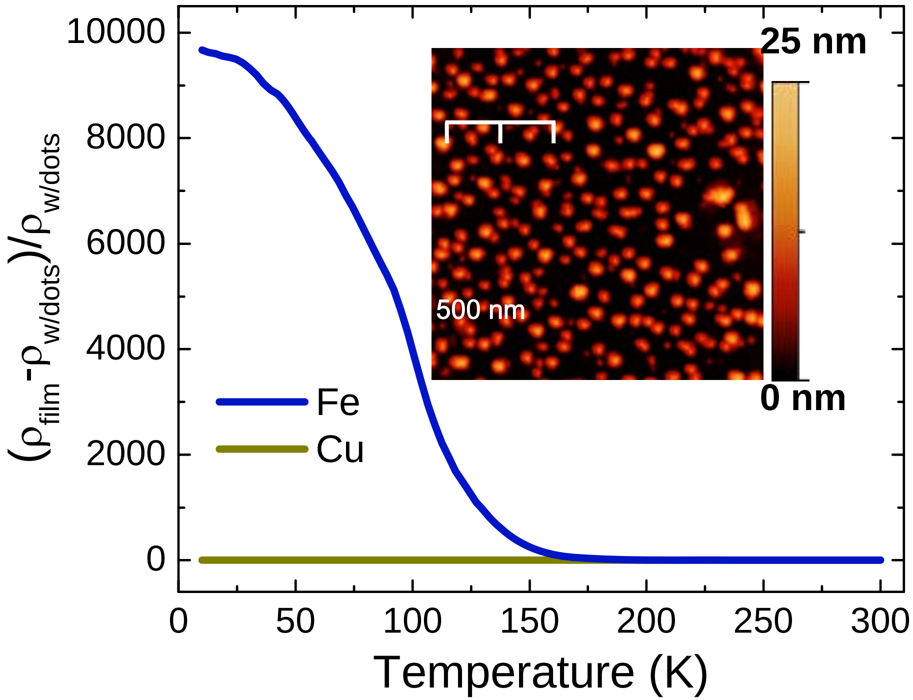


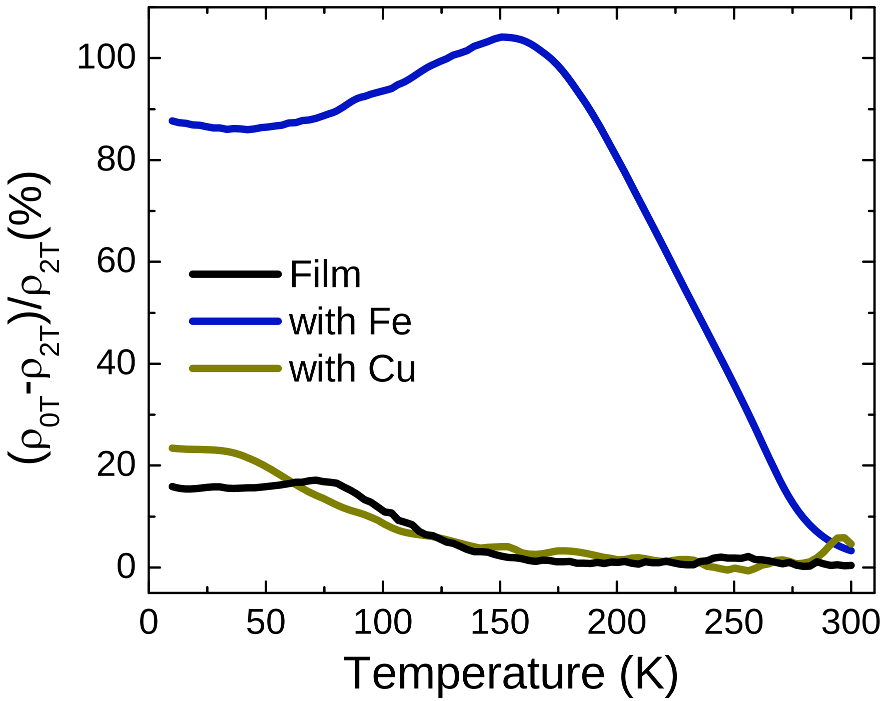


- **20nm thin film of LCMO is an insulator**
- **Ferromagnetic Fe nanodots grown on surface**
- **Becomes metallic with high MIT temperature**



Nonmagnetic Nanodots Have No Effect

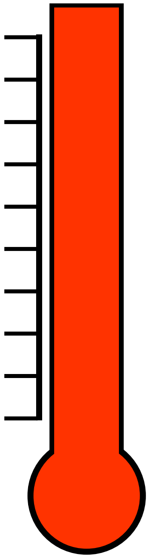


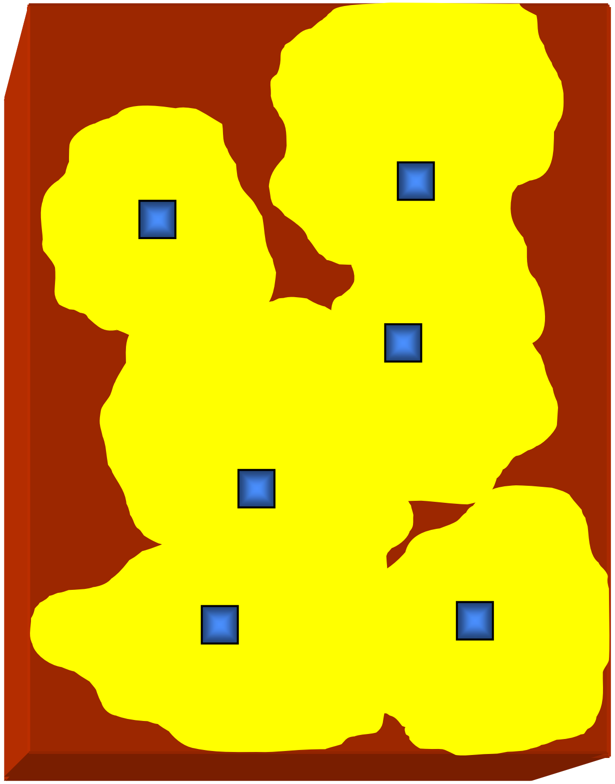


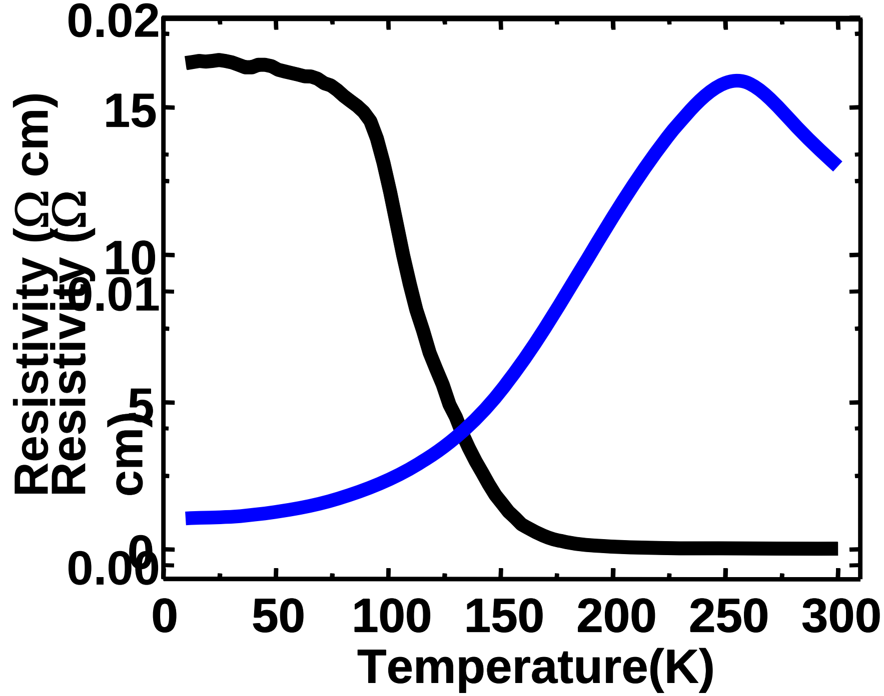
Add non-magnetic metallic Cu nanodots for comparison

- **Change in resistivity is greatly enhanced only by Fe nanodots**
- **Magnetoresistivity is unaffected by simple non-magnetic metal**

Effect of Magnetic Nanodots induced Local Exchange Field

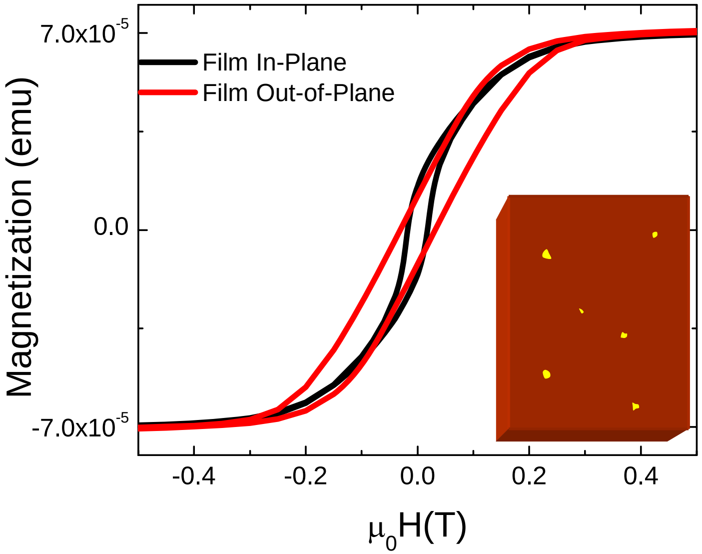


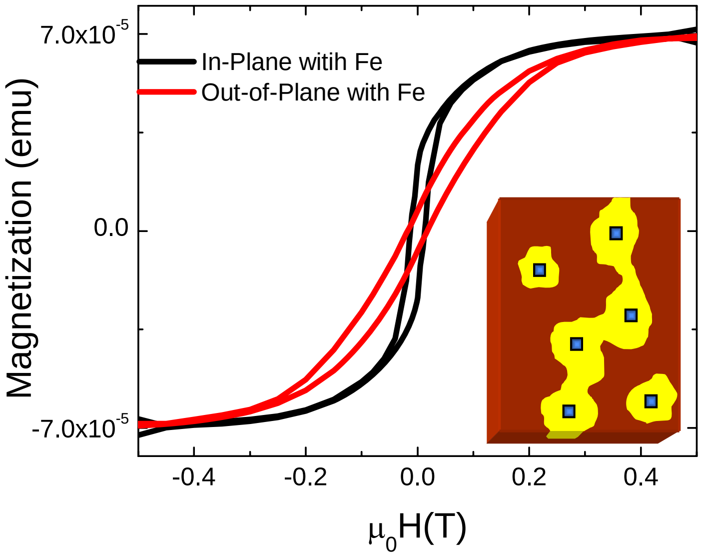




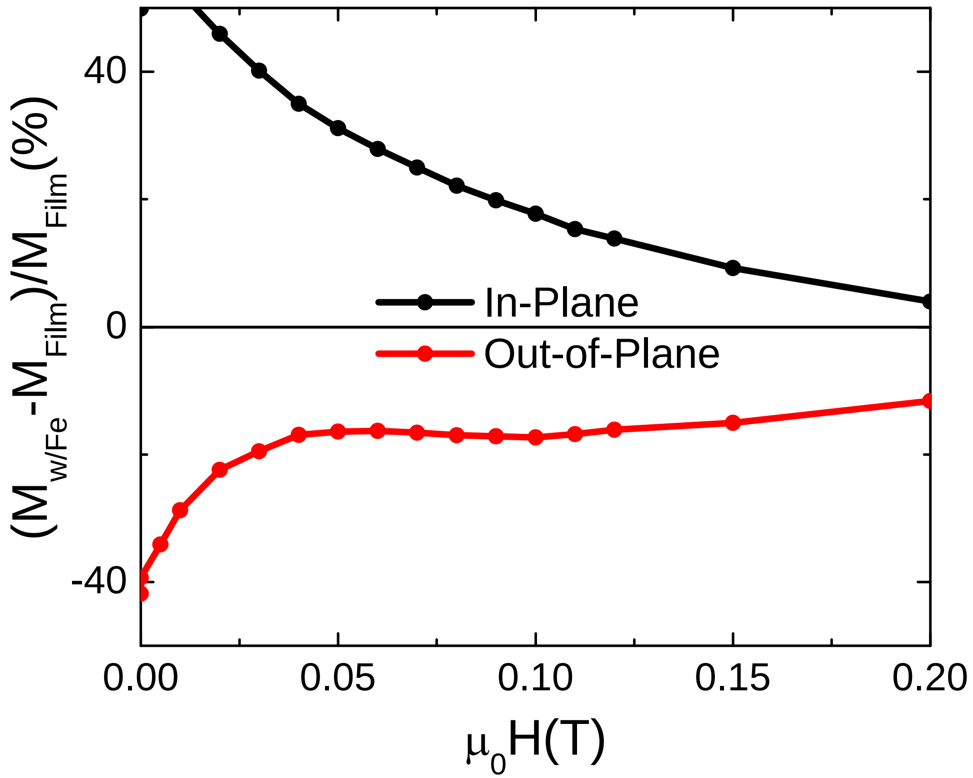
LCMO
film

Direct Evidence of Exchange Coupling between Fe and LCMO Film



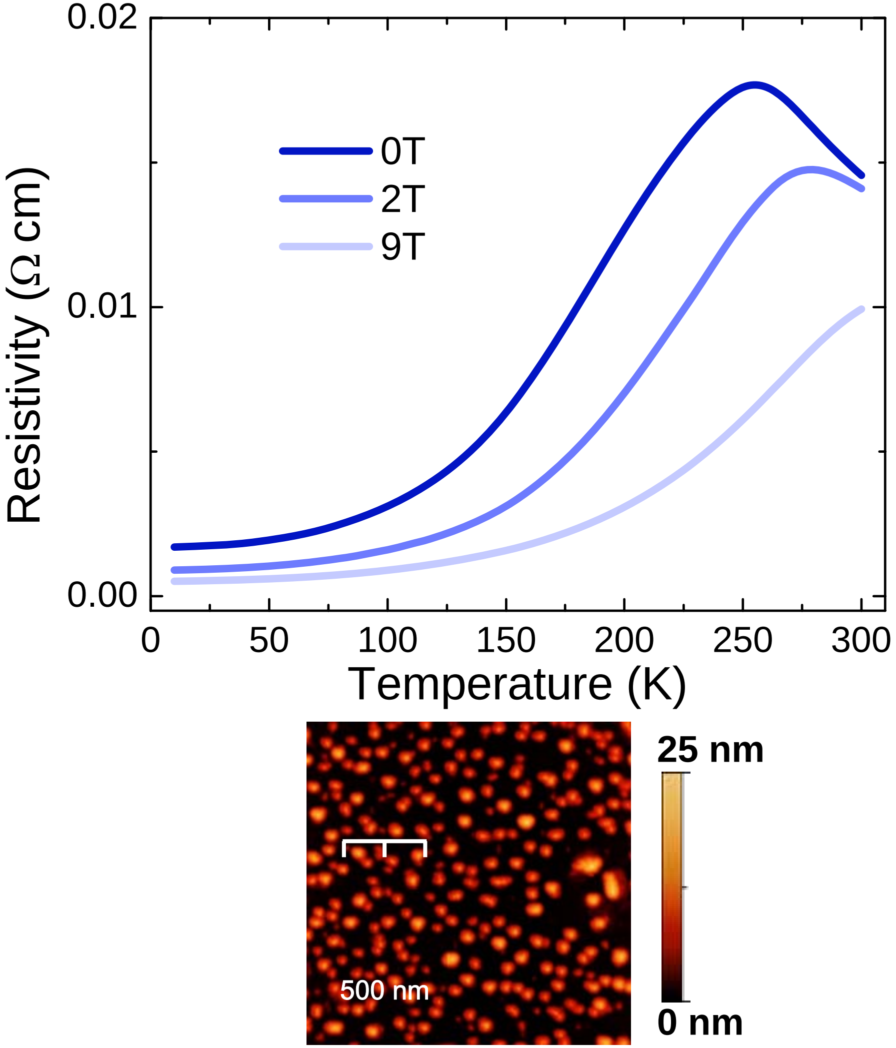


- **As-grown shows no clear preference to easy axis**
- **Fe nanodots' influence aligns spins to in-plane**
- **Spin configuration in the film has been tuned**

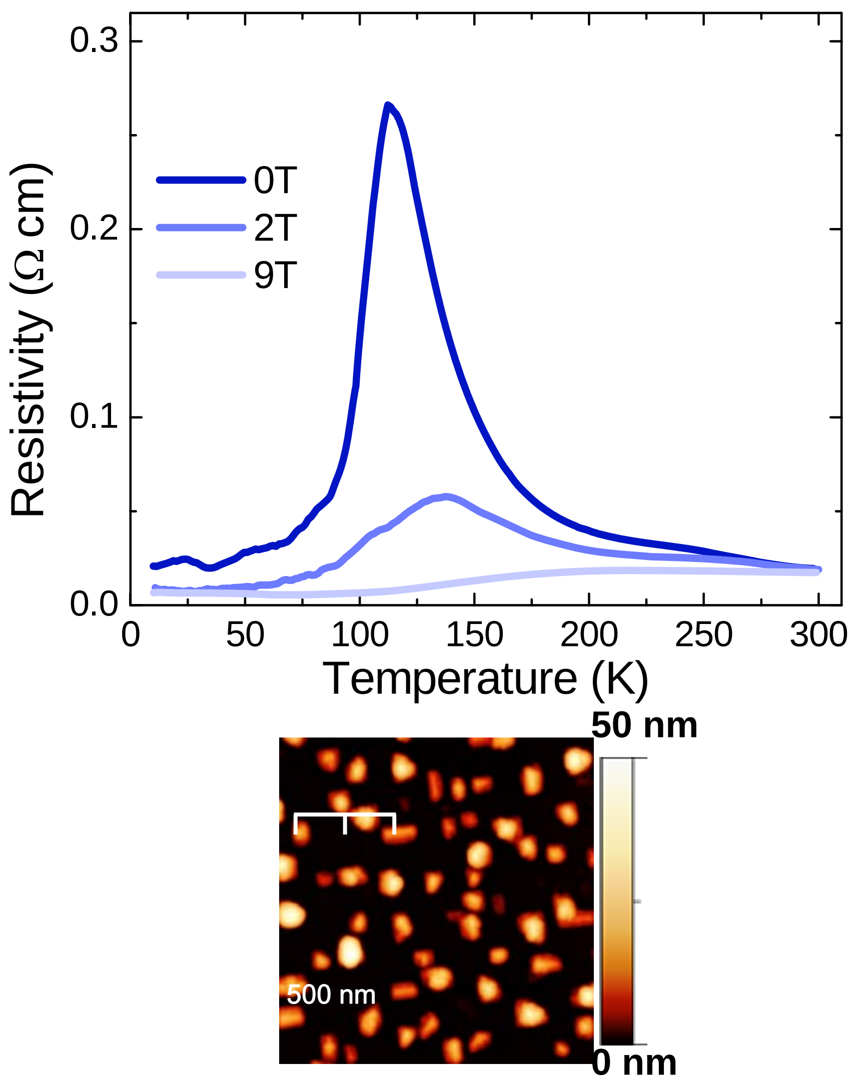


A Tunable Metal-Insulator Transition

High Density



Low Density



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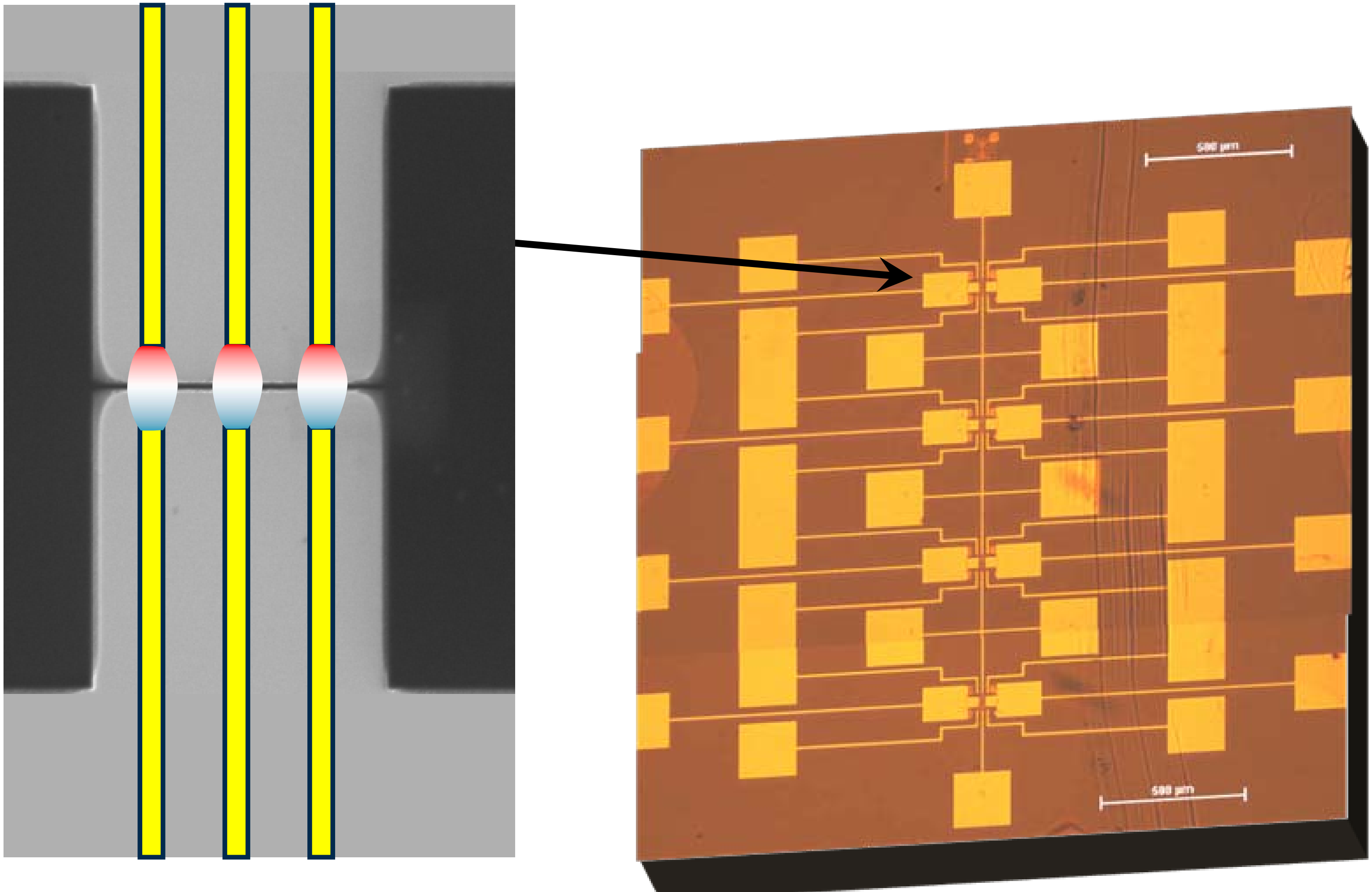
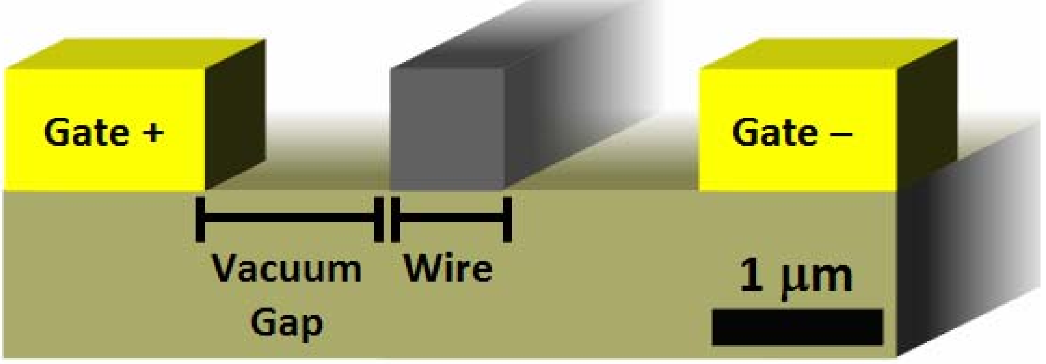
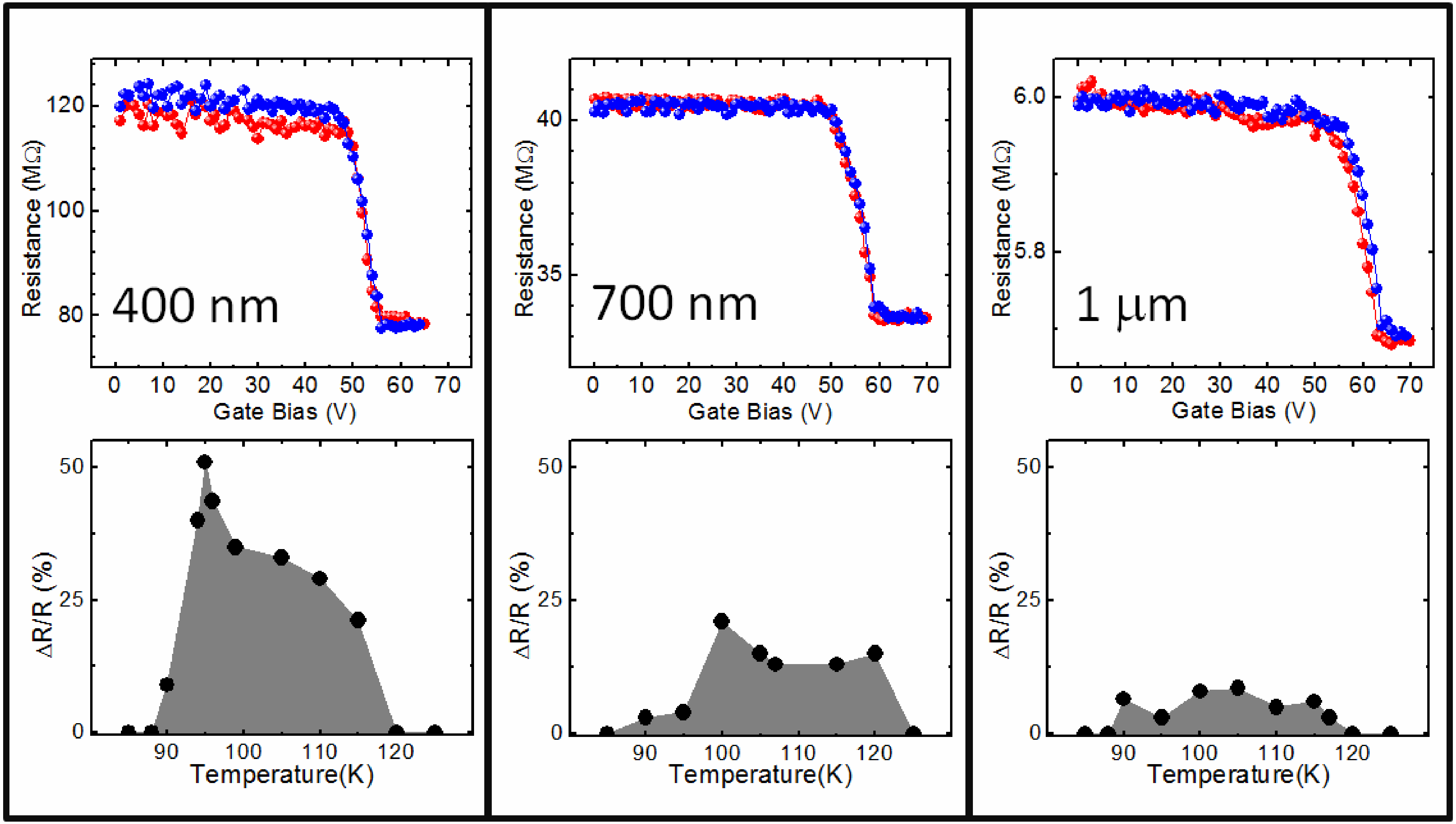
Patterned Local Electric Field

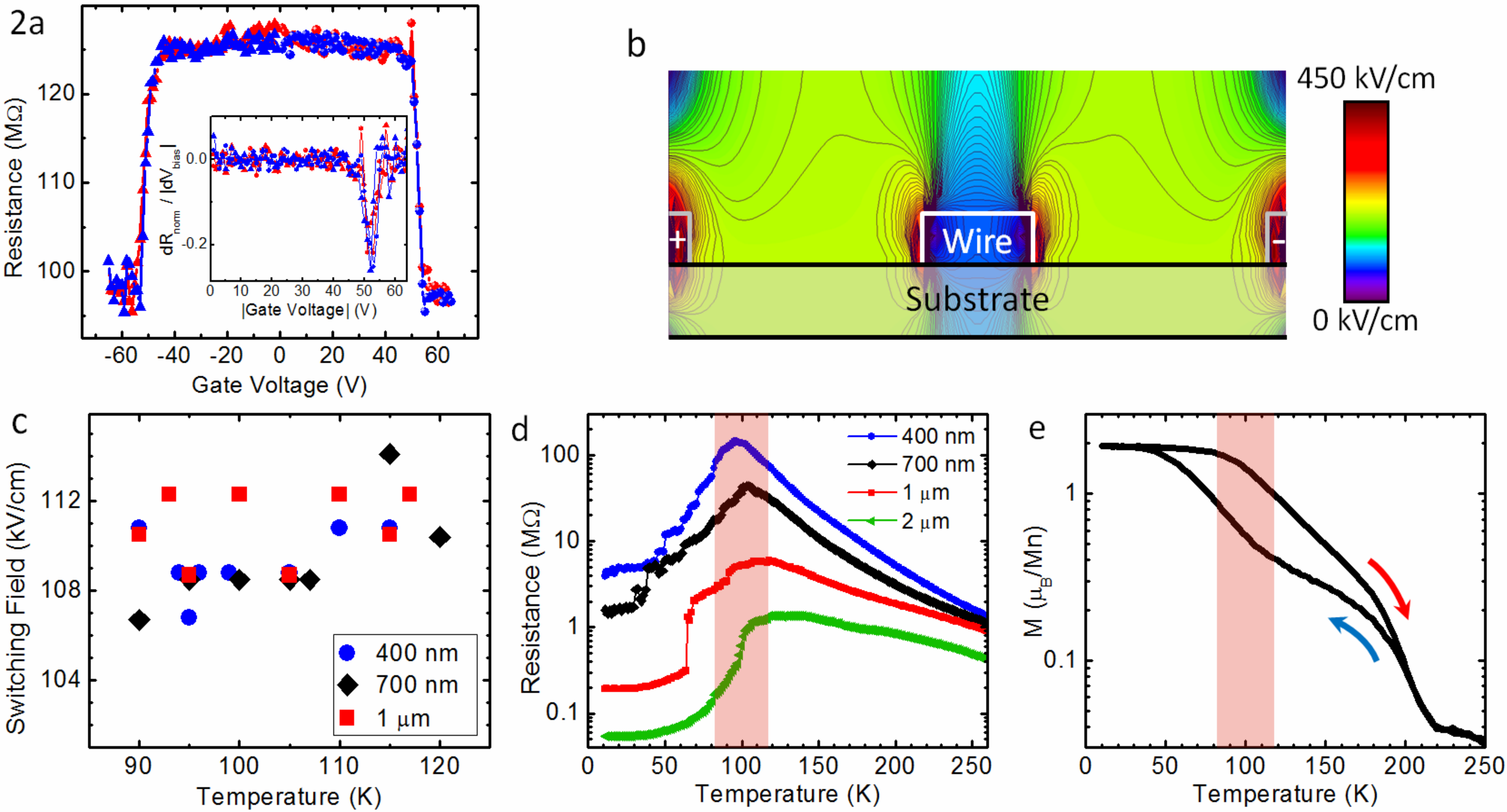


Resistive Switching

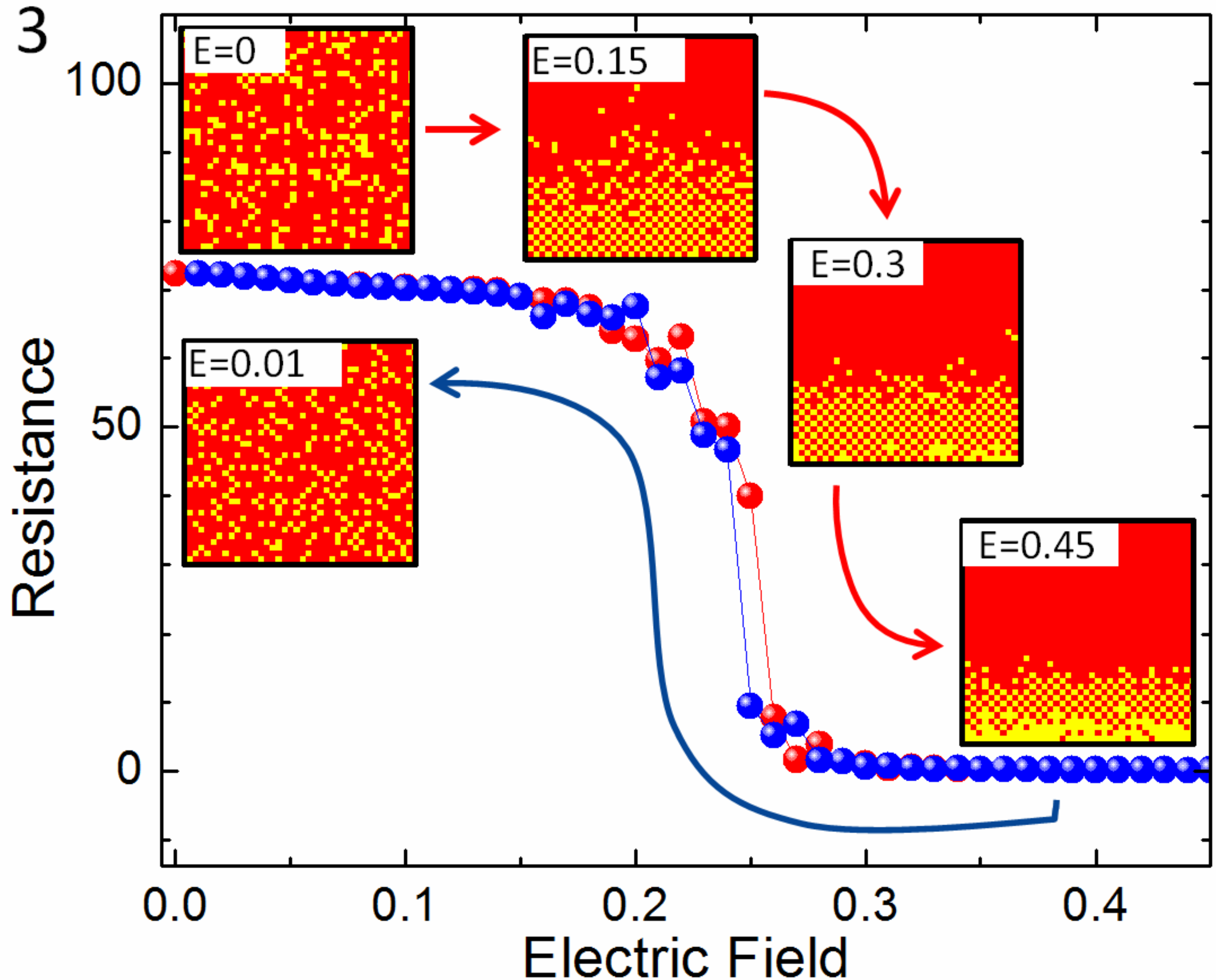




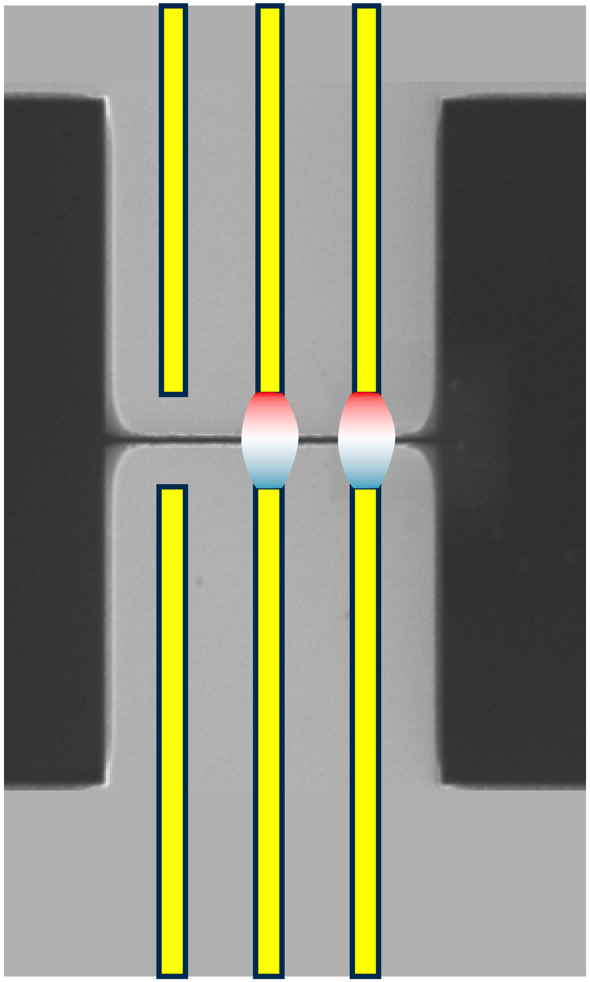
Switching Mechanism

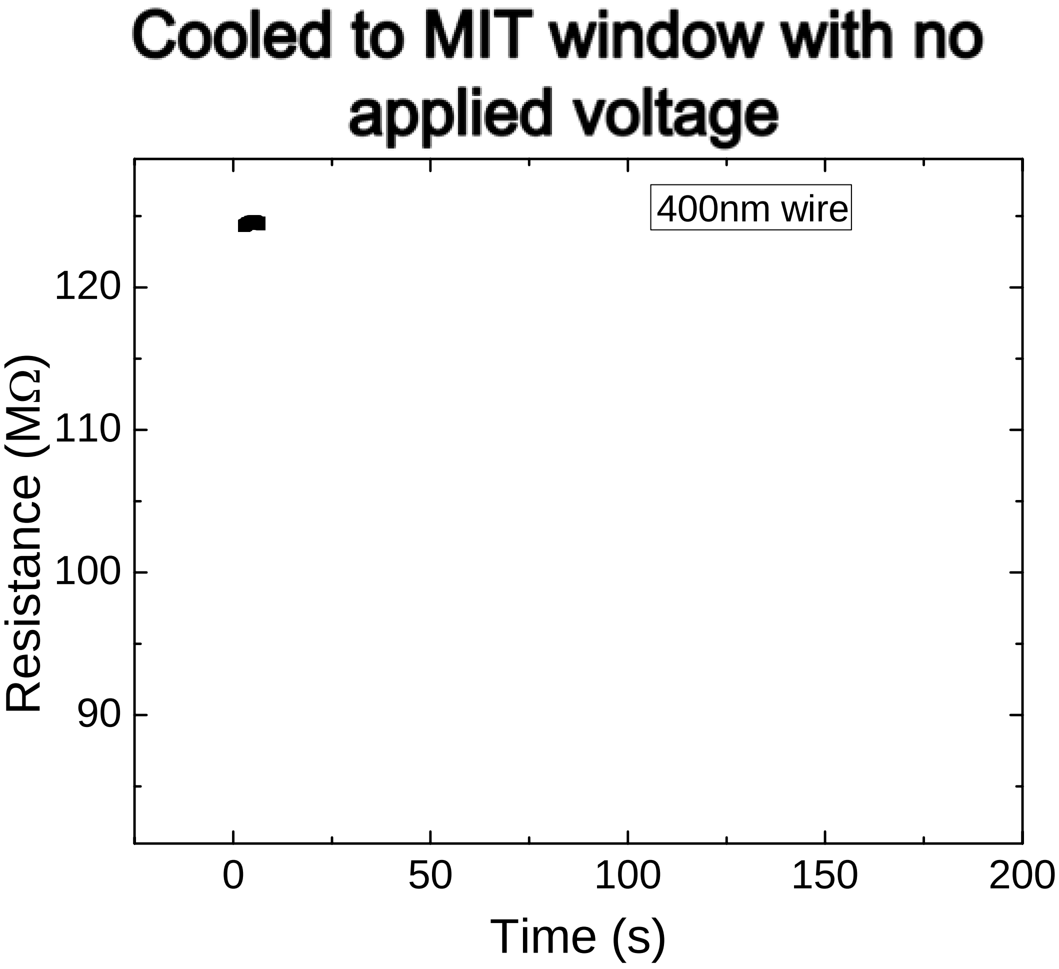


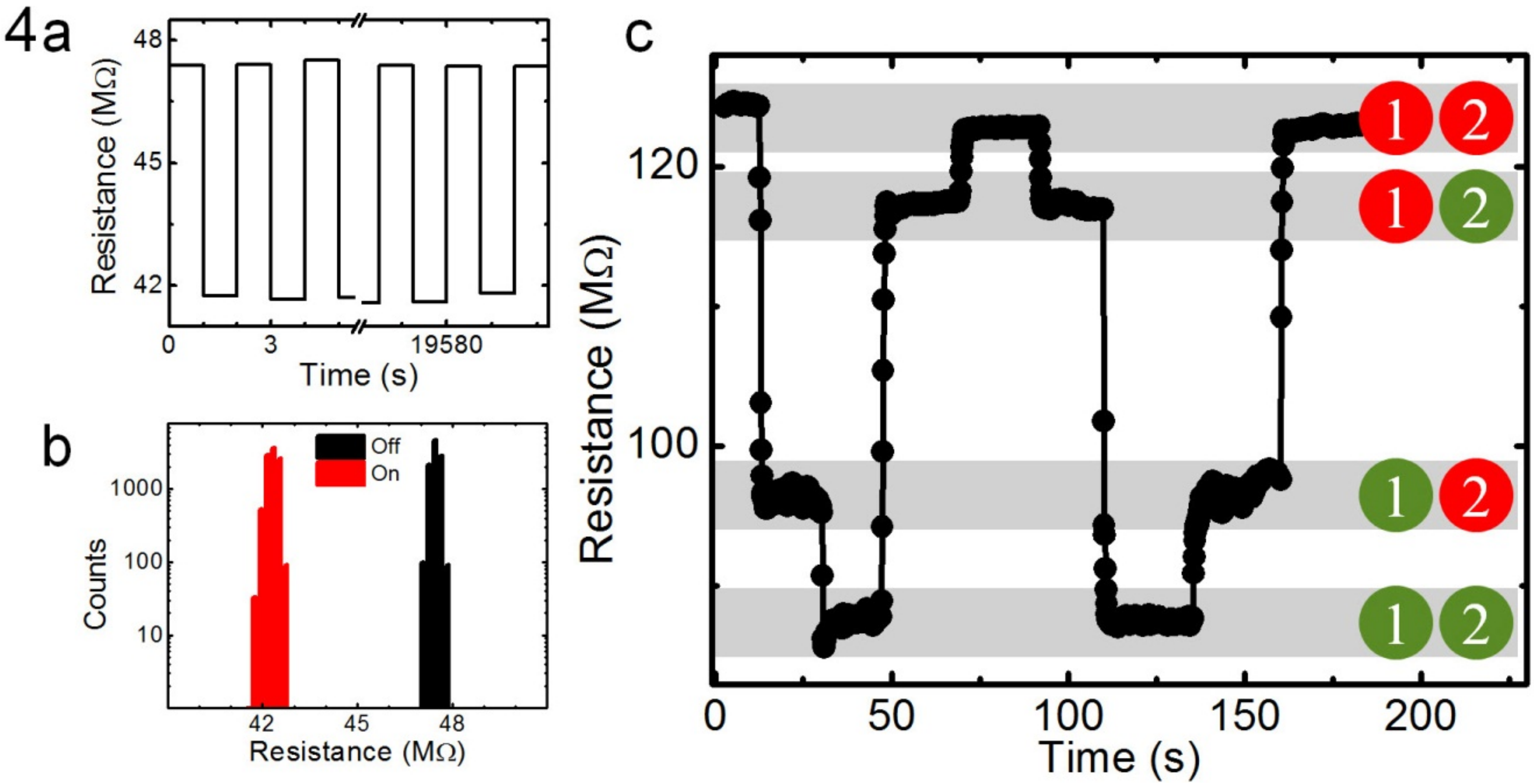
Electric field driven percolation of metallic sites



Multistate Dynamic Switching






4a
48
45
42
Resistance (MΩ)
0
3
19580
Time (s)
b
Off
On
1000
100
10
Counts
42
45
48
Resistance (MΩ)
c
120
100
Resistance (MΩ)
0
50
100
150
200
Time (s)
1 2
1 2
1 2
1 2

Summary

Spatial dimension ~ electron phase separation

- Emergent transport properties
- Dynamics of individual phase domain can be observed
- Time scale of first order phase transition

Electronic nanofabrication

- Electronic Domain shape and density are tunable
- Leading to striking emergent phenomena (large anisotropic resistance, high MIT temperature, multi-state memory)

Acknowledgement

Experiments

T. Z. Ward, Hongying Zhai

L.F. Yin, Z. Gai, J. Budai, H.W. Guo, X.Y. Xu

Simulations

Shuai Dong, E. Dagotto, X.G. Zhang