Emergent Phenomena in Manganites under Spatial Confinement

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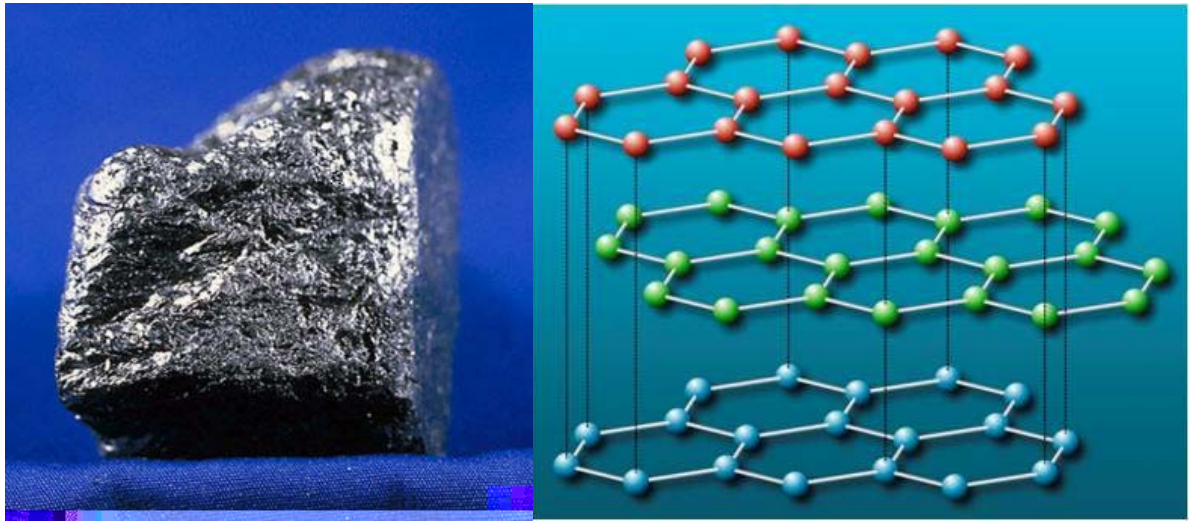
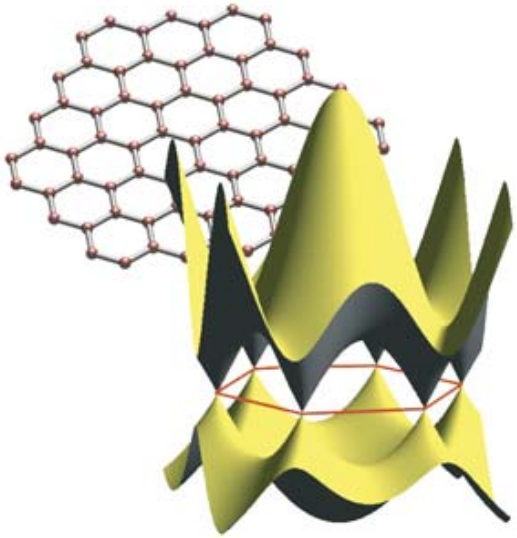
Department of Physics
Fudan University, China

The Excitement in Nanoscale Physics

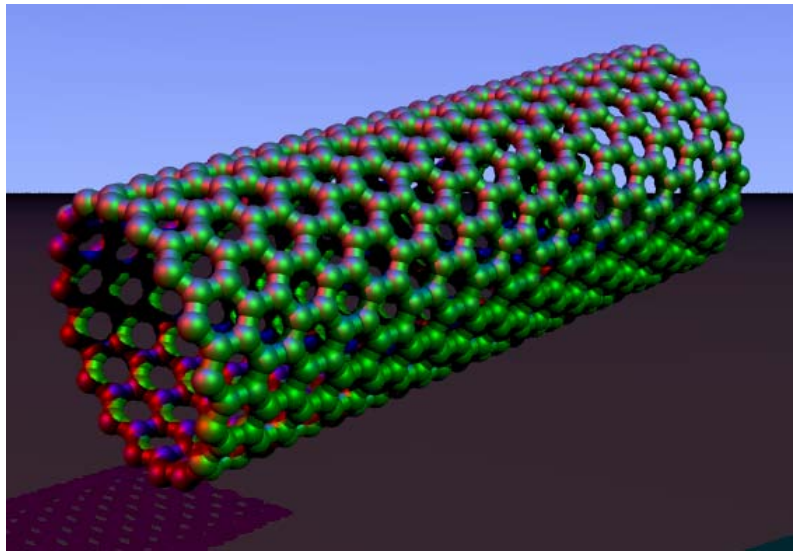
Carbon



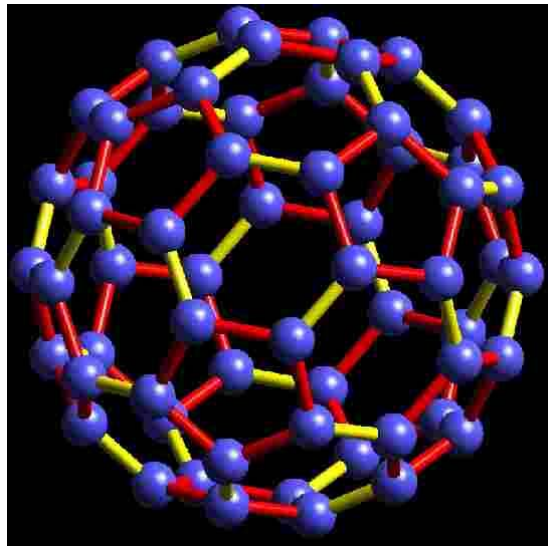
Graphene



Carbon nanotube

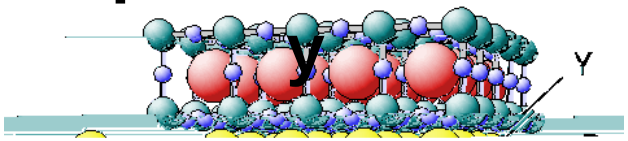


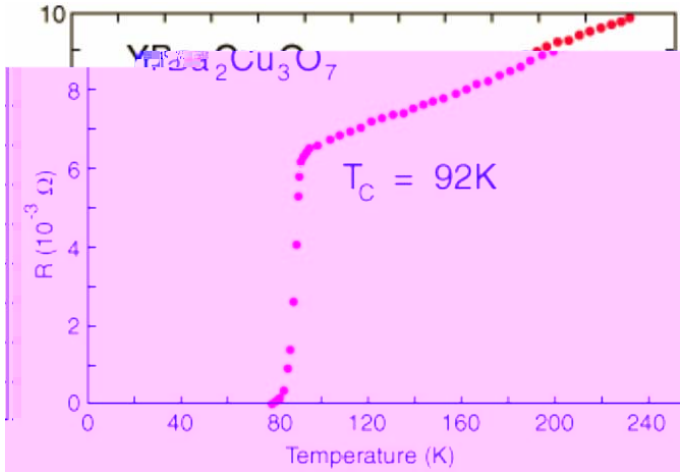
Bucky ball



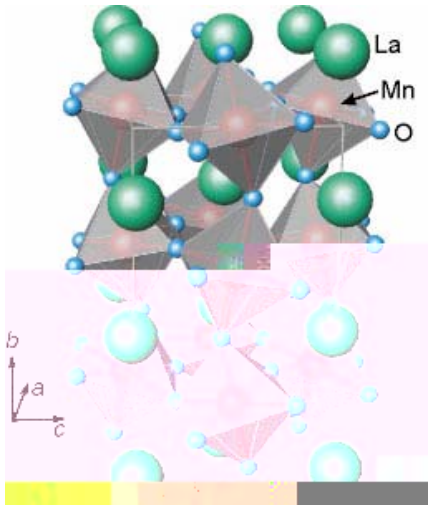
Complexity in Strongly Correlated Systems

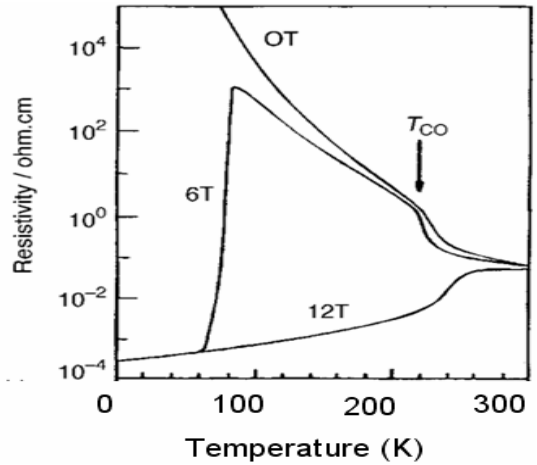
High-Tc Superconductivit



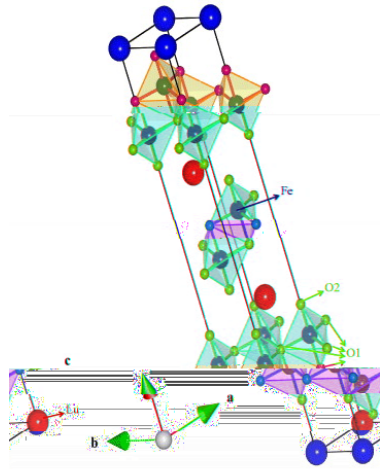


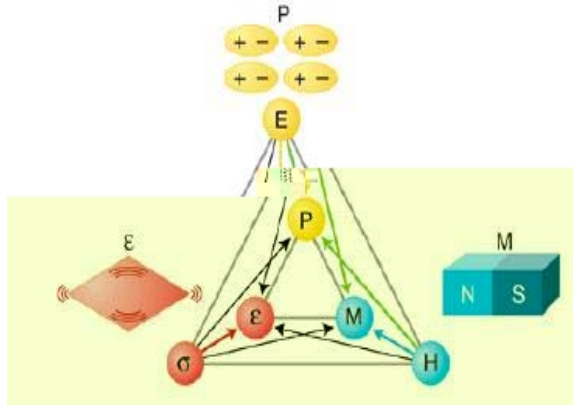
Colossal Magnetoresistance



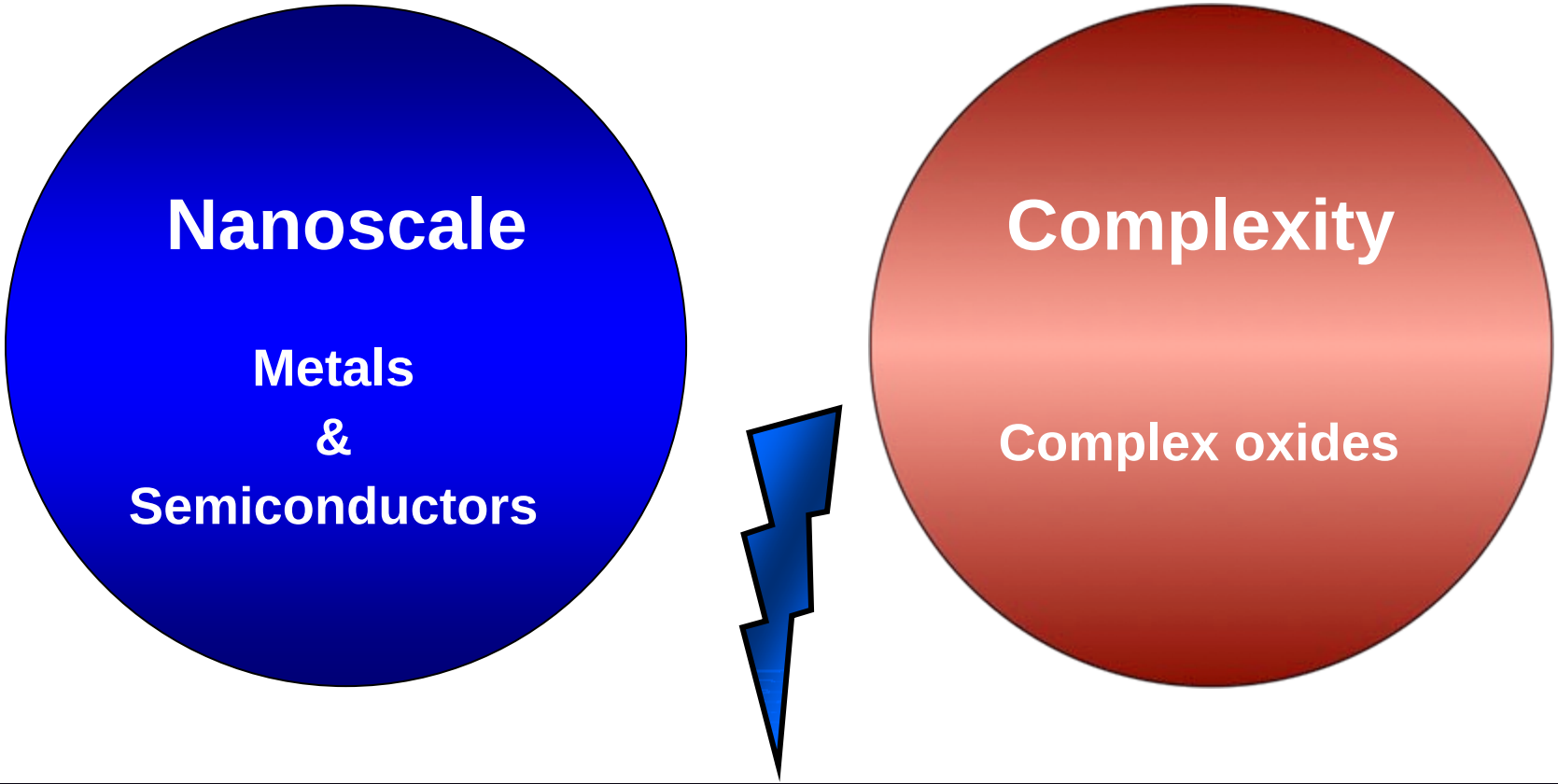


Multiferroicity





Complexity under Spatial Confinement



What exciting phenomena can we observe?

Transition metal oxides

spin

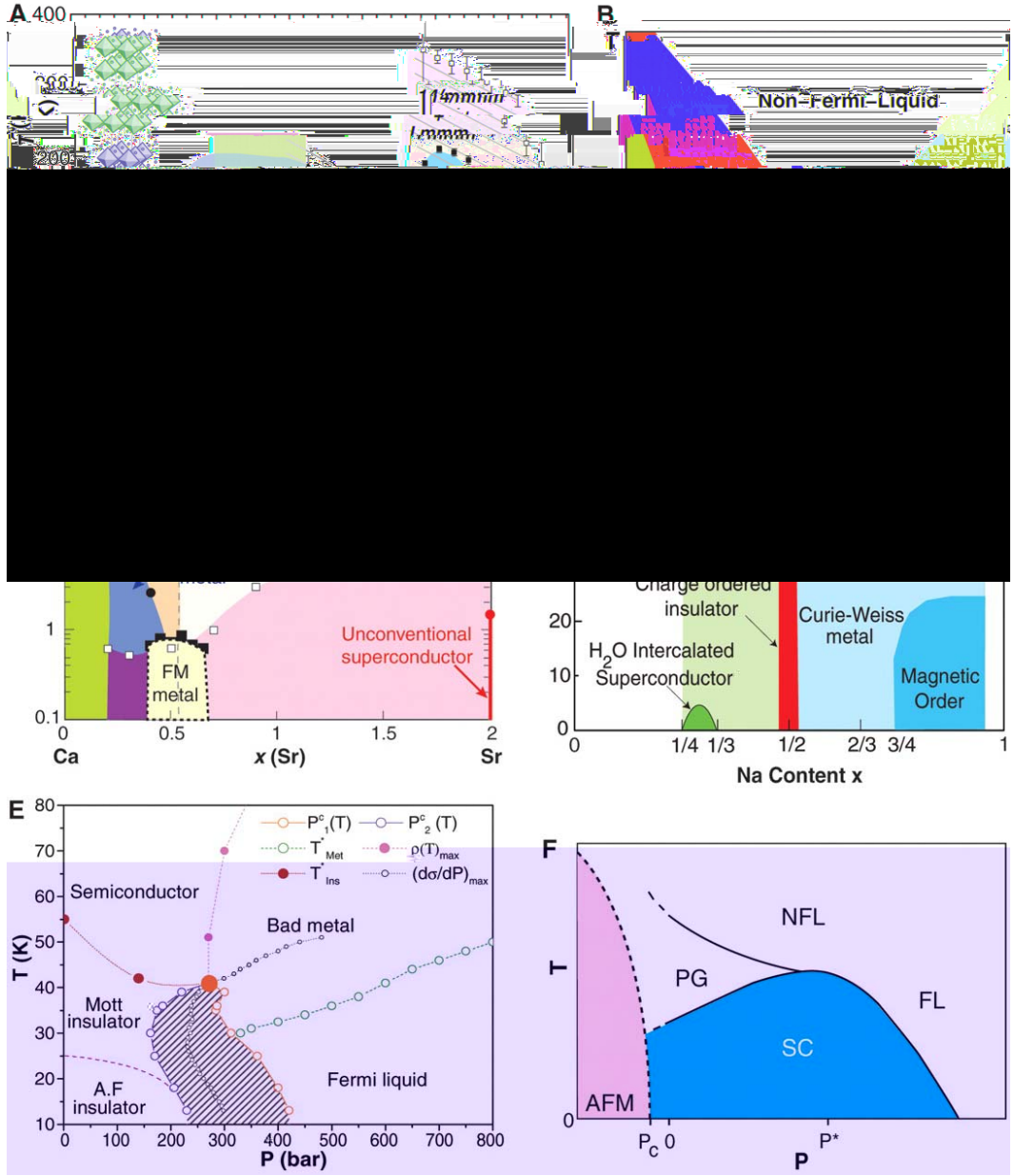
charge

Strong coupling

orbital

lattice

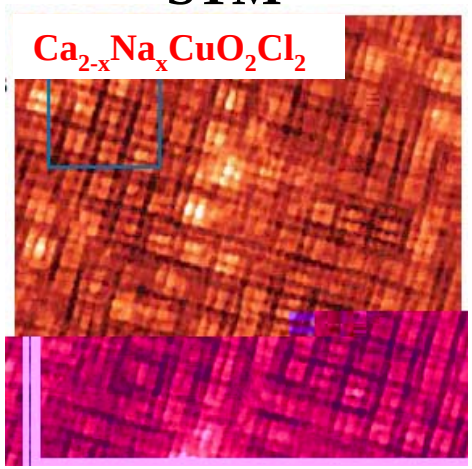
Electronic Phase Separation



E. Dagotto, Science 309, 257 (2005)

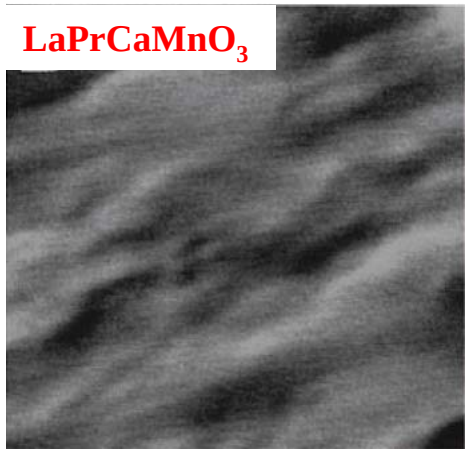
Electronic Phase Separation in Complex Oxides

STM



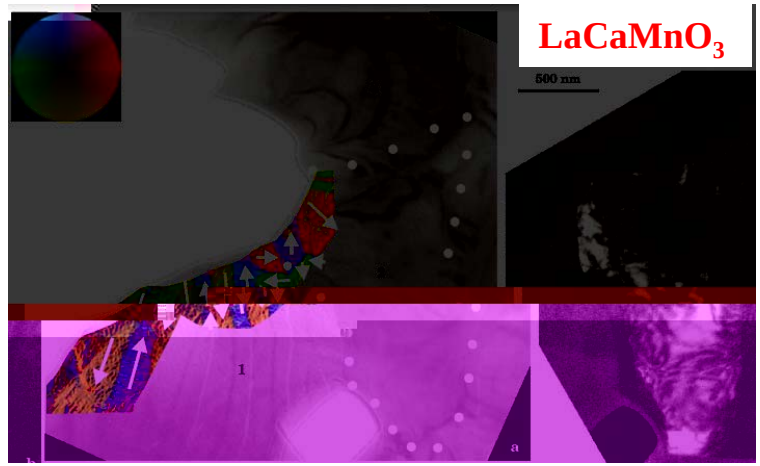
Nature 430, 1001 (2004)

MFM



Nature 415, 412 (2002)

TEM



Nature 420, 797 (2002)

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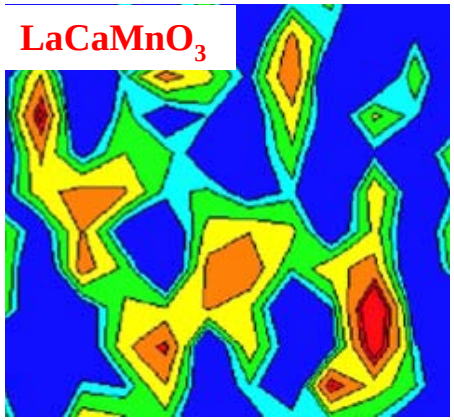
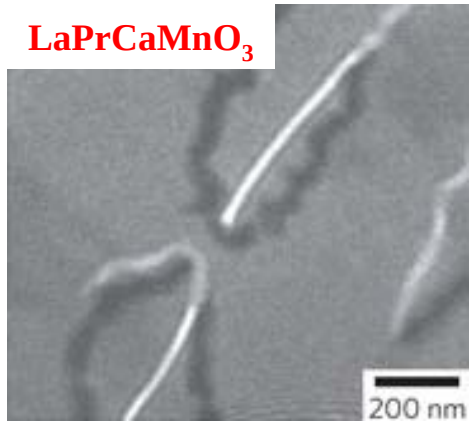


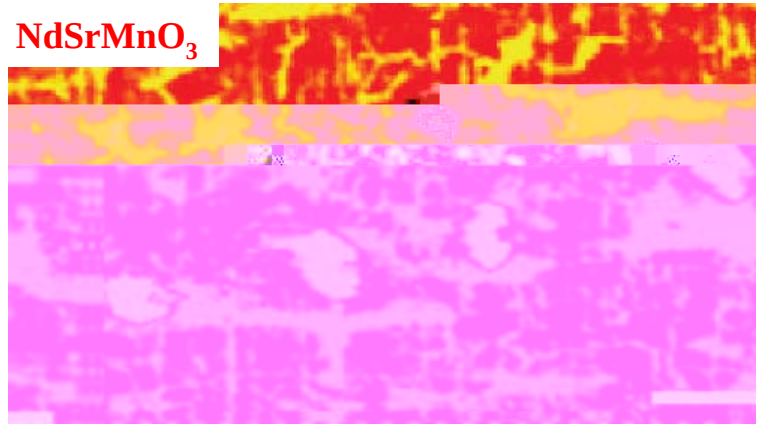
PRL 103, 097202 (2009)

Lorentz Microscope



Nat. Nanotech. 8, 37 (2010)

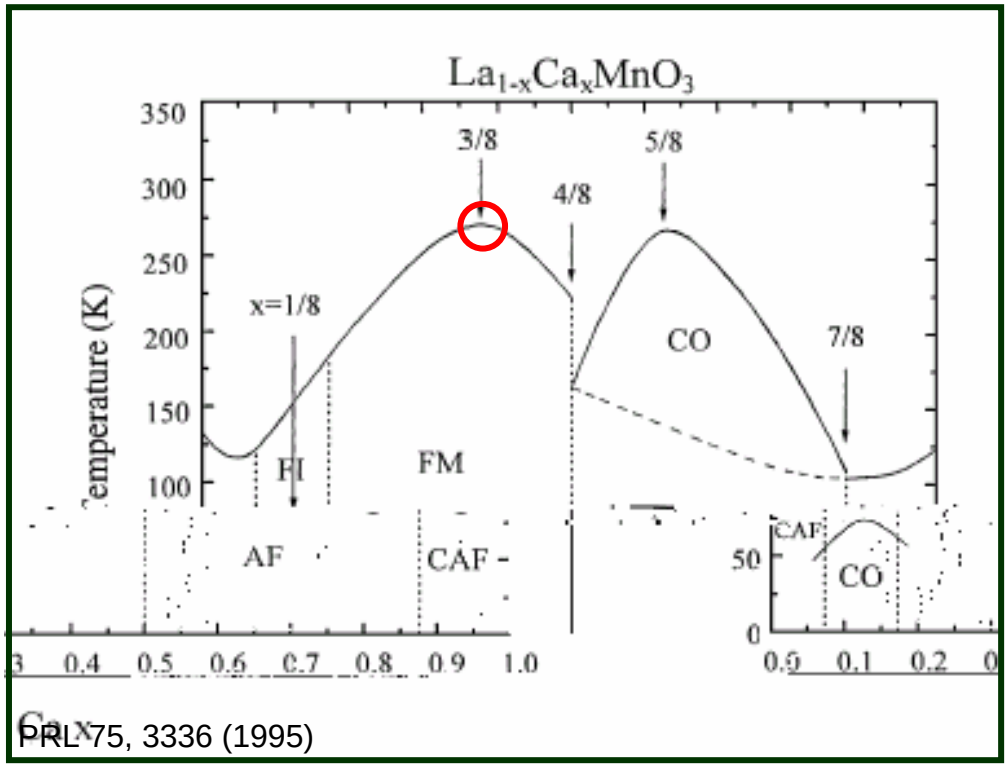
Microwave Impedance Imaging



Science 329, 190 (2010)

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

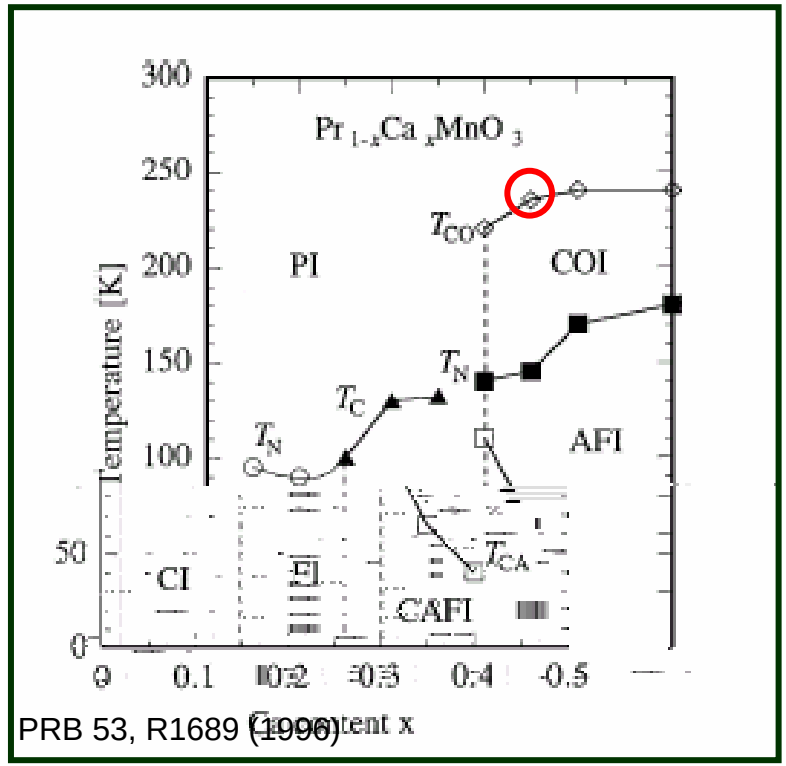
Ferromagnetic metal



PRL 75, 3336 (1995)

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

Charge-ordered Insulator

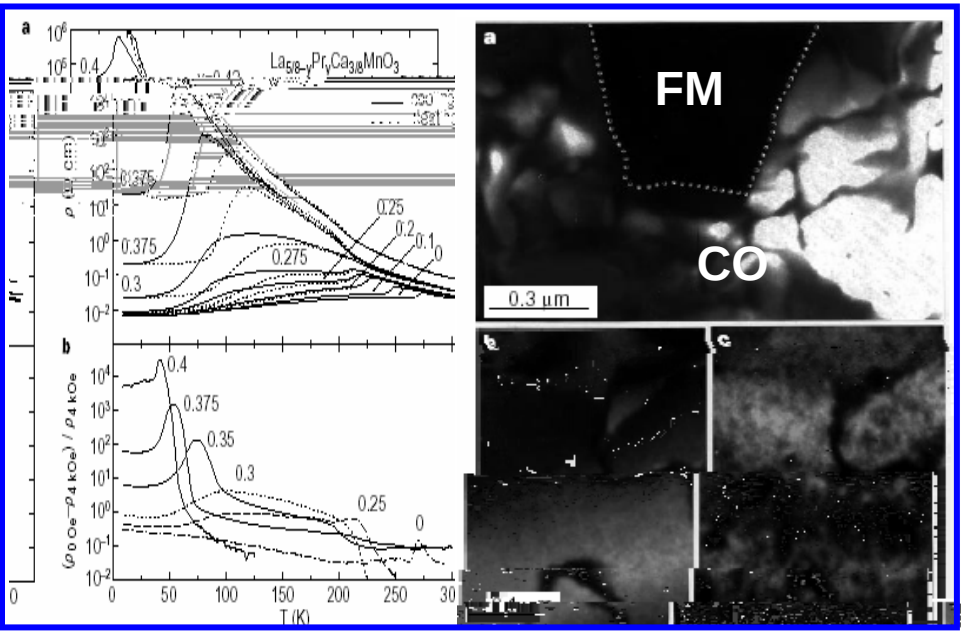


PRB 53, R1689 (1996)

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

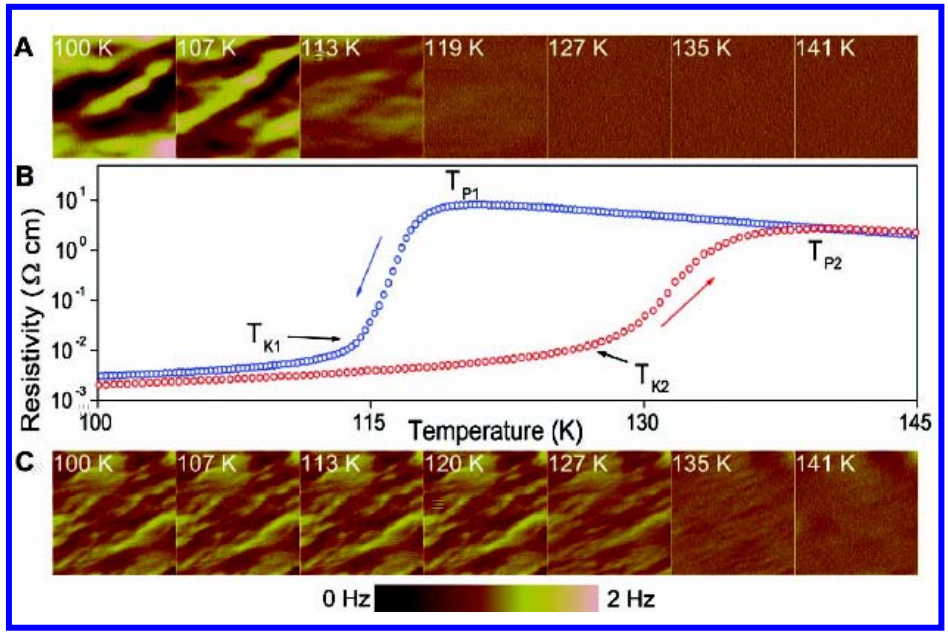
Large-scale (Micron) Phase Separation in LPCMO

TEM



Uehara et al, Nature 399, 560 (1999)

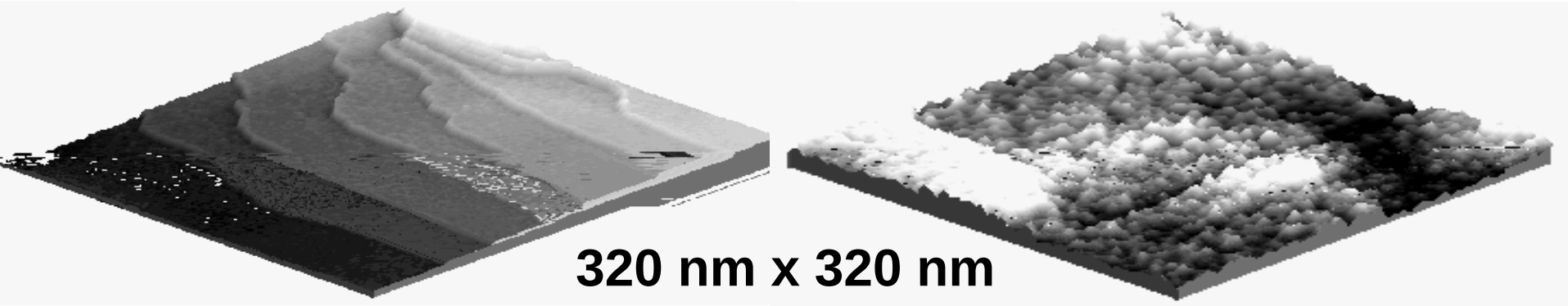
MFM



Zhang et al, Science 298, 805 (2002)

Electronic Phase Separation in LPCMO Film

Morphology **Spectroscopy**



320 nm x 320 nm

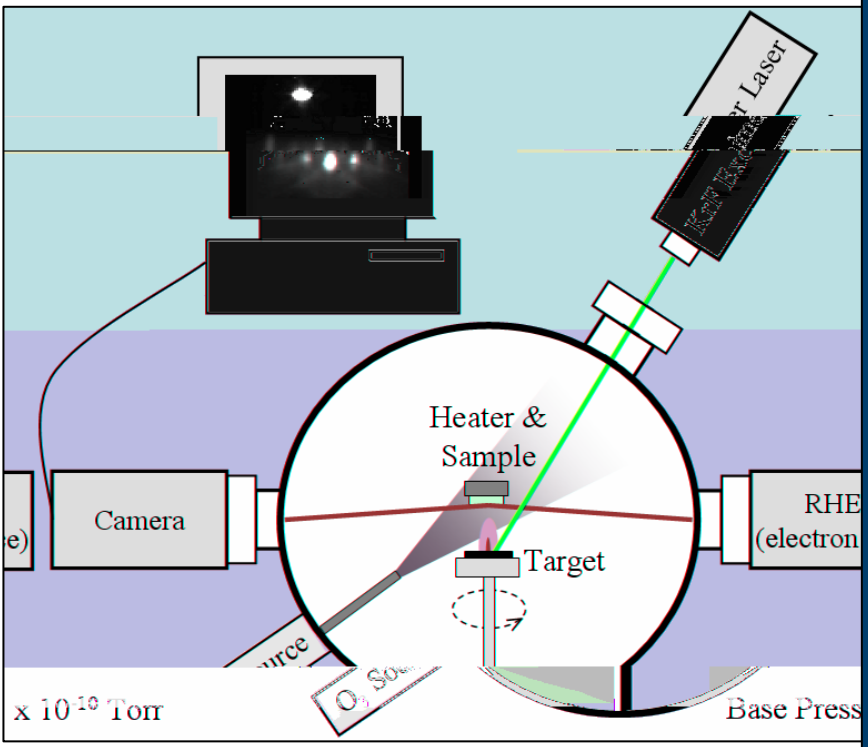
Phys. Rev. Lett. 95, 237210 (05)

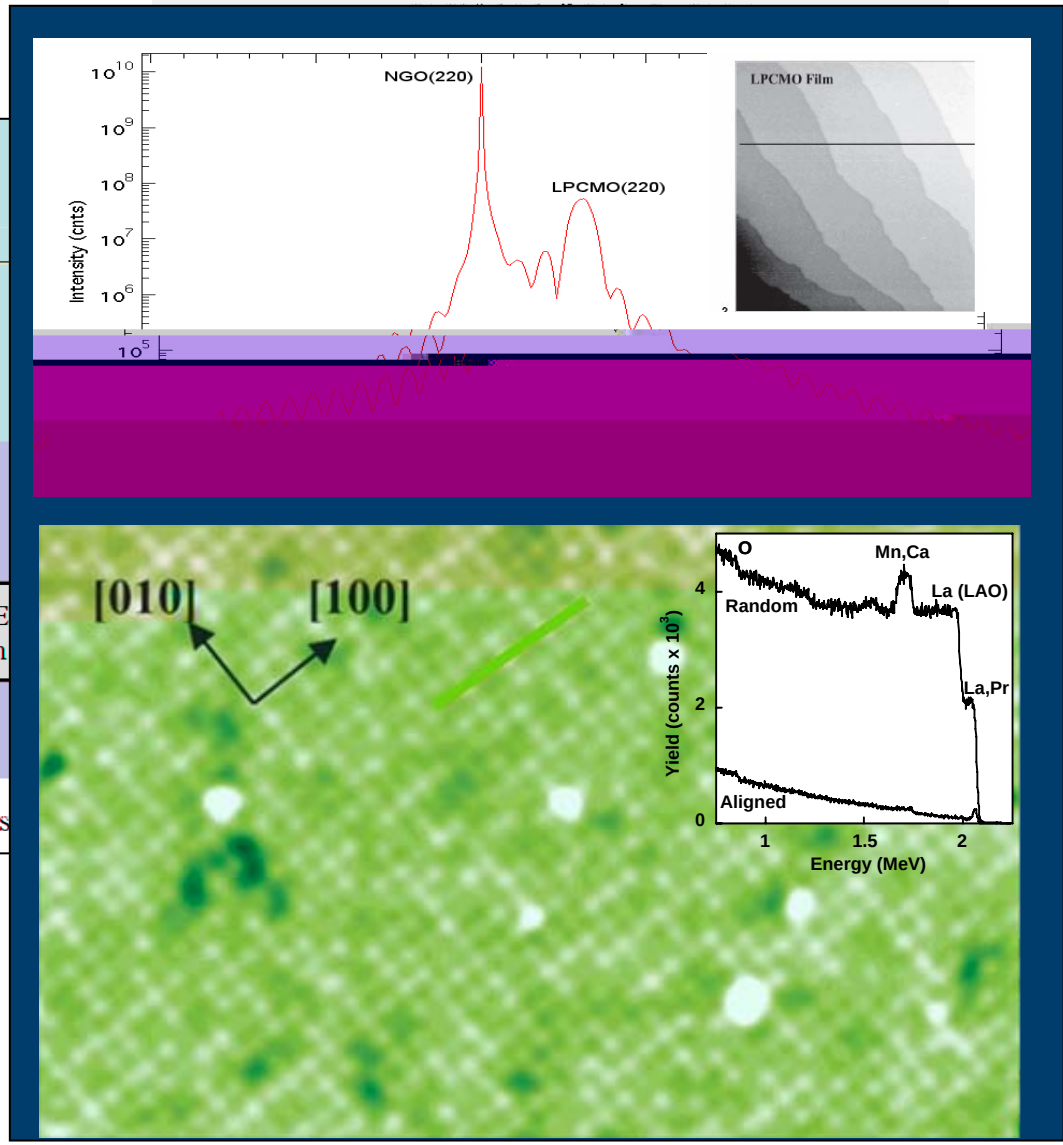
I. **Using spatial confinement to "see" electronic phase separation and their dynamic behavior**

II. **Electronic Nanofabrication**

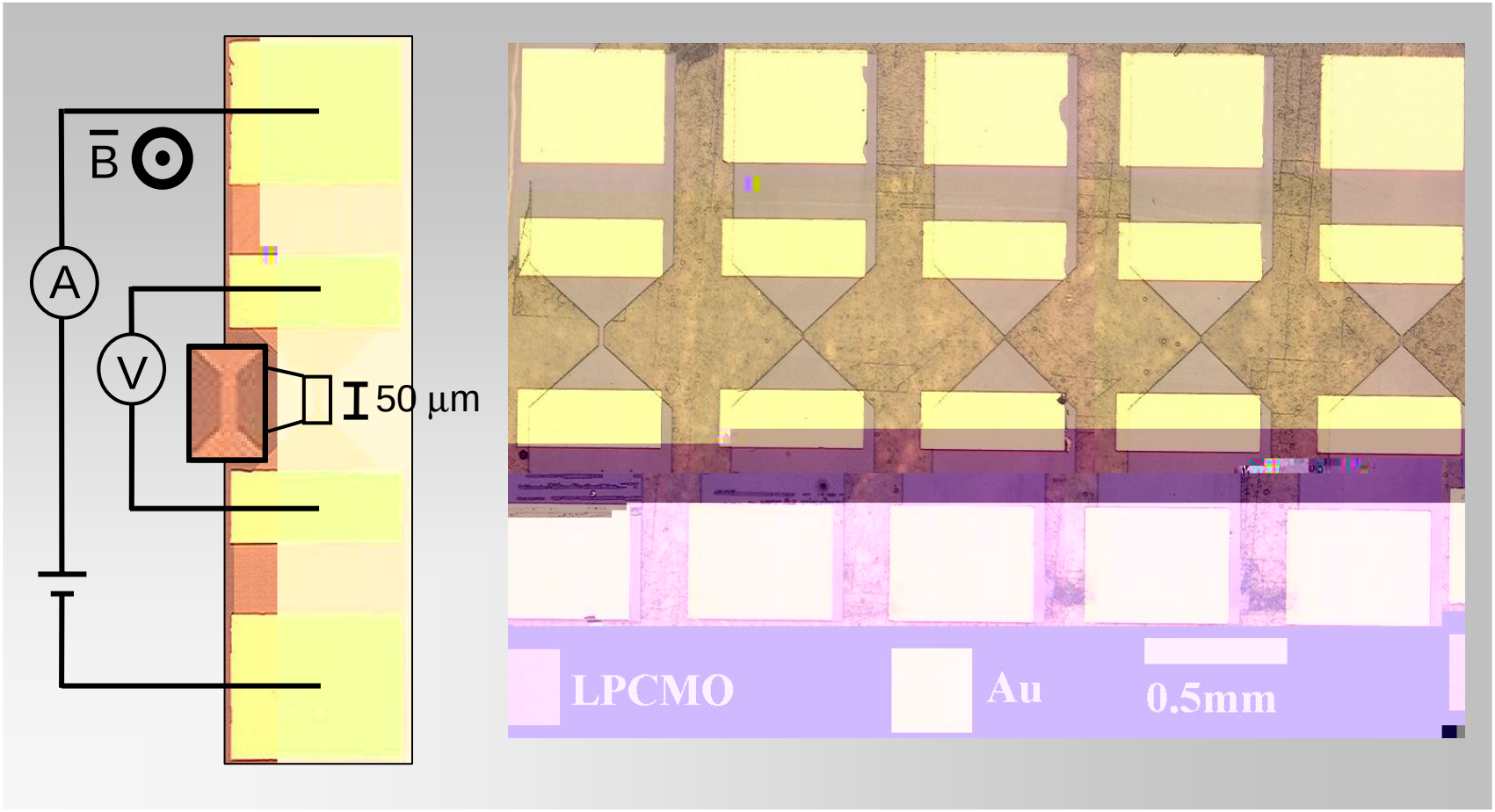
I. Using spatial confinement to “see” electronic phase separation and their dynamic behavior

LPCMO Wire Fabrication Starts from High Quality Thin Film Growth

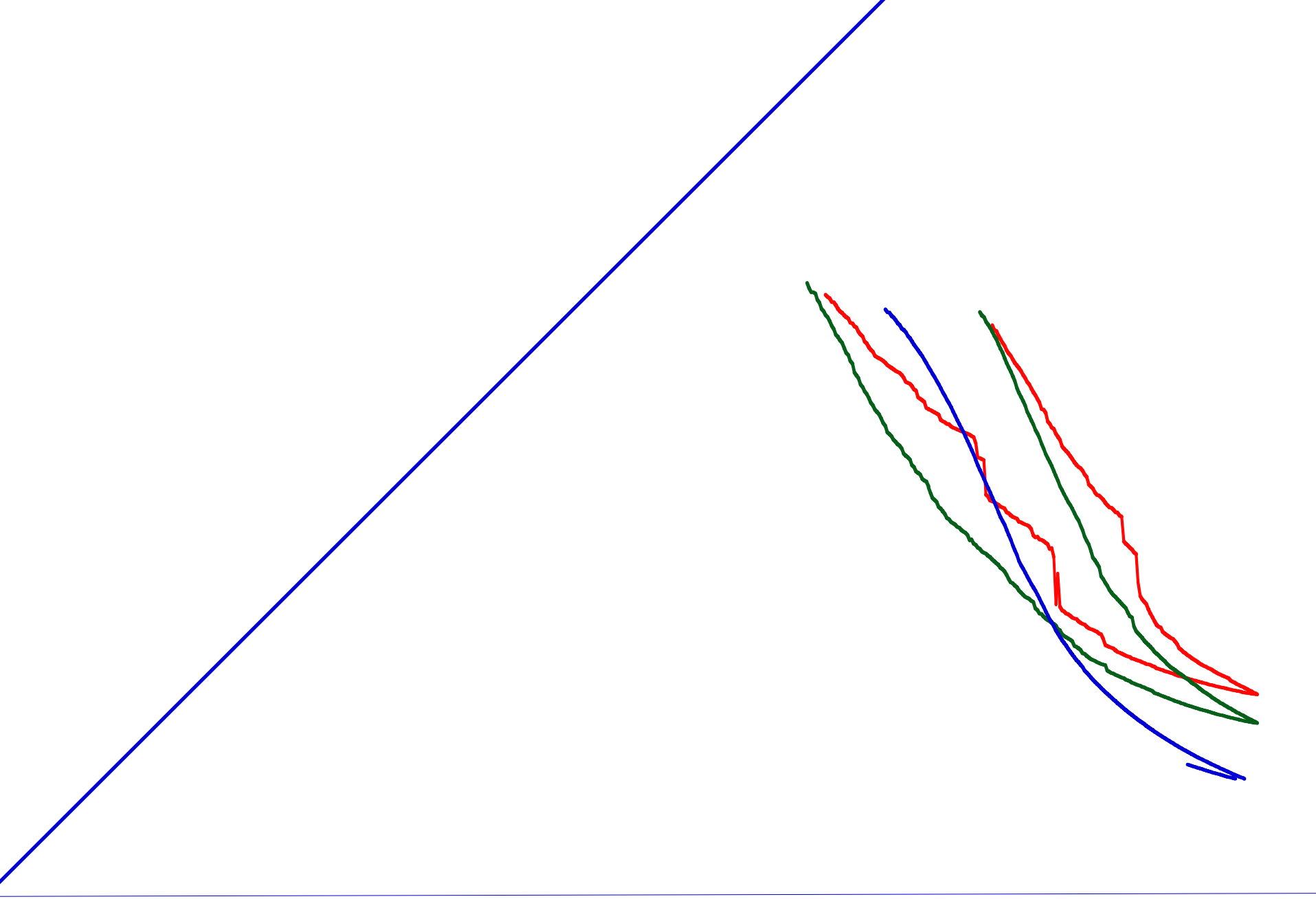




LPCMO Wires

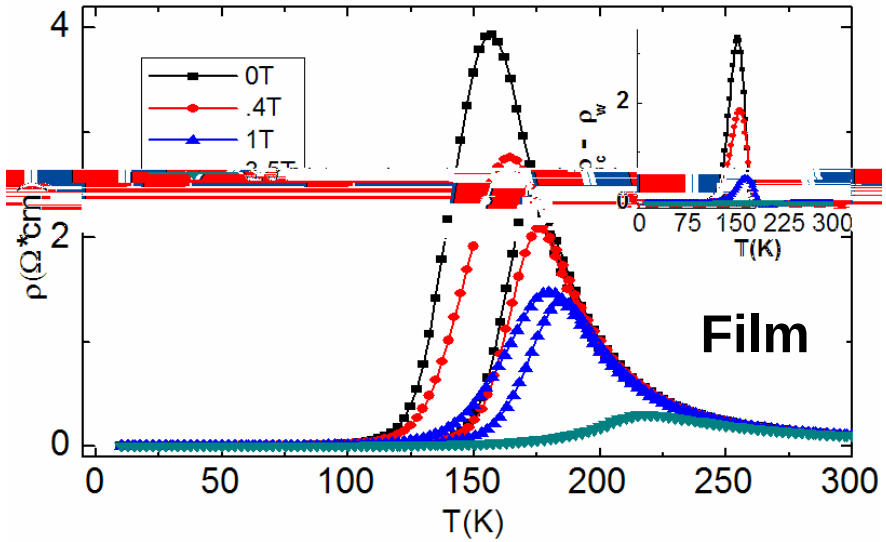


Smallest structure ~ 50 nm

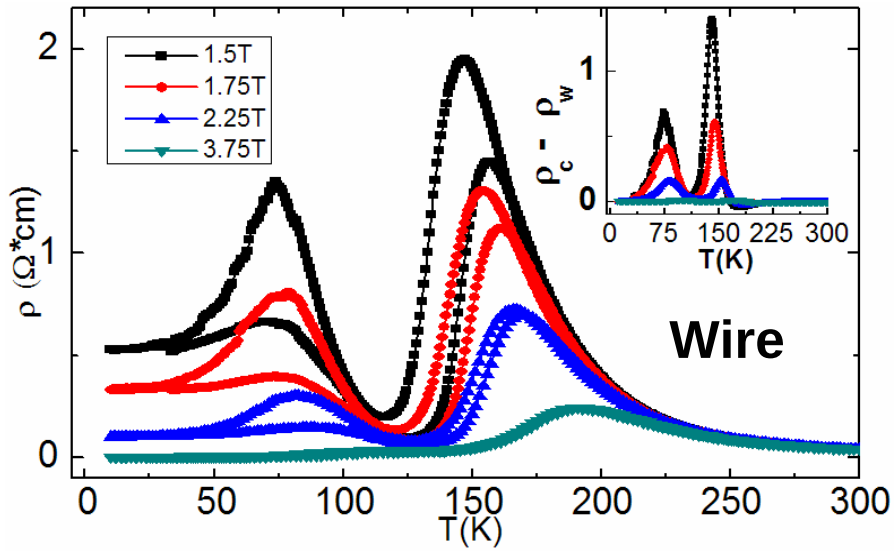


Dramatic Effect of Spatial Confinement

70 nm LPCMO
Film on $SrLaGaO_3$

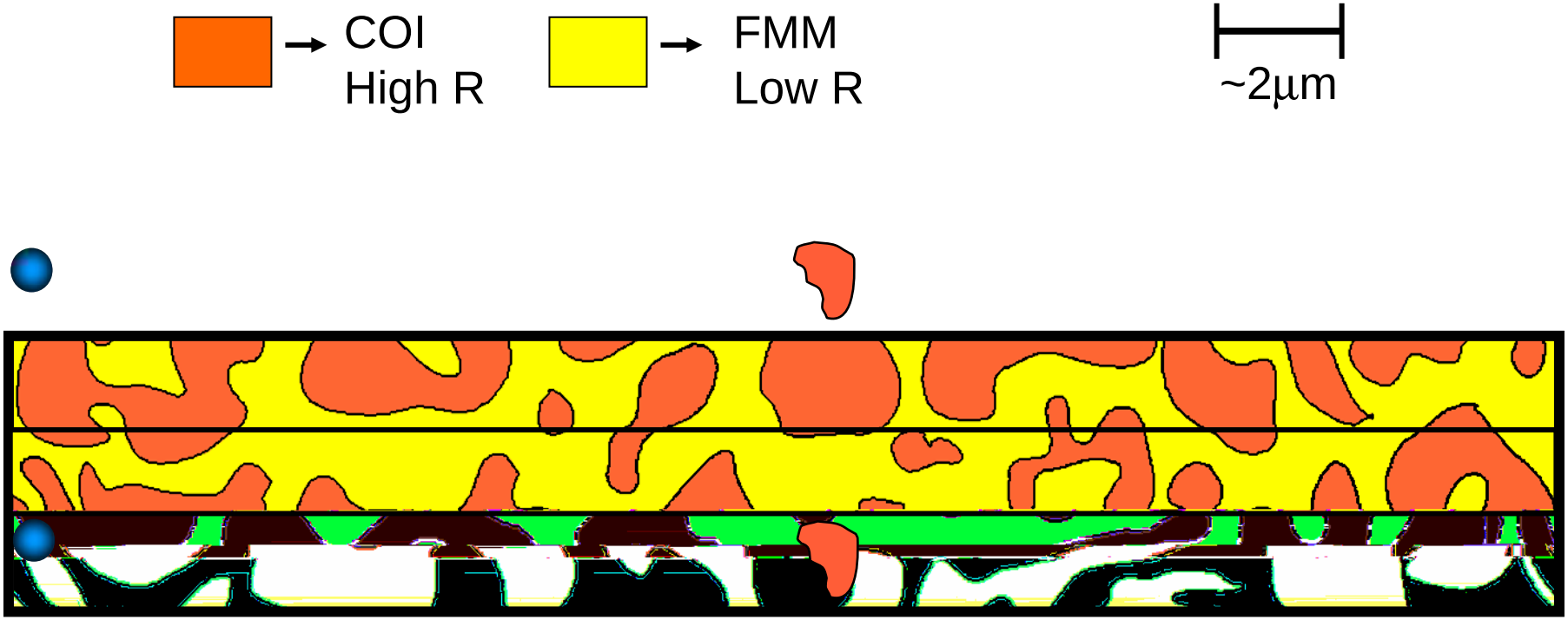


70 nm LPCMO
10μm wires on $SrLaGaO_3$



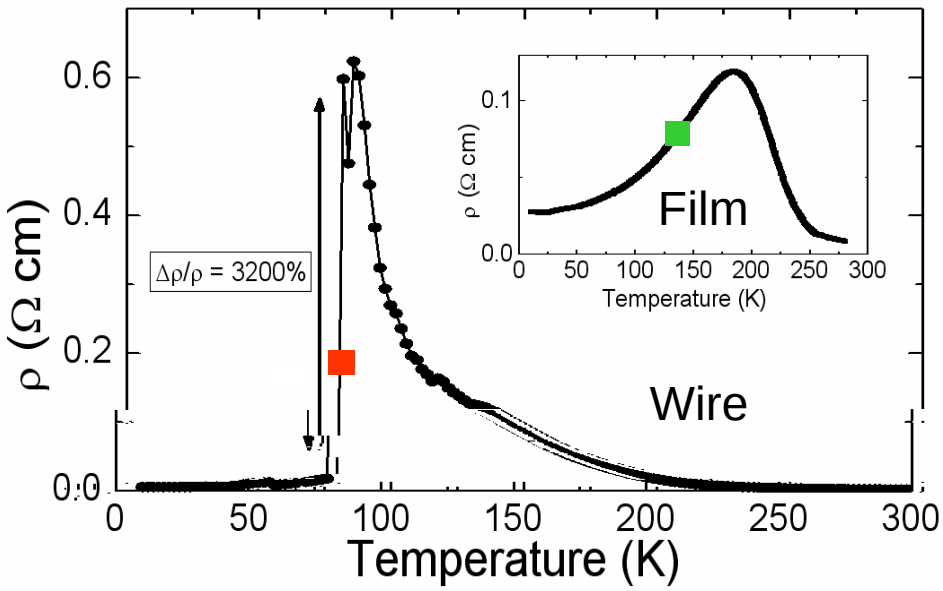
Phys. Rev. Lett. 100, 247204 (2008)

Spatial Confinement Effect of Electronic Phase Separation

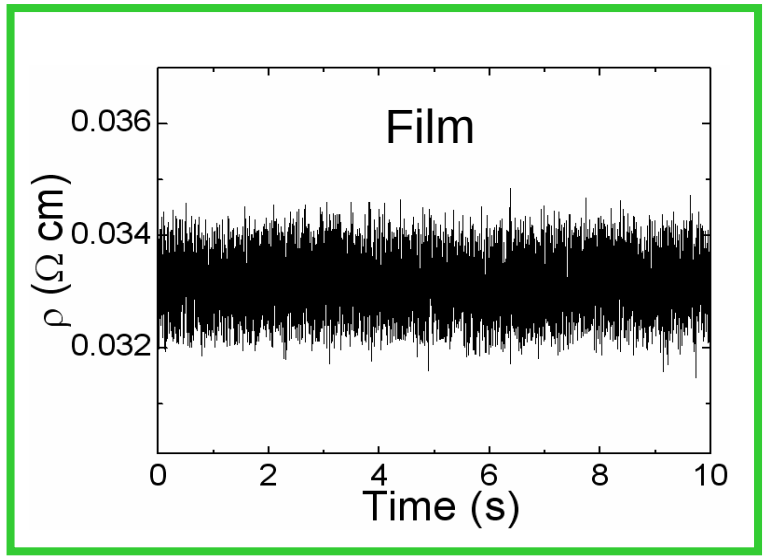


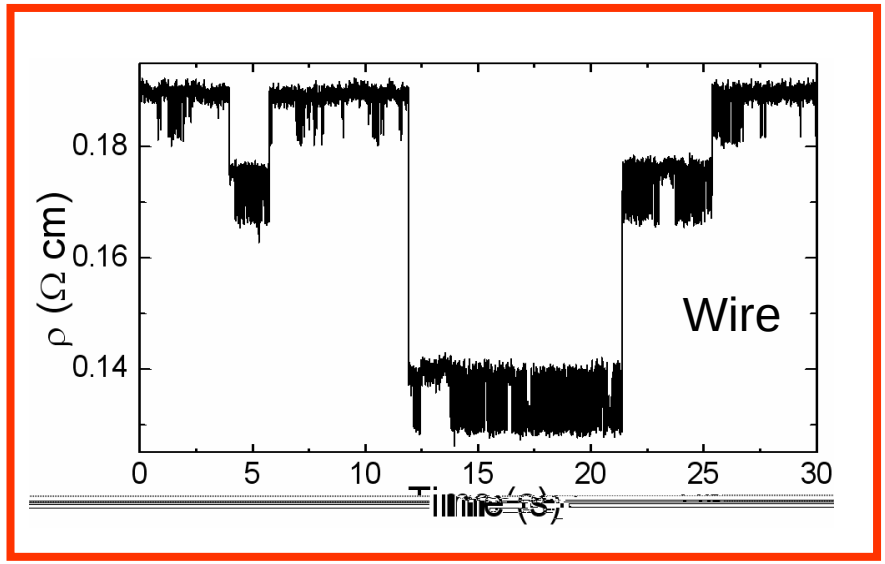
Dynamics of Domain Transitions

Field cooled 3.75 T
warming ρ vs T



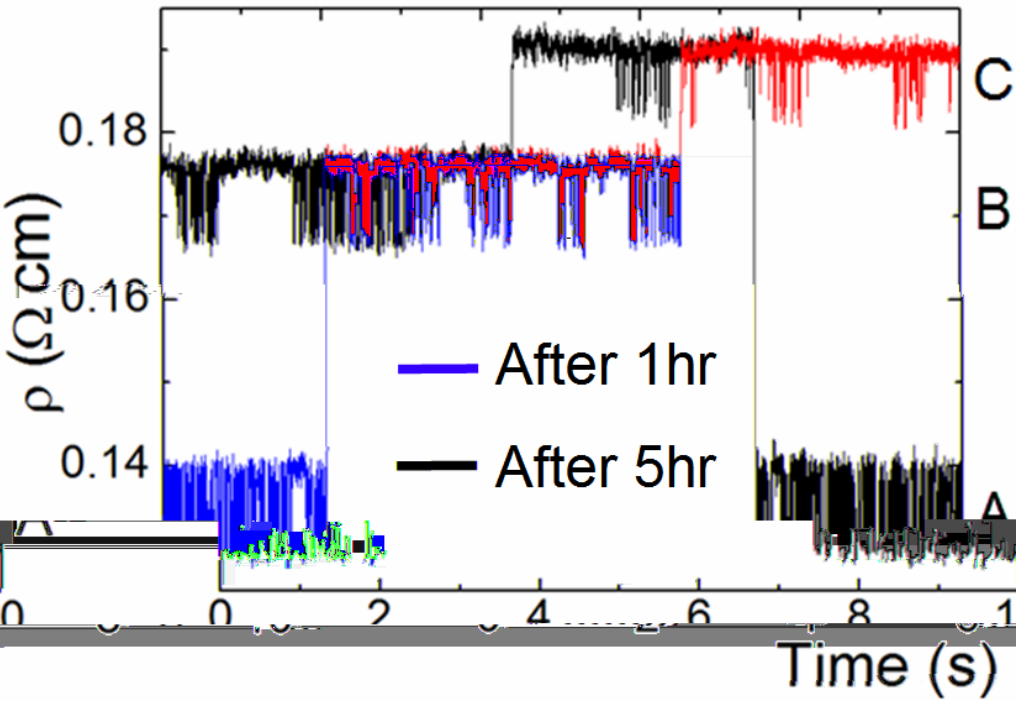
Phys. Rev. Lett. **102**, 087201 (2009)

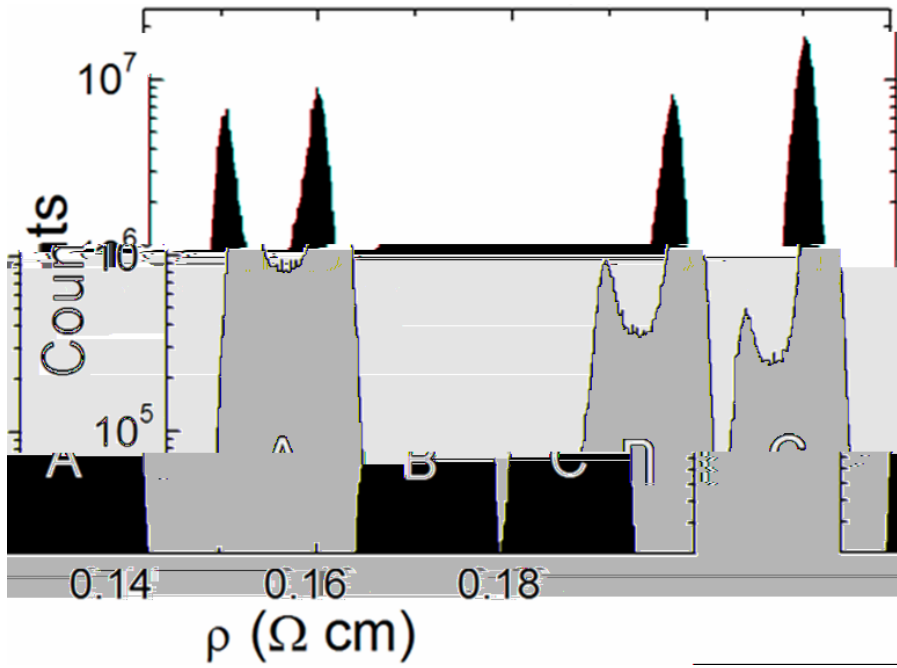




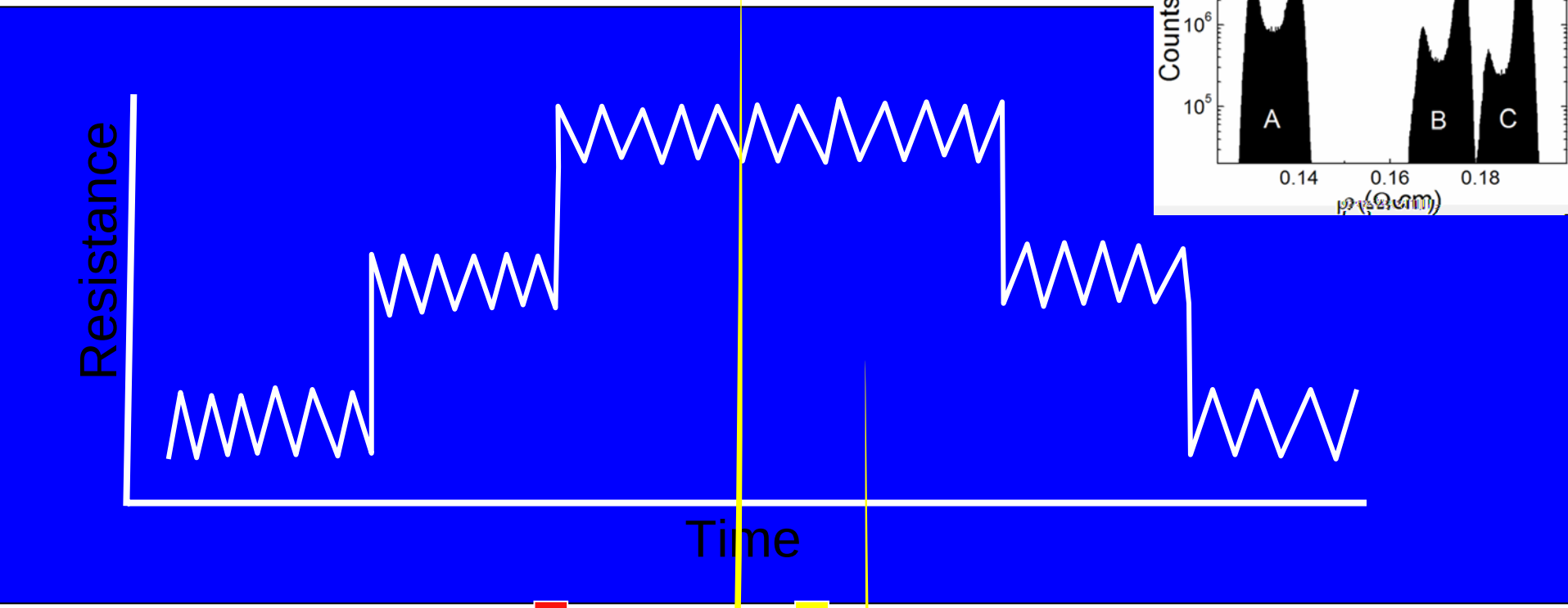
Phase Transition Dynamics

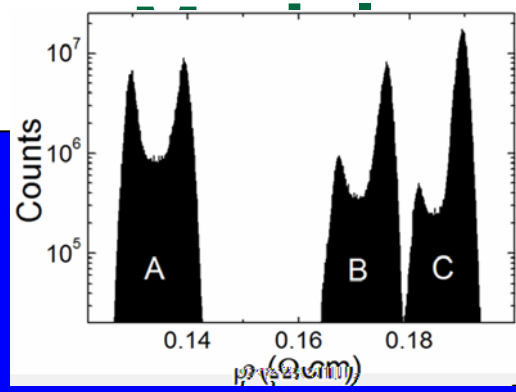
Binned data for 6 hours

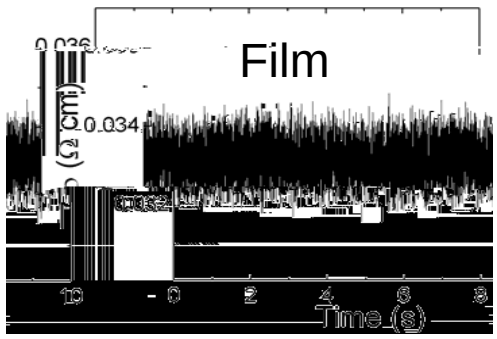


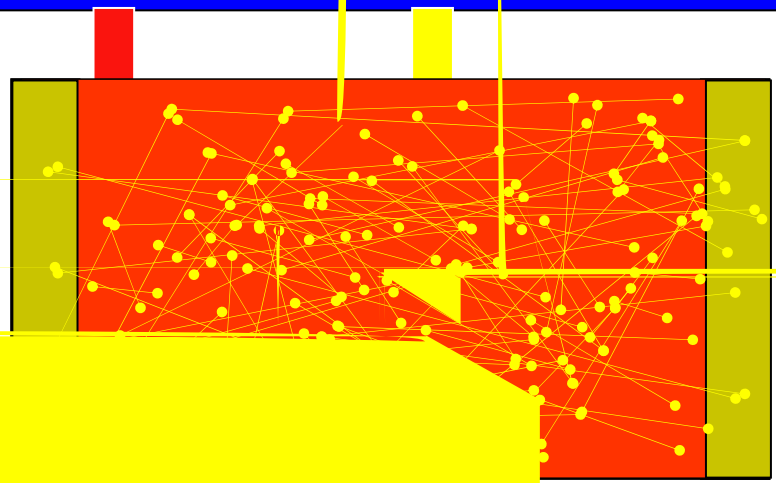


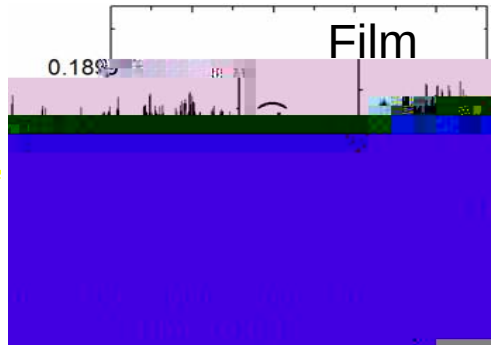
Percolative Switching Network



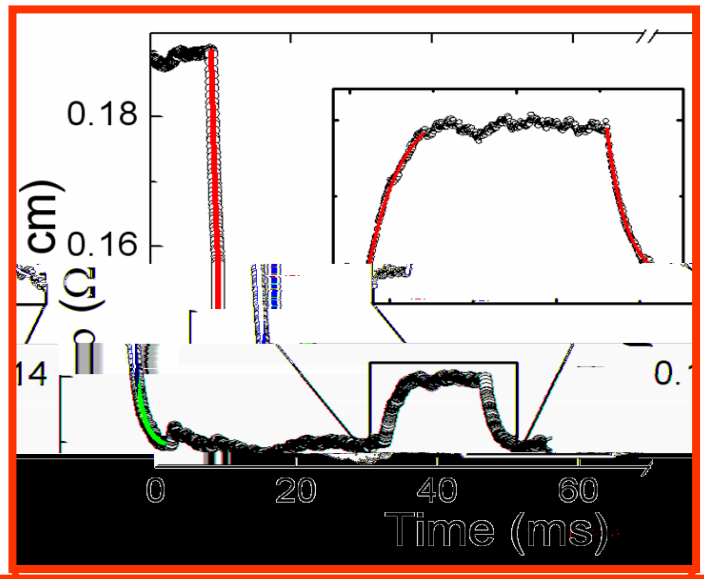


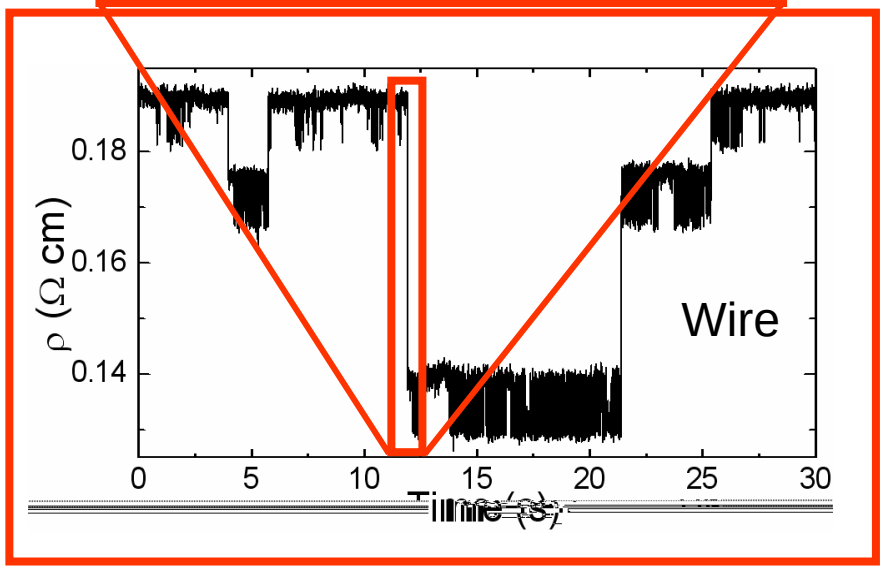




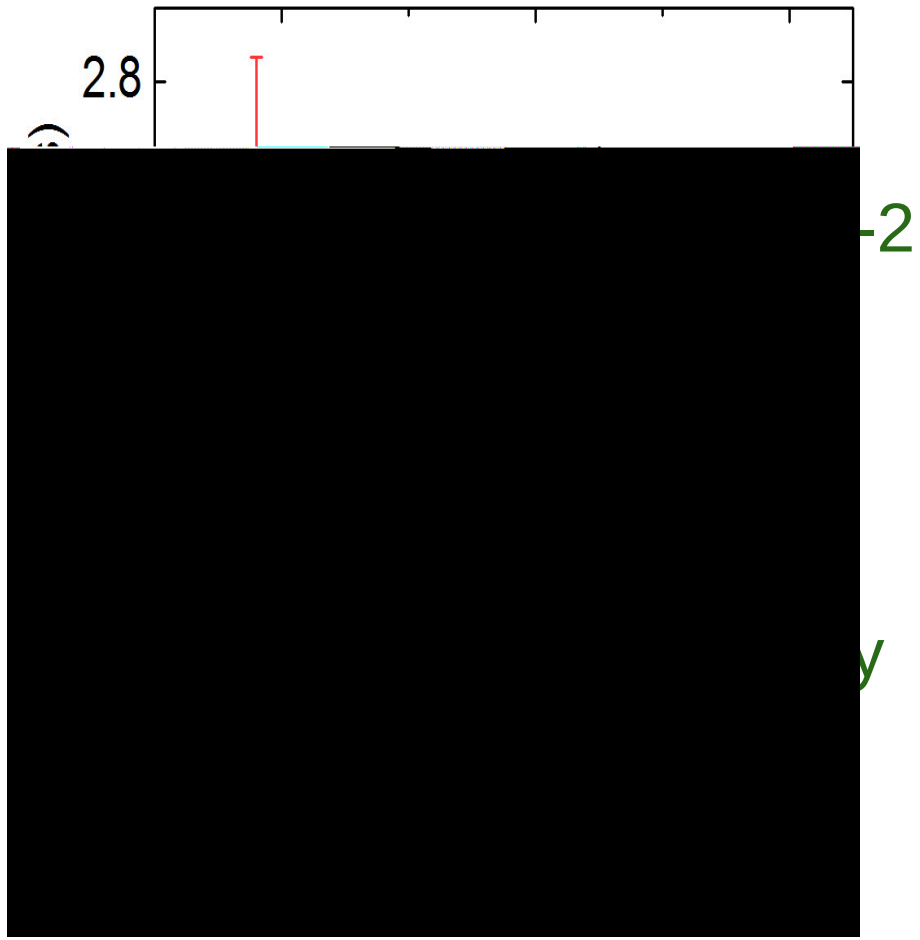


Time Scale of FM - COI Transition



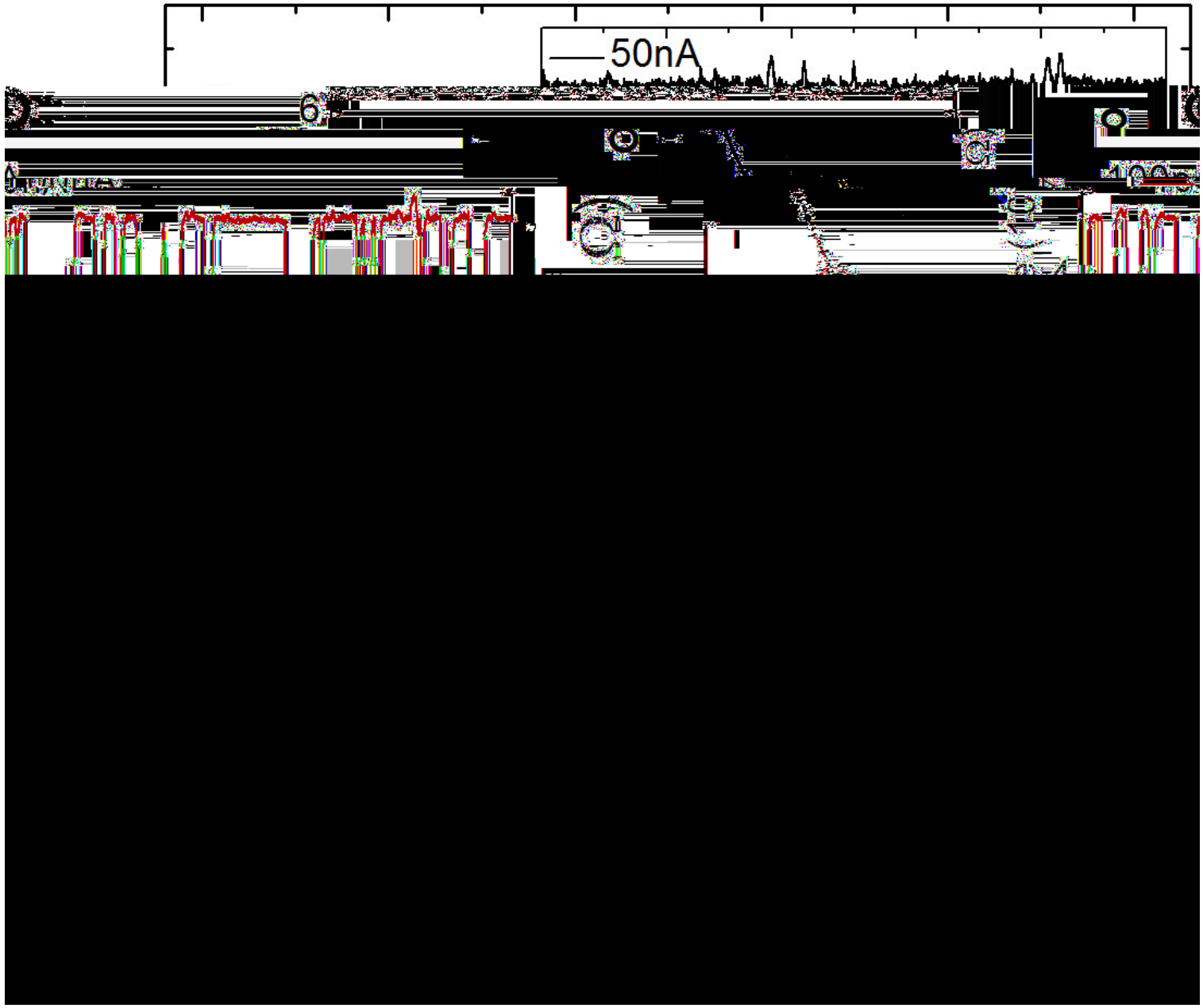


$y = A*e^{-t/\tau}$, τ = lifetime

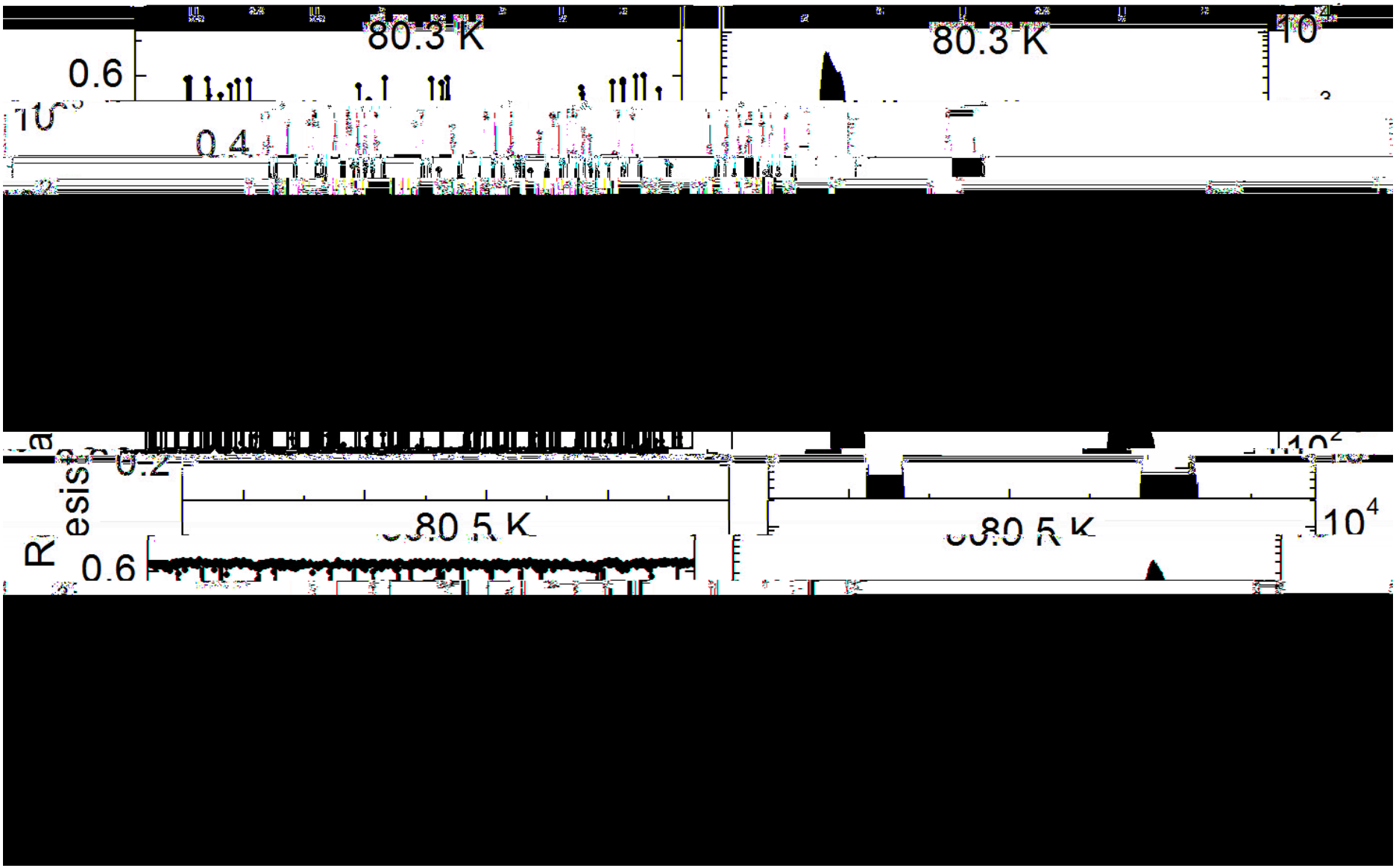


PRB 83, 125125 (2011)

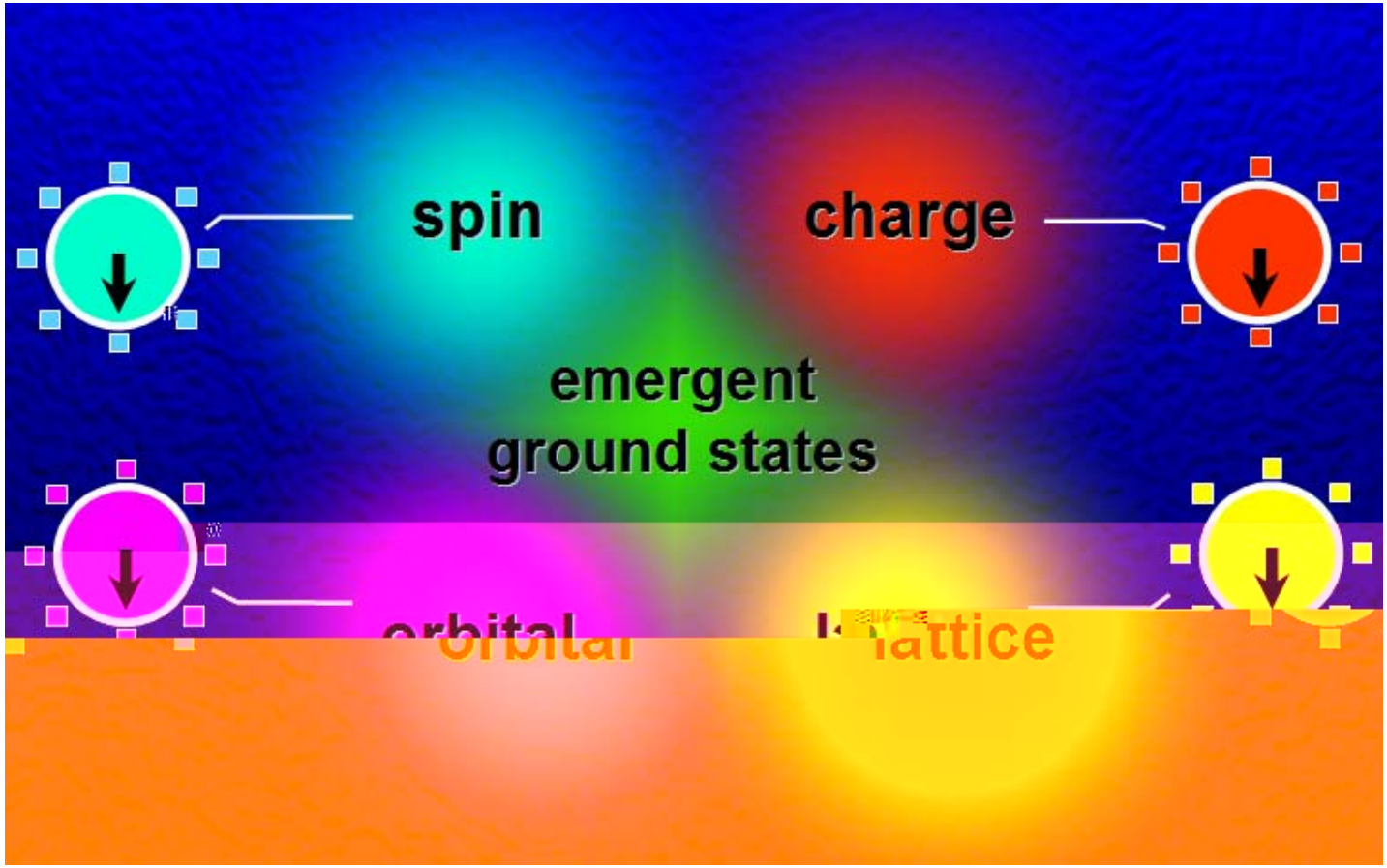
Effect of Measuring Current



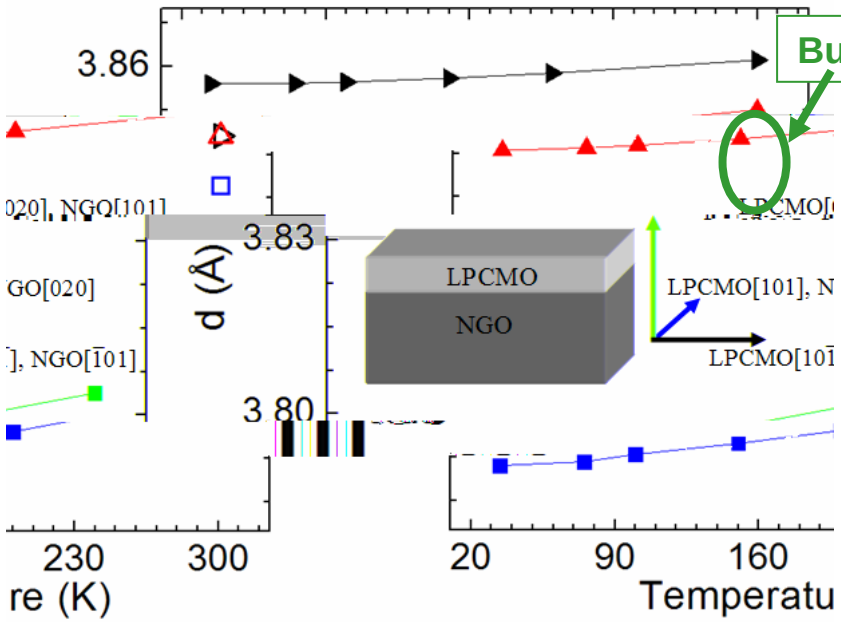
Effect of Measuring Temperature

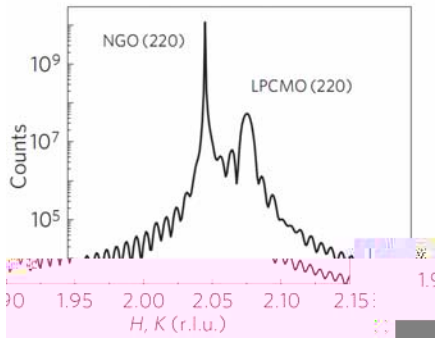


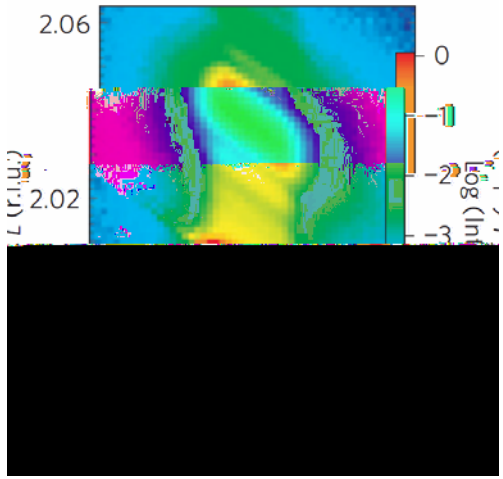
II. Electronic Nanofabrication



Application of Anisotropic Strain Field in LPCMO Films





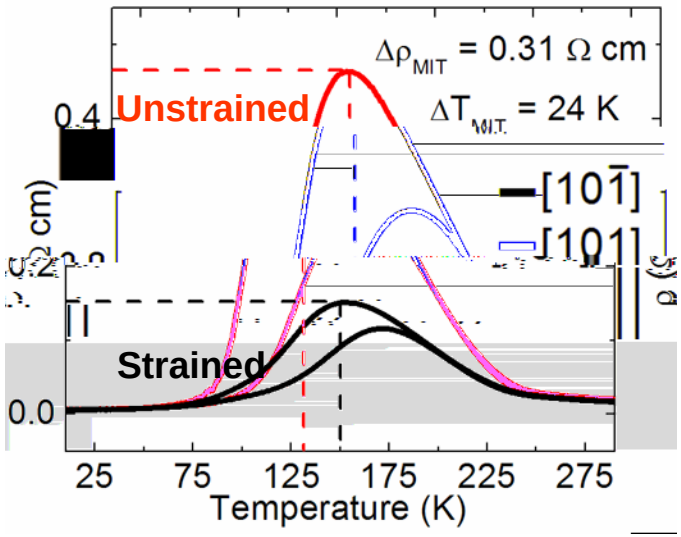


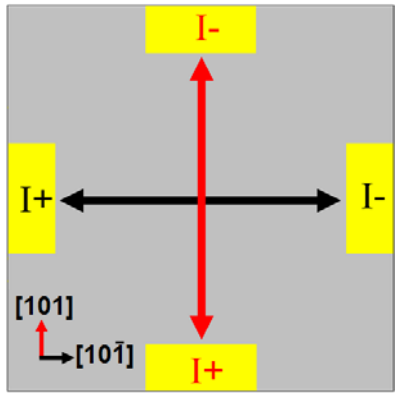
- Pseudo-cubic film locked to orthorhombic NdGaO3 (110) substrate
- Drives in-plane anisotropic strain field

- Film and Substrate commensurate across full temperature spectrum

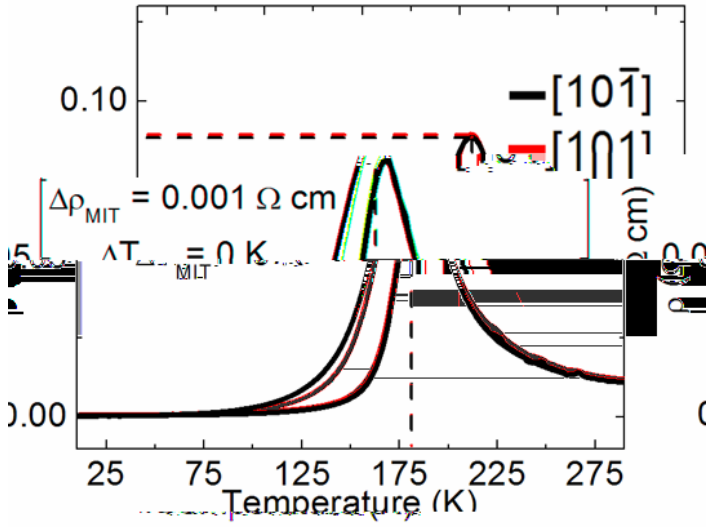
Strain Field Effects on Transport

Anisotropic Strain





Isotropic Strain



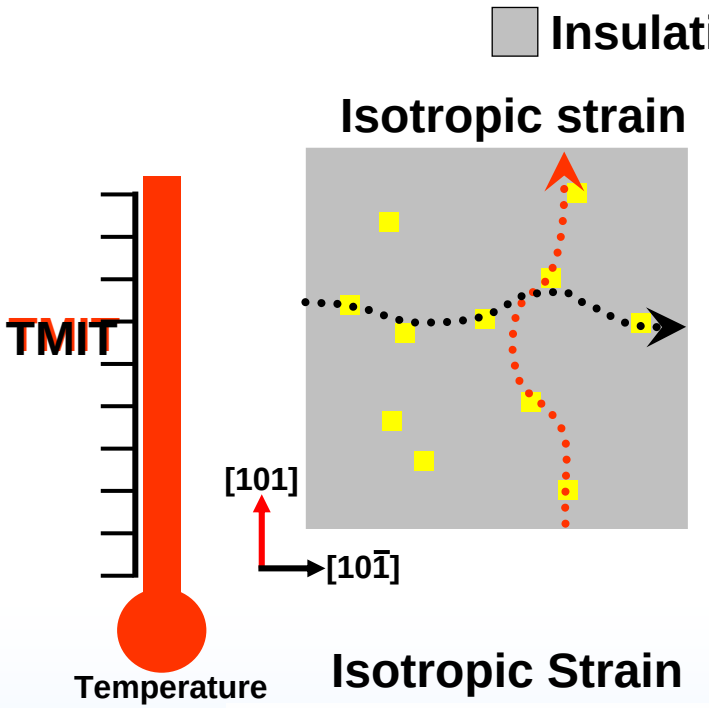
50nm LPCMO on NGO

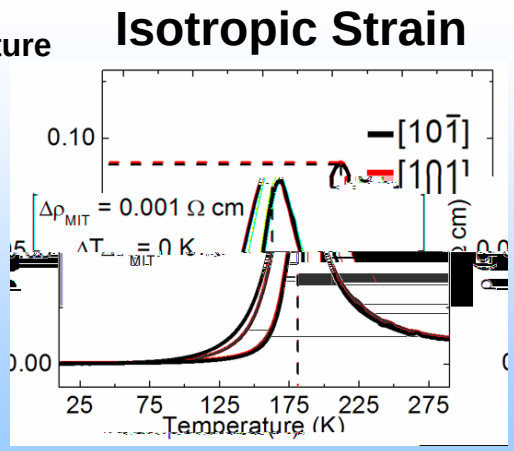
50nm LPCMO on SrLaGaO3

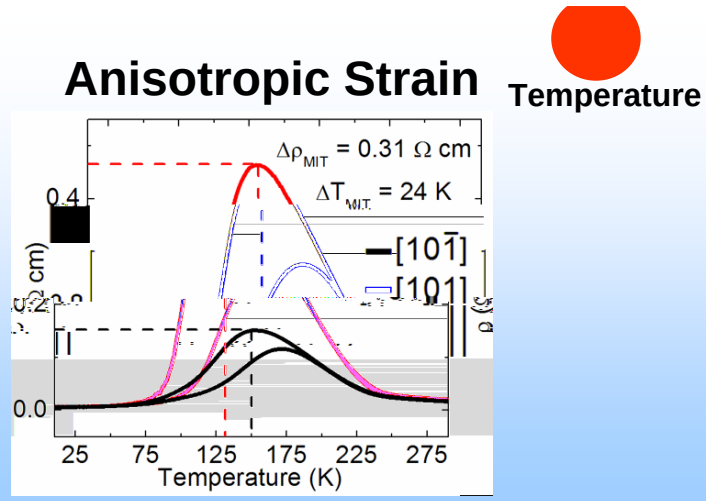
Nature Phys. 5, 885 (2009)

Anisotropic Percolation Model

Insulating Metallic

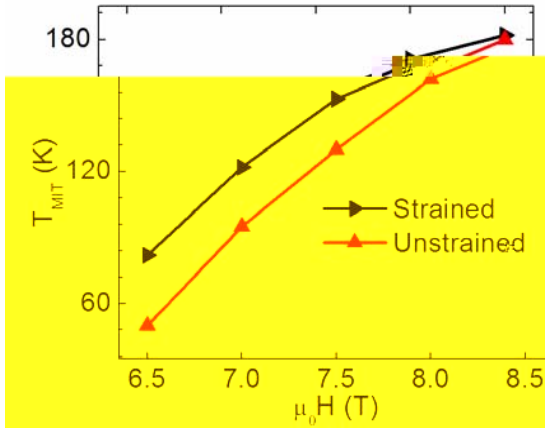




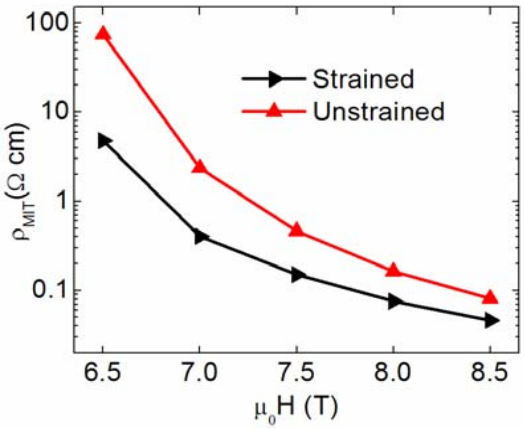


Magnetic Field Effects

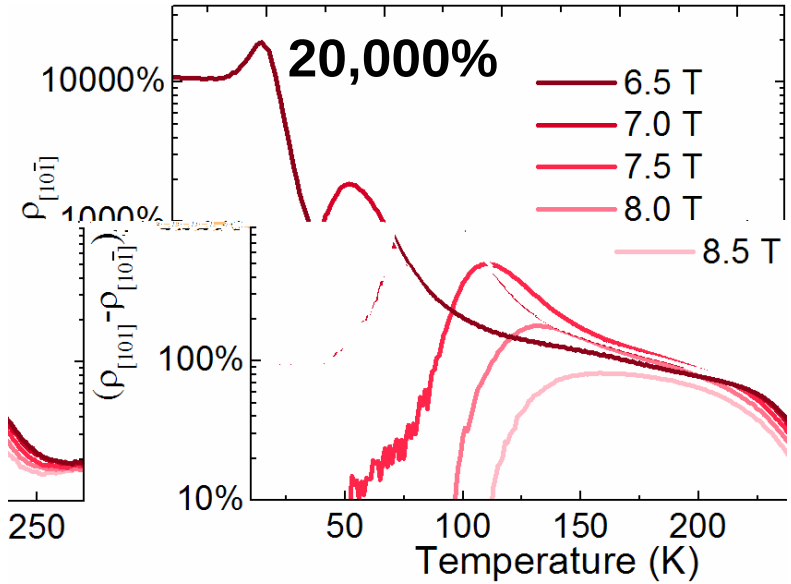
Metal-insulator transition temperature



Resistivity at metal-insulator transition

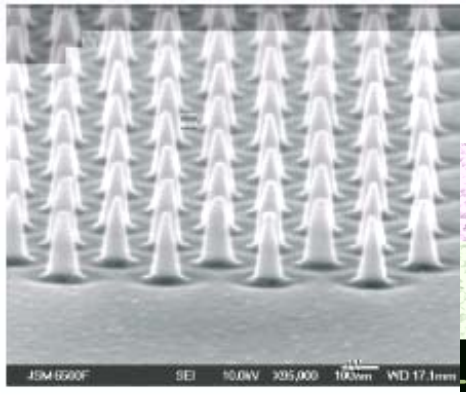


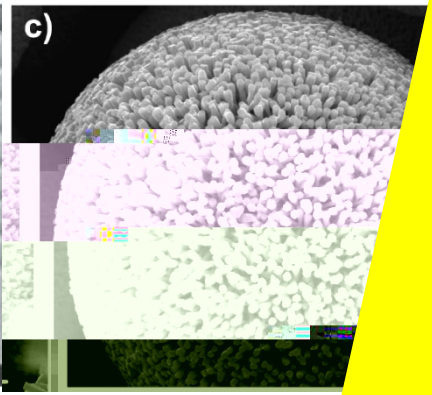
Difference in ρ along two in-plane directions

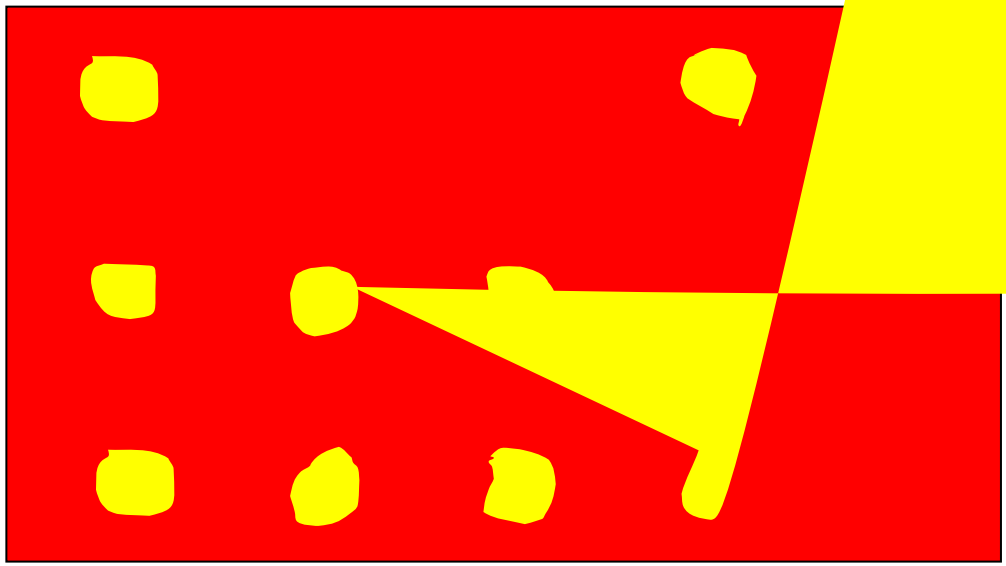


- **High B-field melts insulating phase and leads to isotropic behavior**
- **Low B-field shows strong anisotropic resistivity of over 20,000%**

Electronic Nano

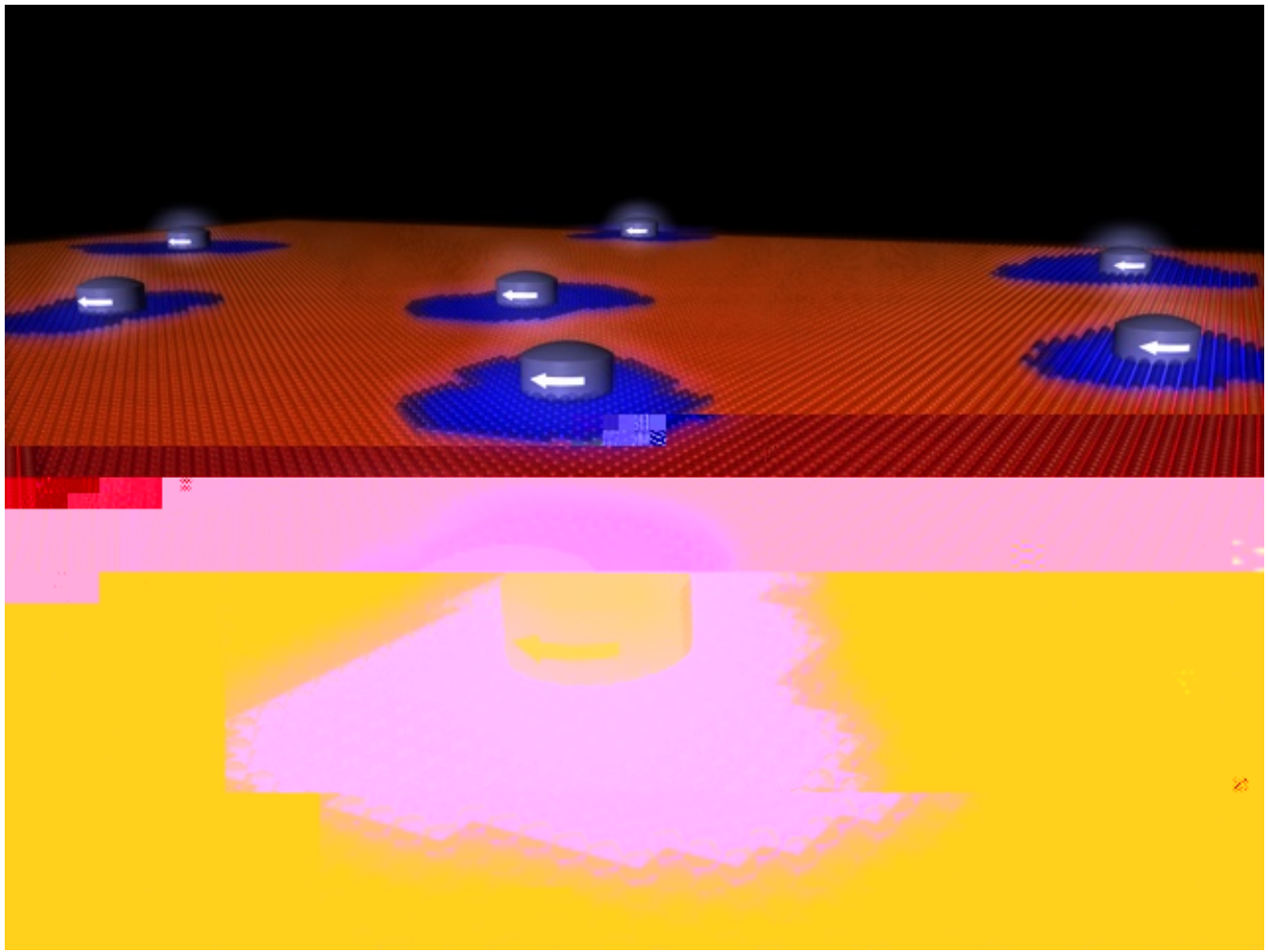




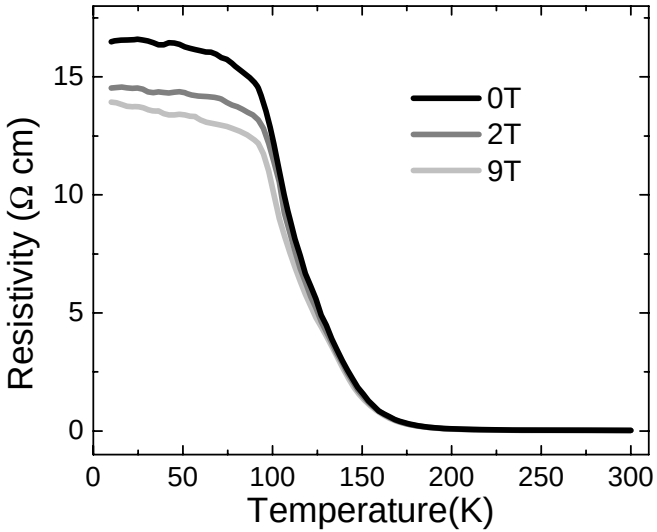


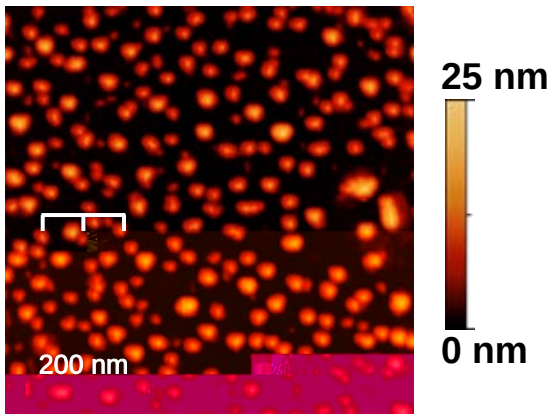
Electronic

Application of Local Magnetic Fields on Manganites Thin Films

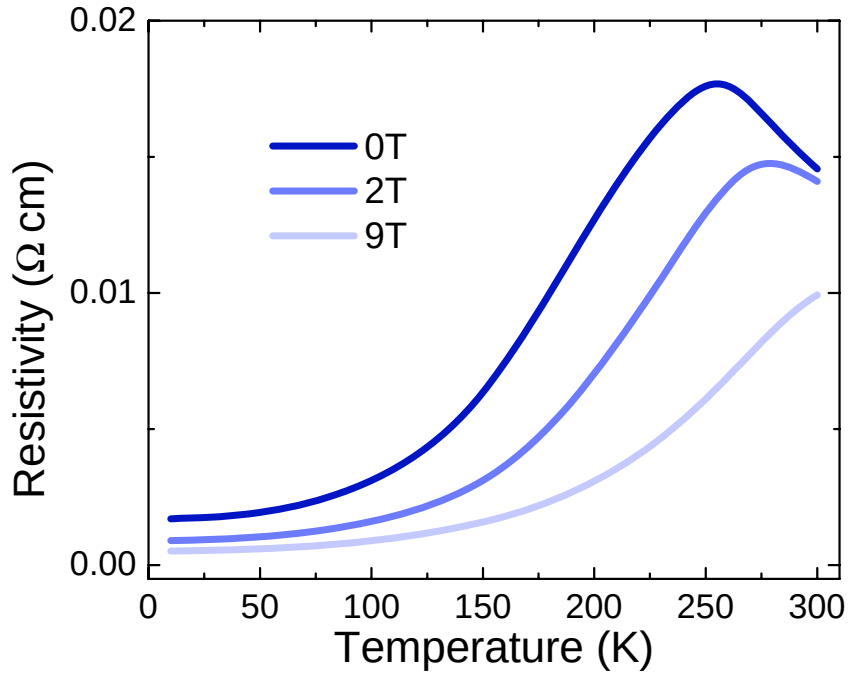


Fe Nanodots on 20nm $La_{0.7}Ca_{0.3}MnO_3$ Thin Film Grown on $LaAlO_3(001)$

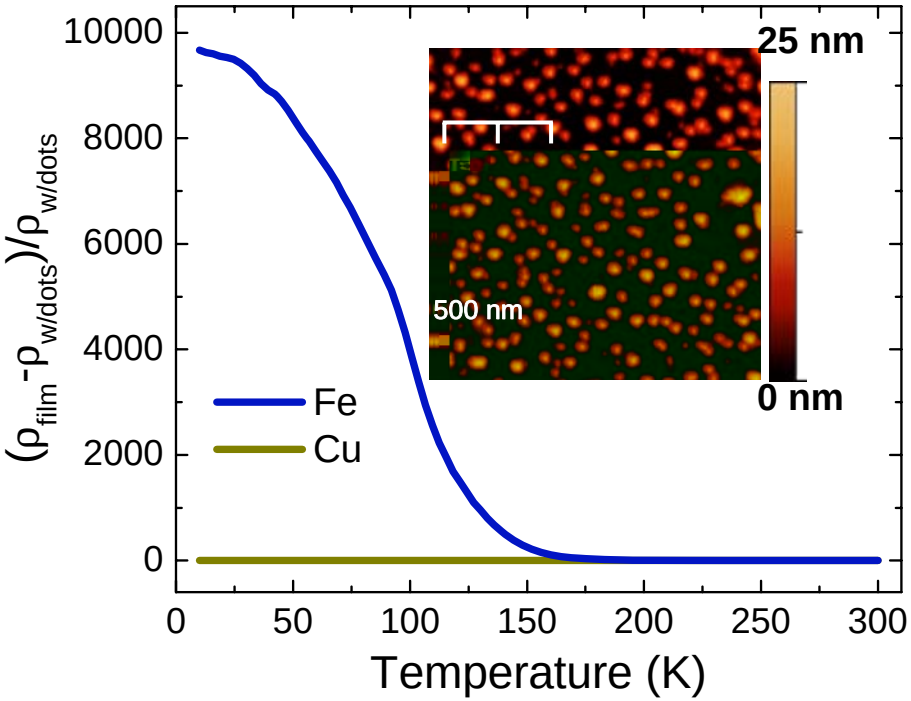


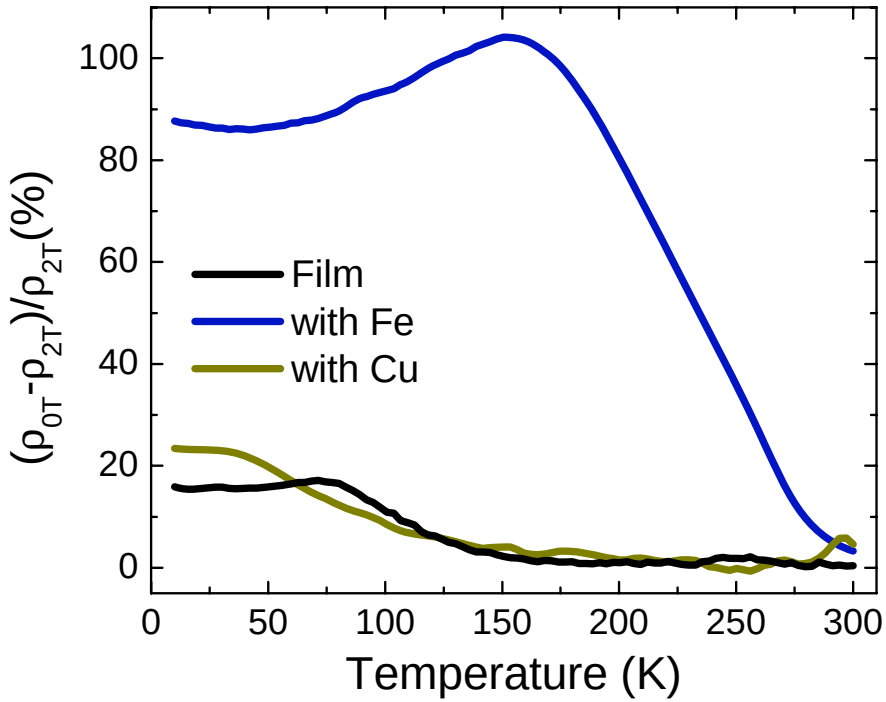


- **20nm thin film of LCMO is an insulator**
- **Ferromagnetic Fe nanodots grown on surface**
- **Becomes metallic with high MIT temperature**



Nonmagnetic Nanodots Have No Effect

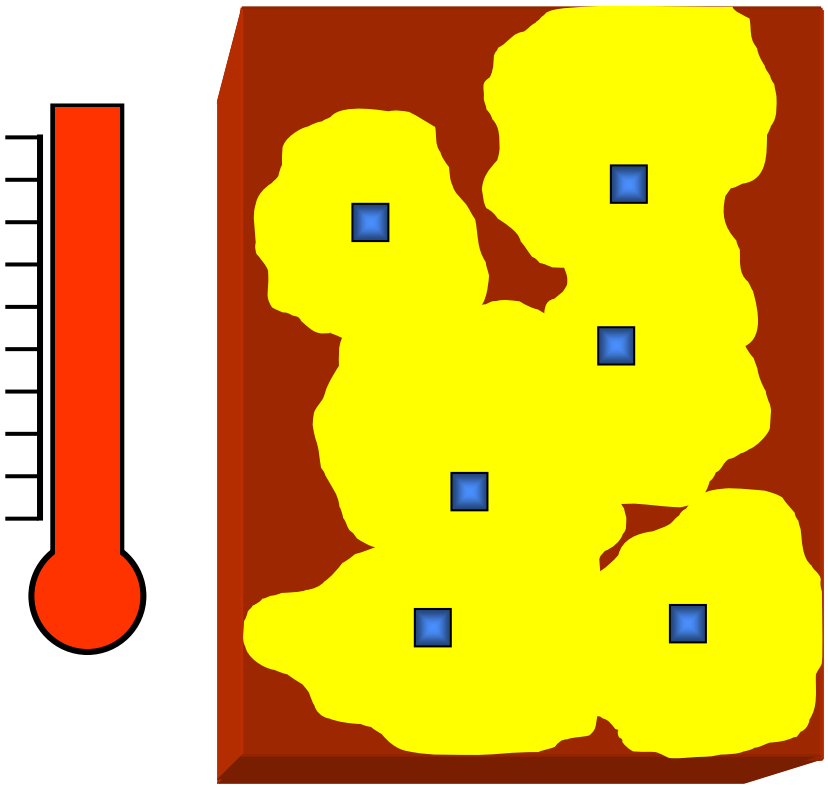


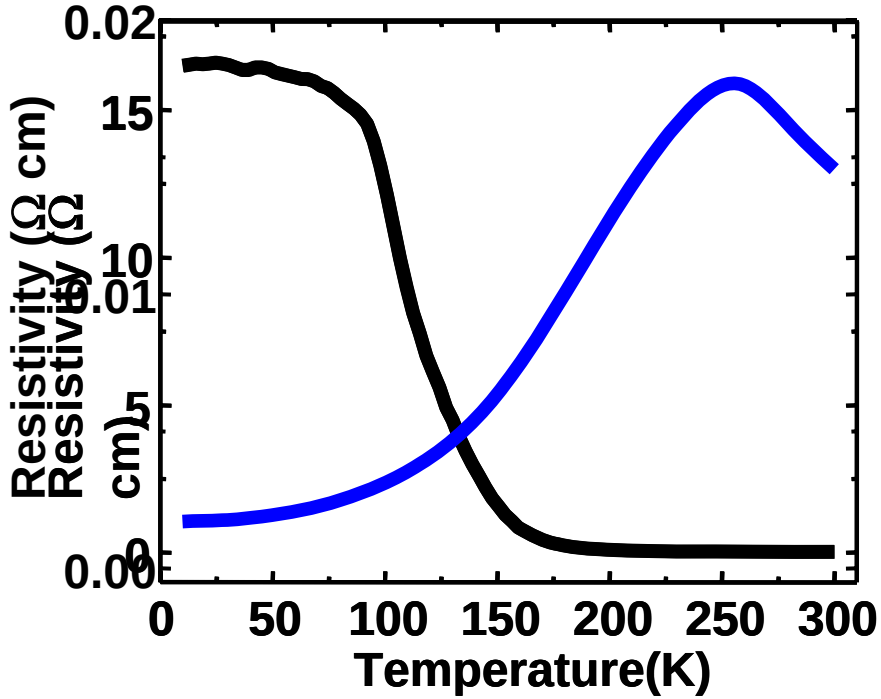


Add non-magnetic metallic Cu nanodots for comparison

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

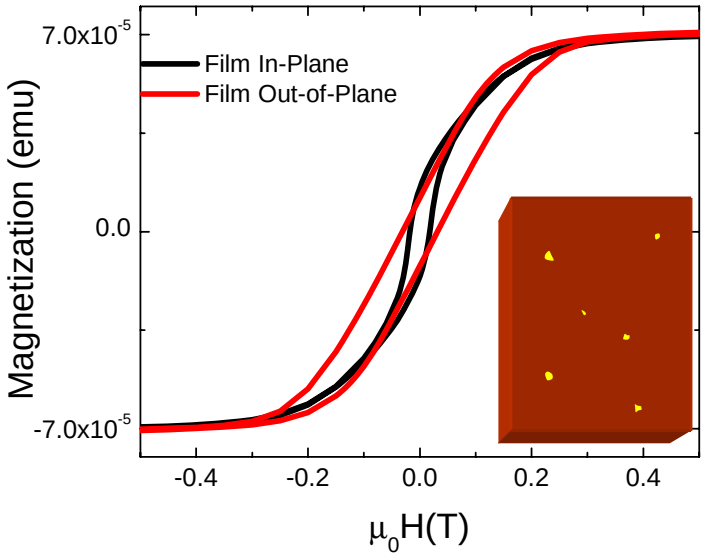
Effect of Magnetic Nanodots induced Local Exchange Field

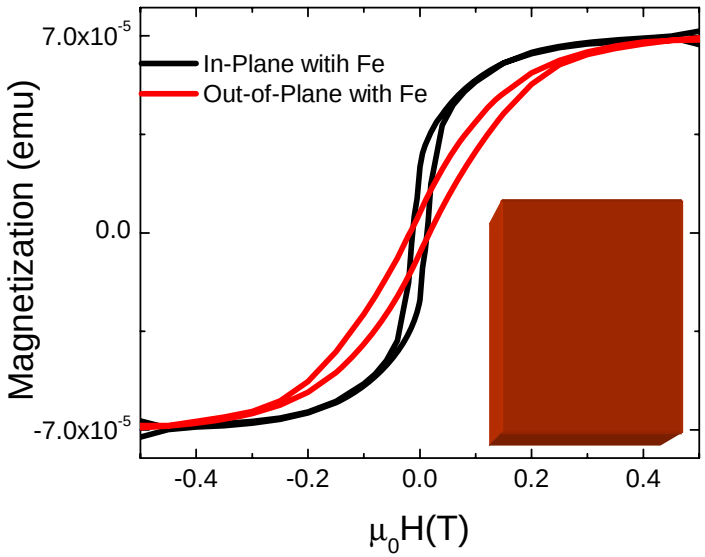


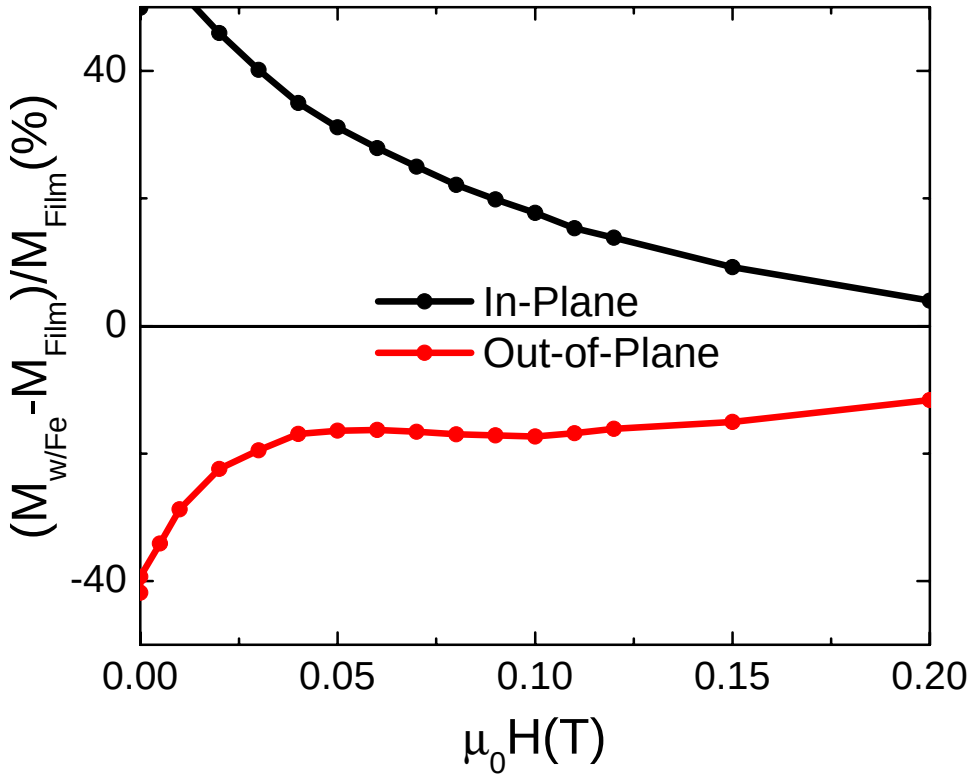


LCMO
film

Direct Evidence of Exchange Coupling between Fe and LCMO Film

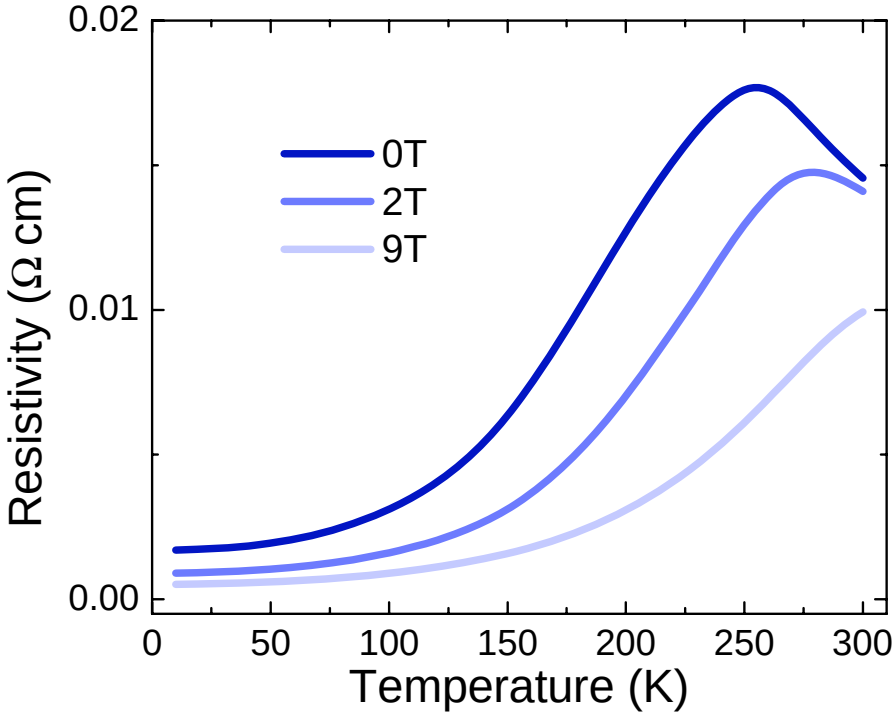


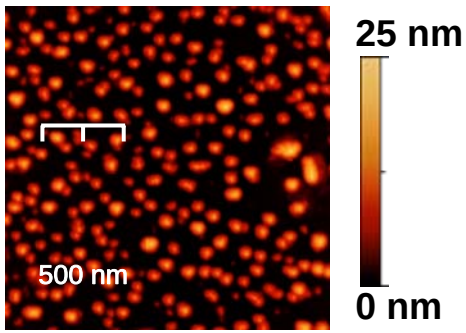




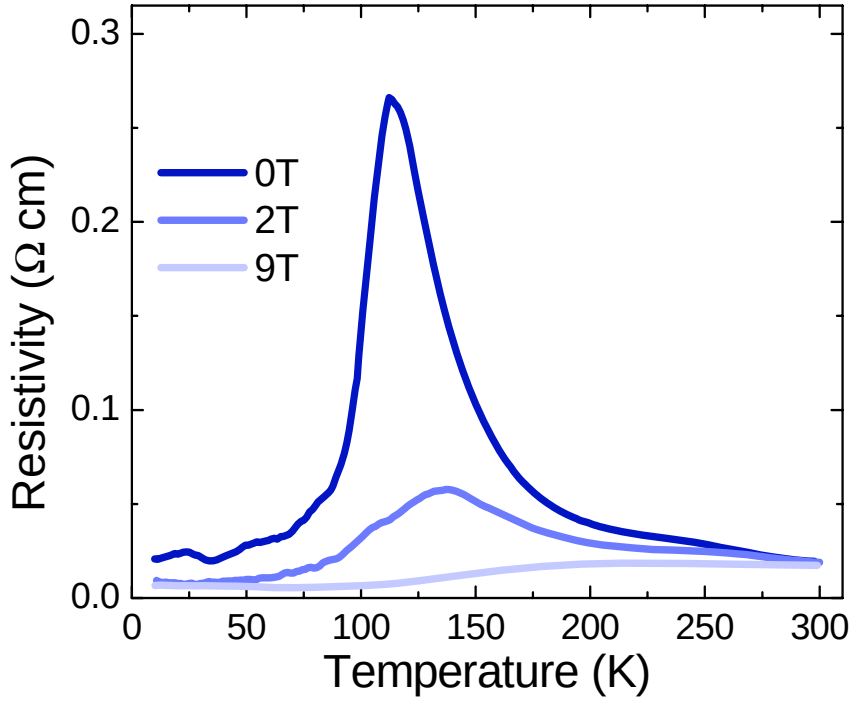
A Tunable Metal-Insulator Transition

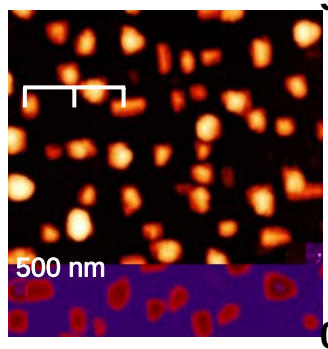
High Density





Low Density





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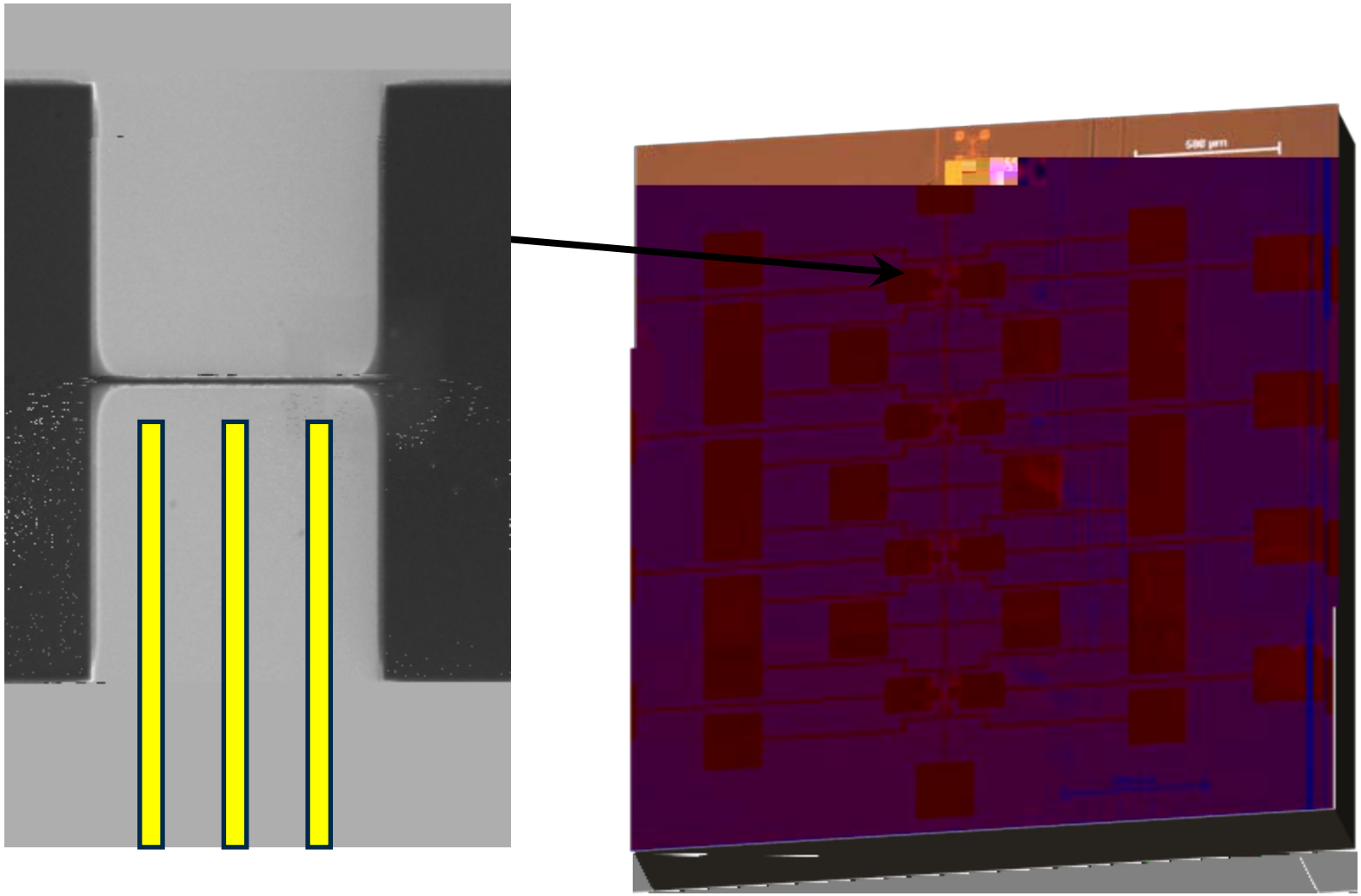
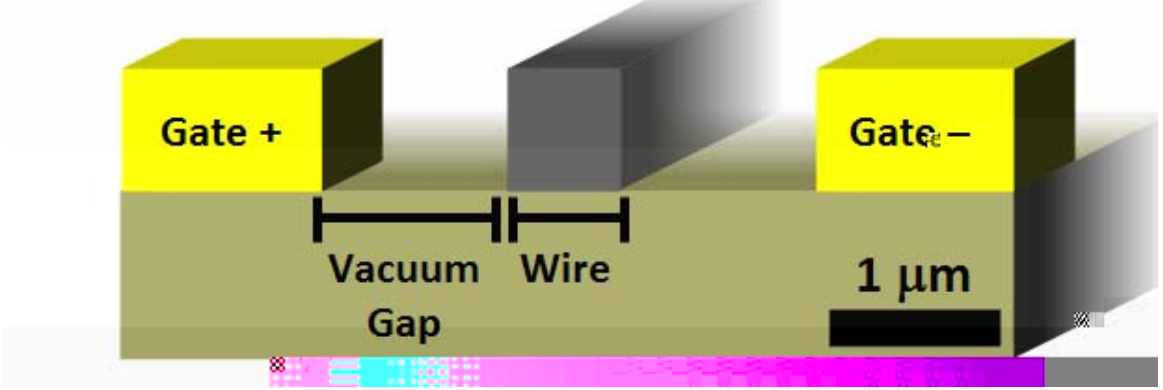
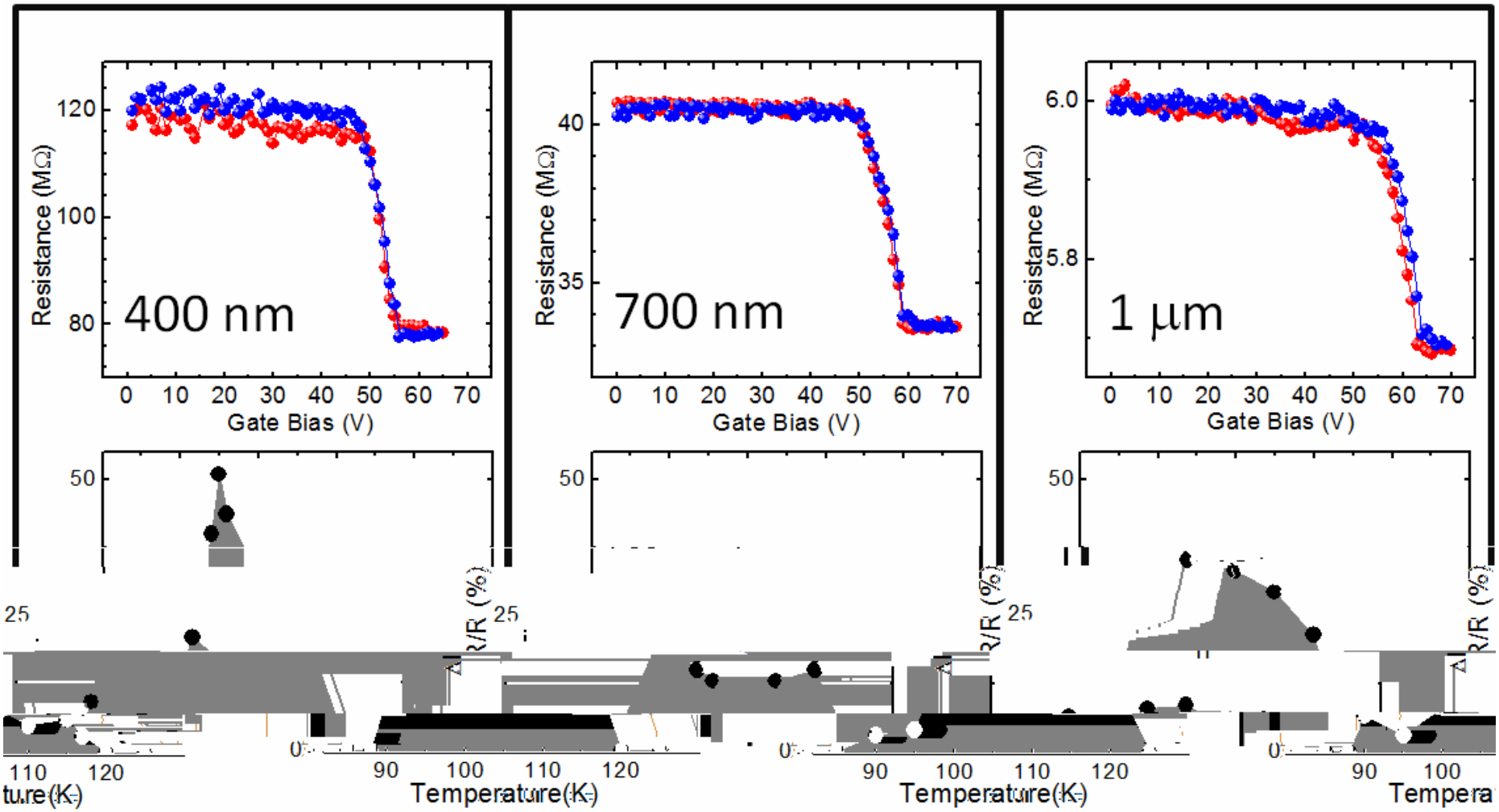
Patterned Local Electric Field

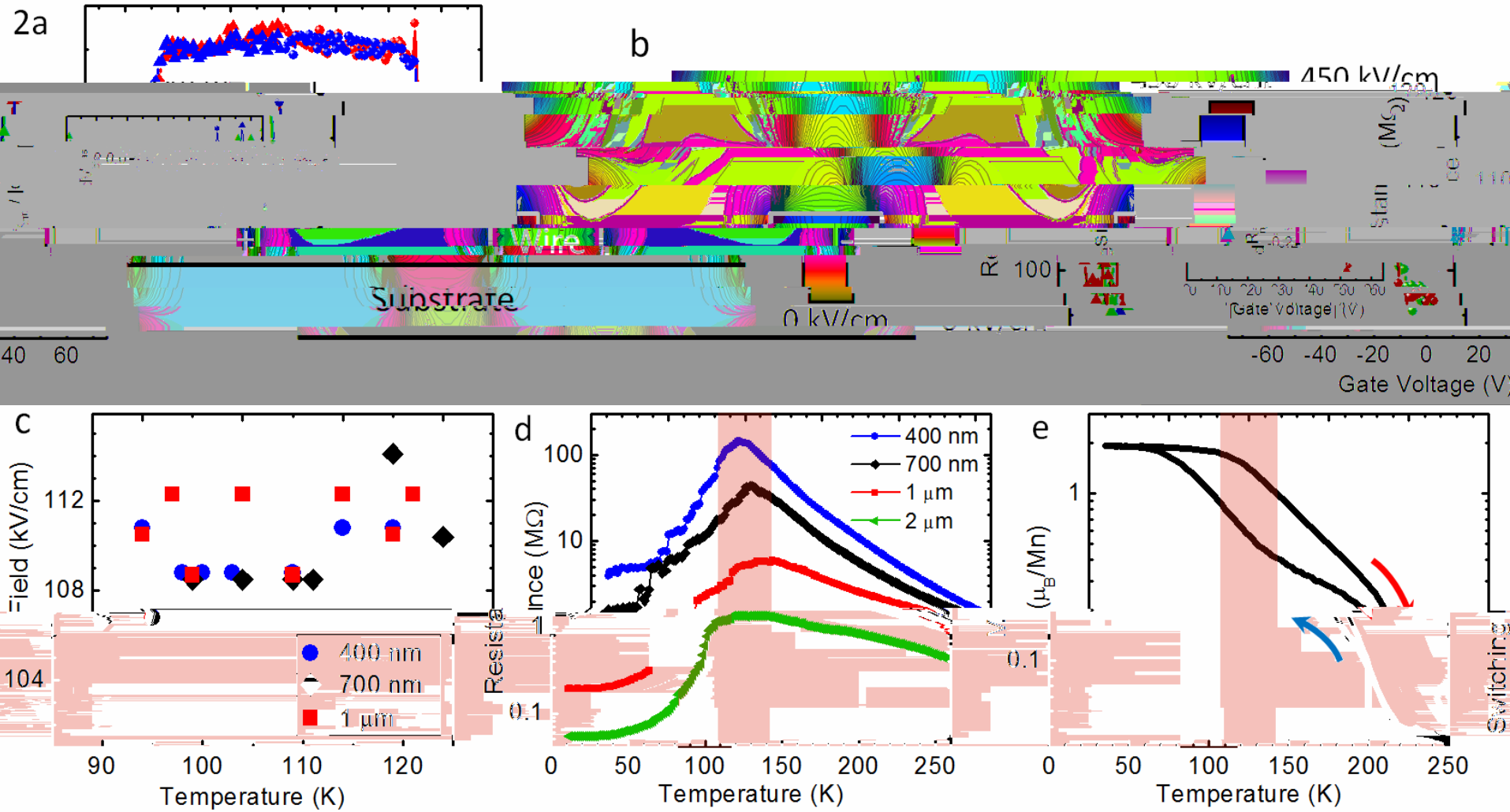


Resistive Switching

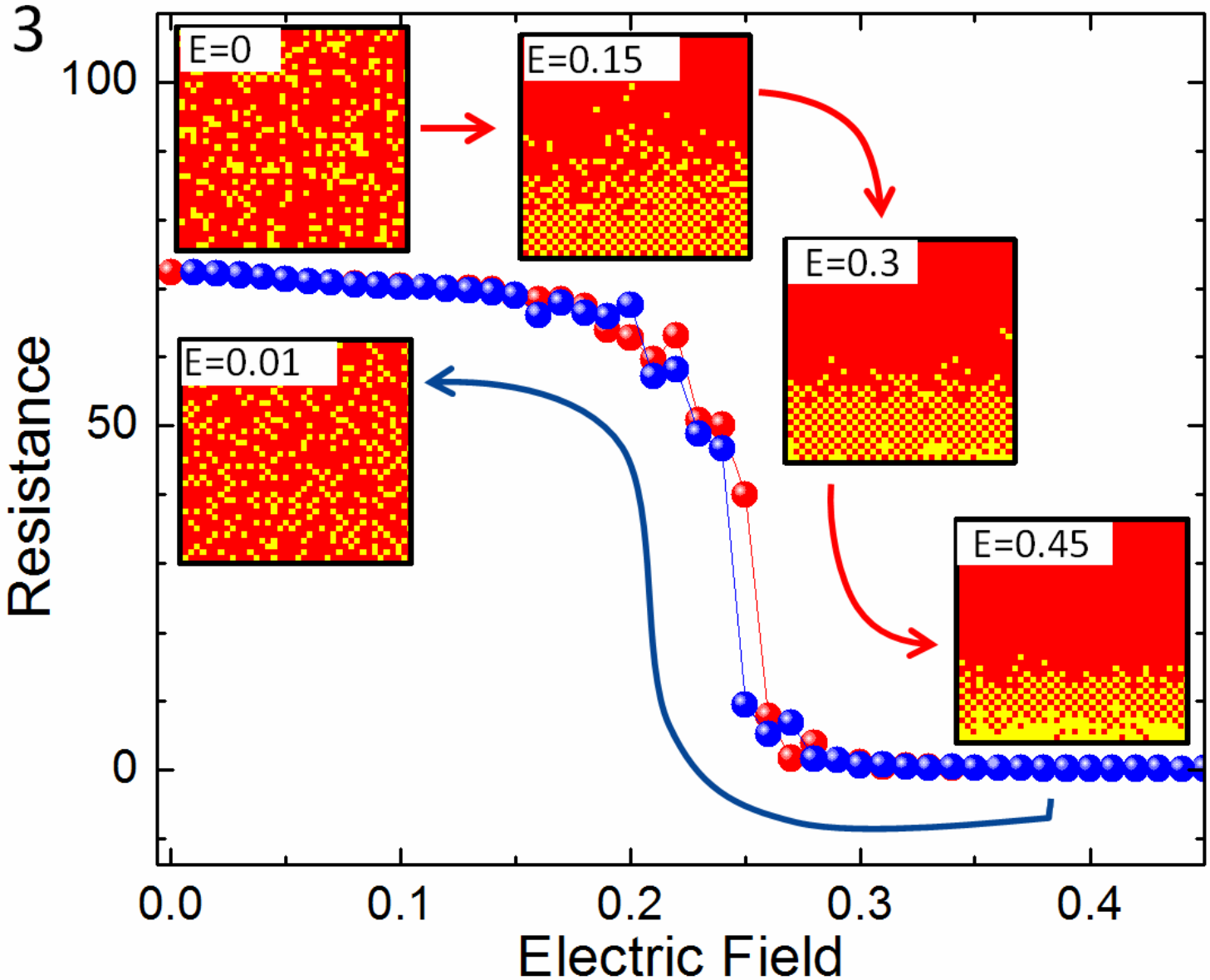




Switching Mechanism



Electric field driven percolation of metallic sites



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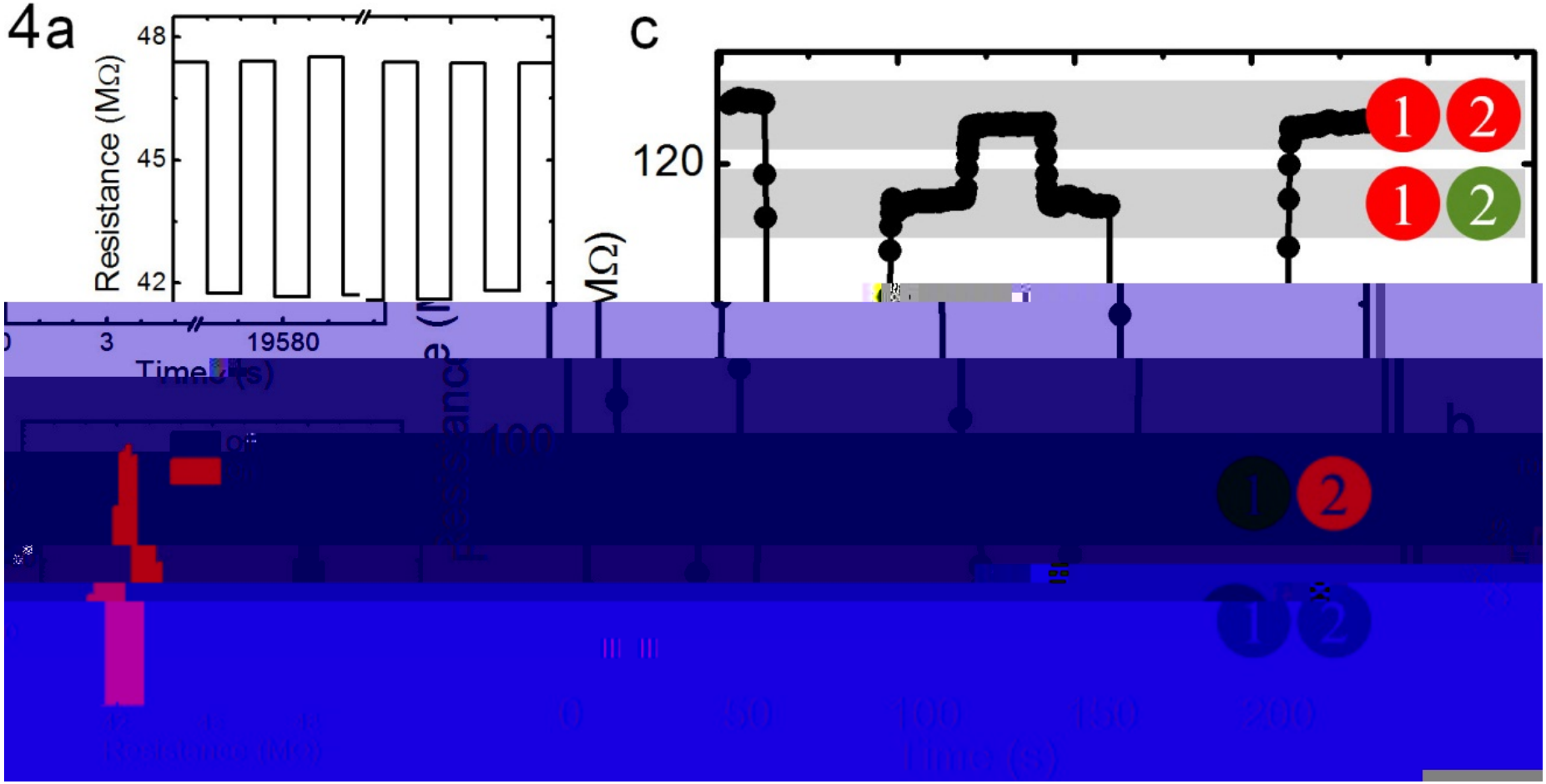
4a
48
45
42
Resistance (MΩ)
3
19580
Time (s)
c
120
100
1
2
1
2
1
2
1
2
0
50
100
150
200
Time (s)

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