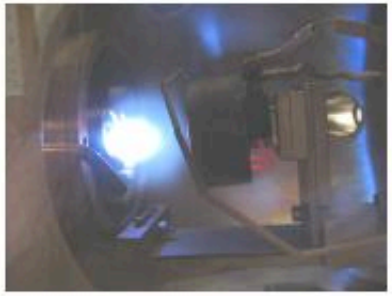
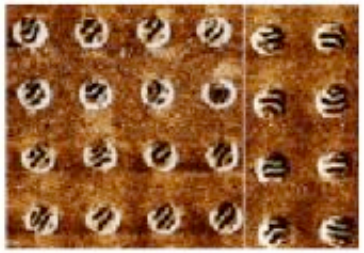
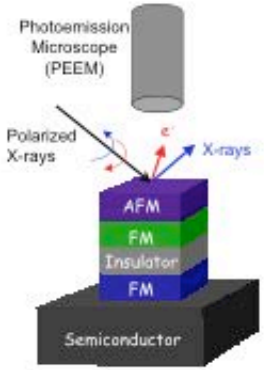
Spin-Polarized Transport in Complex Oxides

John F. Mitchell, Coordinator
Materials Science Division, ANL

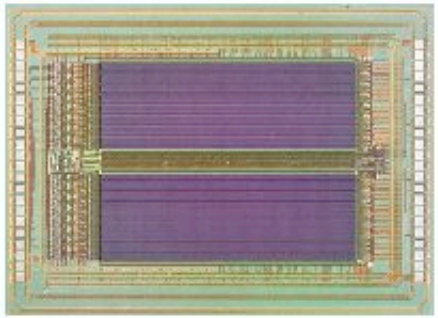






Technology Driver: Magnetic Electronics

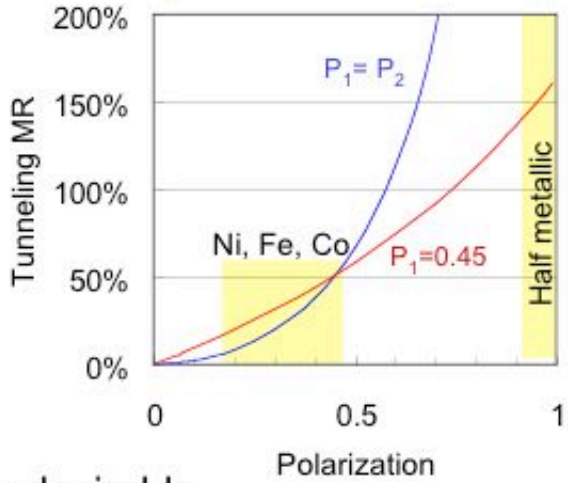
Jon Slaughter, Motorola



MOTOROLA

1 MB MRAM

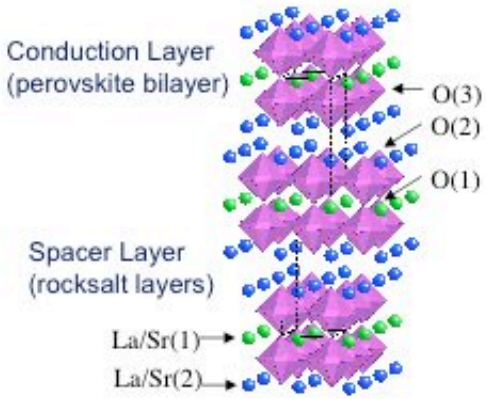
Signal (MR) increase with polarization of electrodes

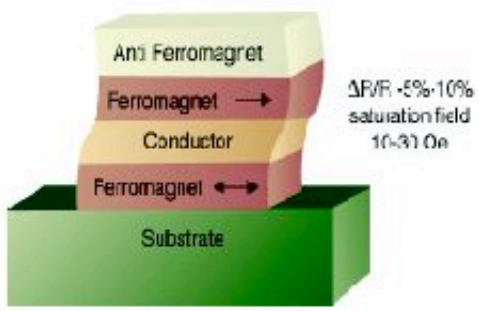


- Half-metallic FM in fixed layer extremely desirable
- High TMR
- Faster circuits

Energy relevance: reduced power consumption, improved manufacturability, quantum computing . . .

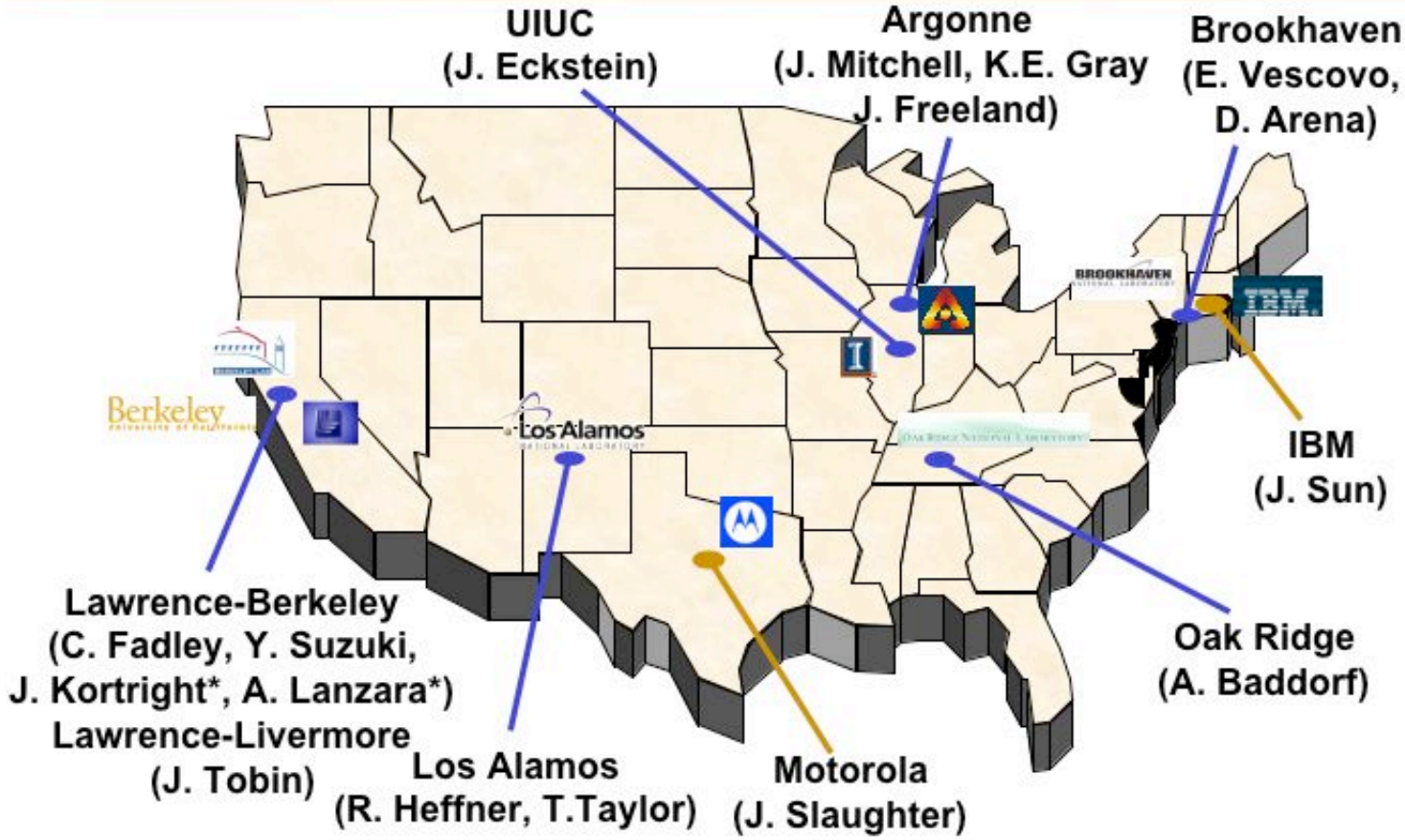
What is our scientific motivation?





- Competing phases
- Insulator-metal transition
- Carrier dynamics, e^-/phonon
- Impact of surface/interfaces
- Routes to materials for better performance
- Potential for combined functionality

Who are we?


UIUC
(J. Eckstein)
Argonne
(J. Mitchell, K.E. Gray
J. Freeland)
Brookhaven
(E. Vescovo,
D. Arena)
IBM
(J. Sun)
Berkeley
Los Alamos
Lawrence-Berkeley
(C. Fadley, Y. Suzuki,
J. Kortright*, A. Lanzara*)
Lawrence-Livermore
(J. Tobin)
Los Alamos
(R. Heffner, T.Taylor)
Motorola
(J. Slaughter)
Oak Ridge
(A. Baddorf)

"Jumpstart" Workshop: Santa Fe, Sept. 2003

CSP Oxide Spintronics Workshop

Zia A&B Room
Eldorado Hotel, Santa Fe, NM
September 15-16, 2003

Agenda

Monday, September 15, 2003
8:45 am - 5:30 pm

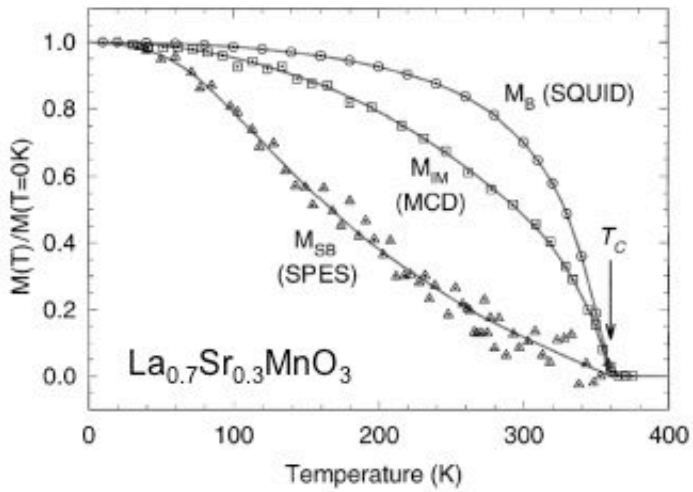
8:00 am	Complementary Continental Breakfast
8:45 - 9:10	Introductory Remarks George Samara, Sandia National Lab John Mitchell, Argonne National Lab
	Introductory Talks
9:10 - 9:40	"Magnetic Oxide Spintronics: Materials and Devices" Jonathan Sun, IBM
9:40 - 10:10	"Electron Spin Injection from Ferromagnetic Contacts" Darryl Smith, Los Alamos
	Research Group Reports/Updates
10:10 - 10:30	Argonne National Lab Report Ken Gray
10:30 - 10:50	**BREAK**
10:50 - 11:10	Los Alamos National Lab Report Brian Crone
11:10 - 11:30	Brookhaven National Lab Report Elio Vescovo
11:30 - 11:50	Oak Ridge National Lab Report Art Baddorf
11:50 - 12:10	U. C. Berkeley Report Yuri Suzuki
12:10 - 12:30	Livermore National Lab Report Jim Tobin
12:30 - 2:00	LUNCH – catered at the Eldorado Hotel
2:00 - 2:20	IBM Report Jonathan Sun
2:20 - 2:40	Lawrence Berkeley Laboratory Report Chuck Fadley
2:40 - 3:00	University of Illinois Report Jim Eckstein
	Focused Discussion Sessions
3:00 - 4:00	Electronic Devices – Jonathan Sun (IBM), Discussion Leader
4:00 - 4:20	**BREAK**
4:20 - 5:20	Electronic Properties – Ken Gray (ANL), Discussion Leader
6:30 - 7:30	No Host Reception
7:30	DINNER catered at the Eldorado Hotel

Tuesday, September 16, 2003
8:30 am – 12:30 pm

	Focused Discussion Sessions
8:00 am	Complementary Continental Breakfast
8:30 - 9:30	Structural Properties – John Mitchell (ANL), Discussion Leader
9:30 - 10:30	Optical Properties – Toni Taylor (LANL), Discussion Leader
10:30 - 10:50	**BREAK**
10:50 - 11:50	Synthesis and Processing – Quanxi Jia (LANL), Discussion Leader
11:50 - 12:30	Wrap up – John Mitchell (ANL), Discussion Leader

Workshop Outcome

Critical Issue: Poor Temperature Dependence



Project Goal: Understand and improve T behavior

Research Themes

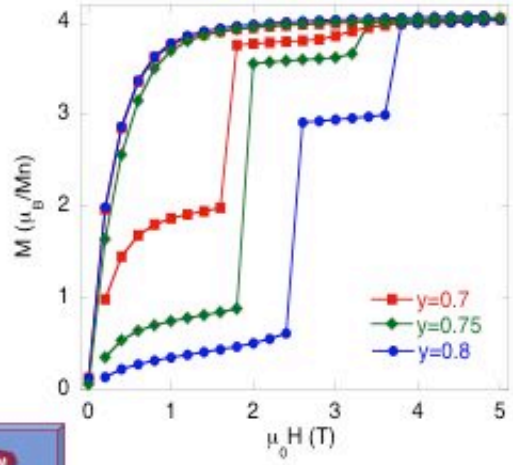
Disorder and Phase Segregation
-or-
"Why are manganites so complex?"

Surface spin polarization:
materials and probes

Microscale Phase Inhomogeneity

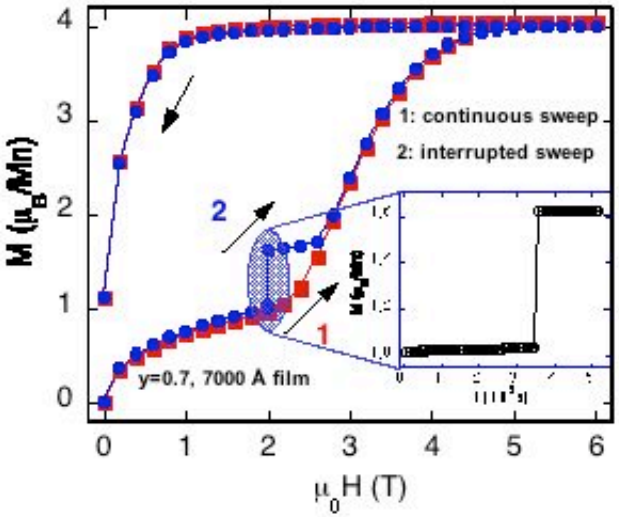
Bulk Crystals

$Pr_{0.65}(Ca_ySr_{1-y})_{0.35}MnO_3$



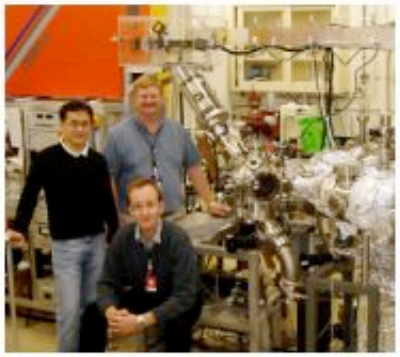
'avalanche' with $\Delta H < 2$ Oe

PLD Films

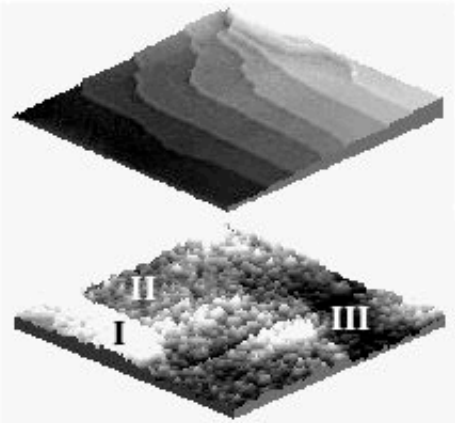


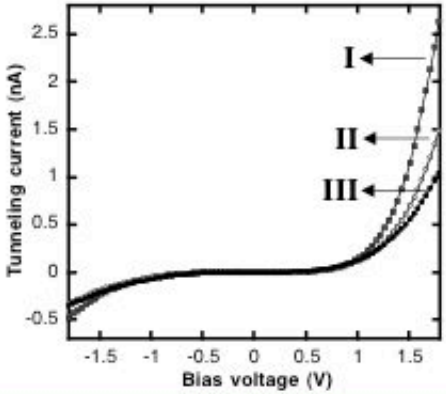
J. Mitchell, T. Wu (ANL)

Nanoscale Electronic Homogeneity

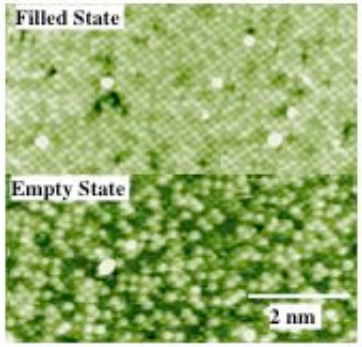


A. Baddorf, J.X. Ma, Z. Gai, M. A. Torija, E. W. Plummer, and J. Shen



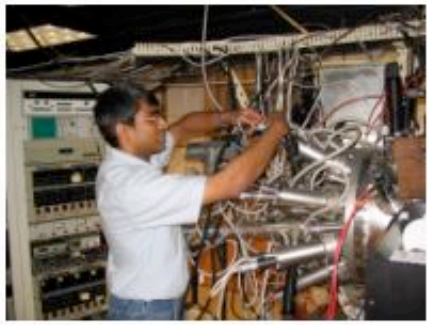


$(La,Pr)_{5/8}Ca_{3/8}MnO_3$

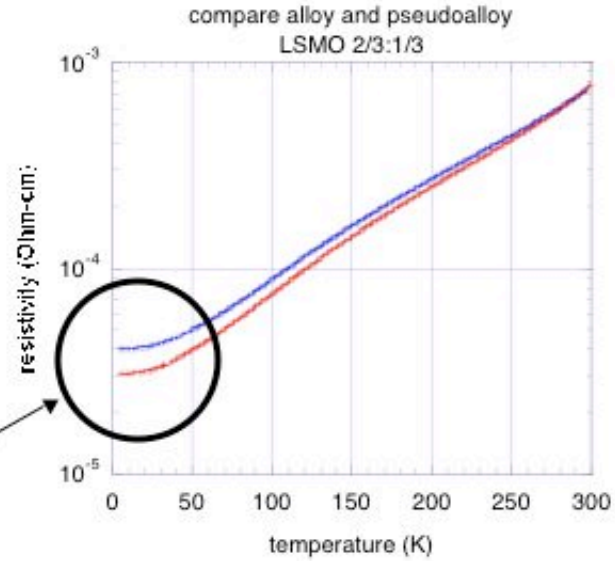


Structurally 'perfect' but electronically inhomogeneous

Synthetic Control of Disorder



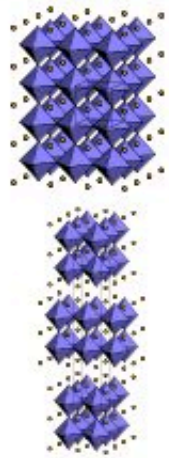
M. Warusawithana
J. Eckstein

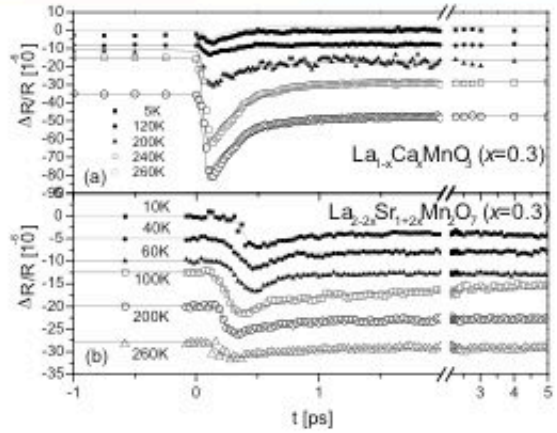


Improved RRR from reduced impurity scattering

Sub-Picosecond Dynamics of Charge+Lattice

T. Taylor, H. Lee, R. Prasankumar, R. Averitt

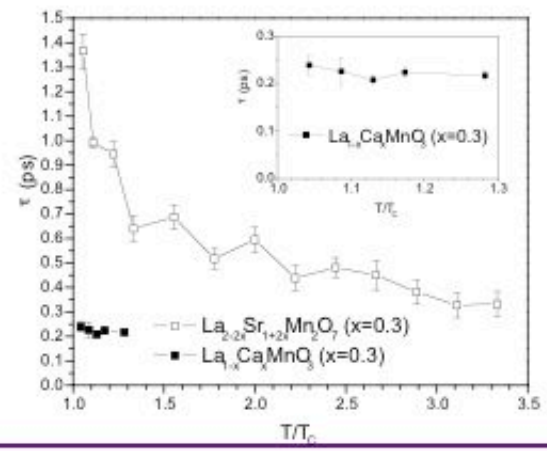




$T < T_C$: e-p weak, similar to normal metals (Au, Ag)

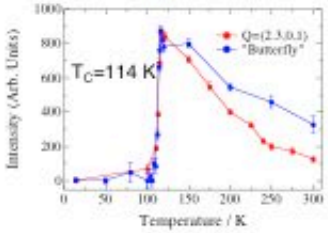
$T > T_C$: strong e-p, rapid retrapping (Jahn-Teller)

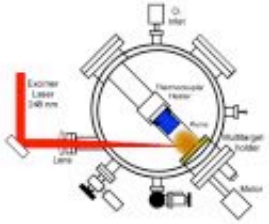
$\tau_{2D} > \tau_{3D}$: enhanced FM order



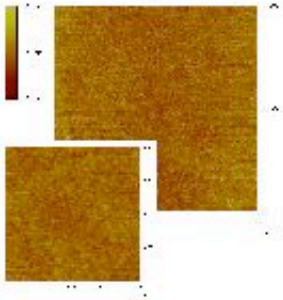
Synthesis of Layered Manganites

$La_{2-2x}Sr_{1+2x}Mn_2O_7$

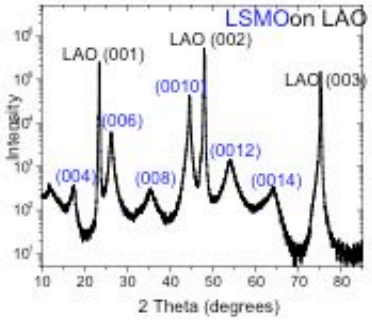




875 °C, 30 min

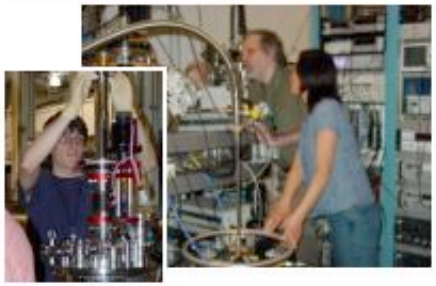


T_C = 120 K
= bulk T_C

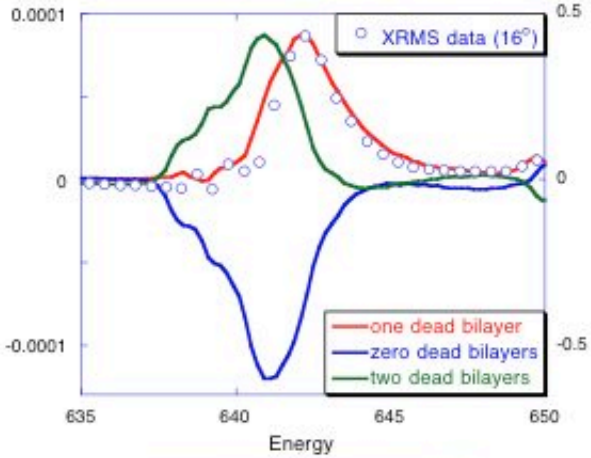


Y. Suzuki, Y. Takamura

Surface Properties of Layered Manganites

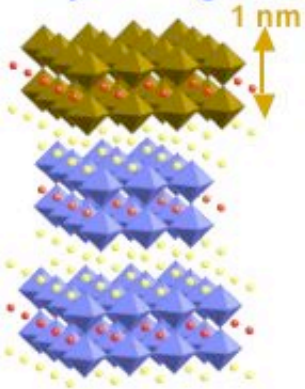


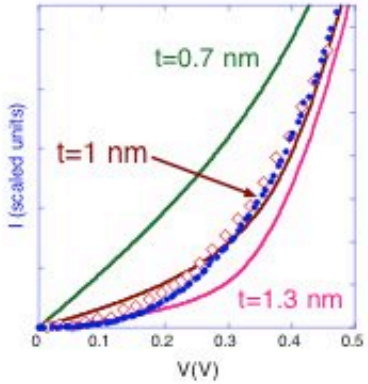
J. Freeland, K. Gray, J. Eckstein, J. Mitchell



XRMS
Data fit best by single 1 nm thick nonmagnetic layer

bilayer manganite

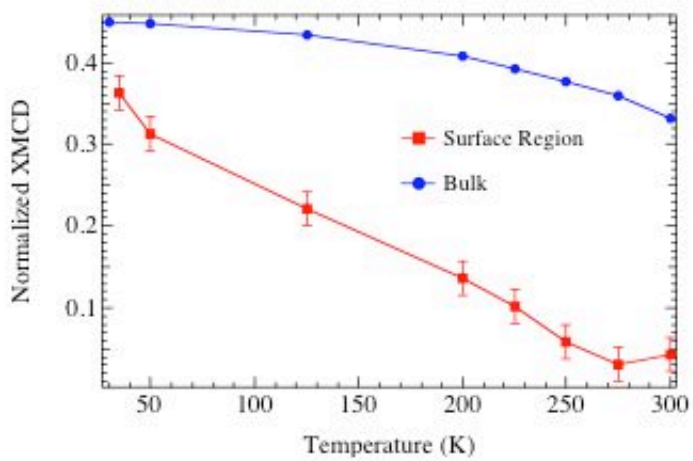




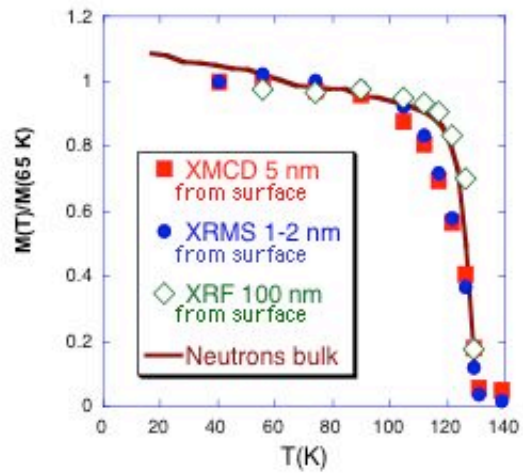
Tunneling
1 nm thick insulating barrier, ~350 meV

Surface Properties of Layered Manganites

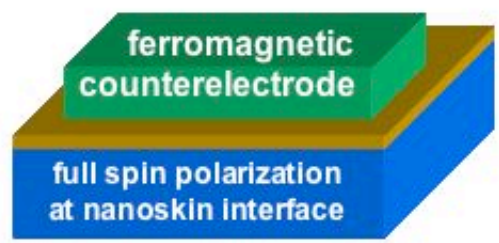
3D Perovskite



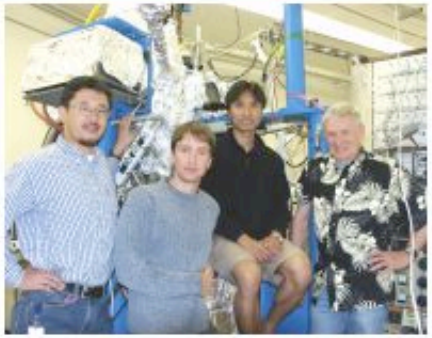
2D Bilayer

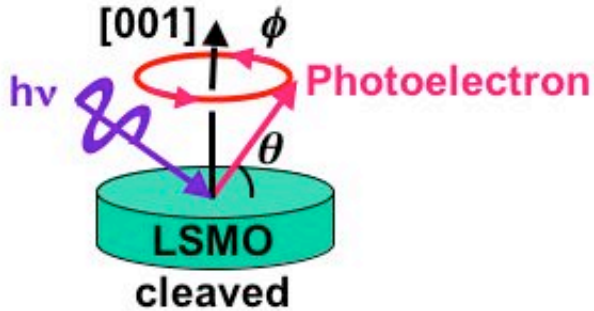


- Cleaved Crystal has intrinsic 1 nm barrier
- t << 5 nm 'dead layer'
- Naturally forms 2/3 magnetic tunnel junction

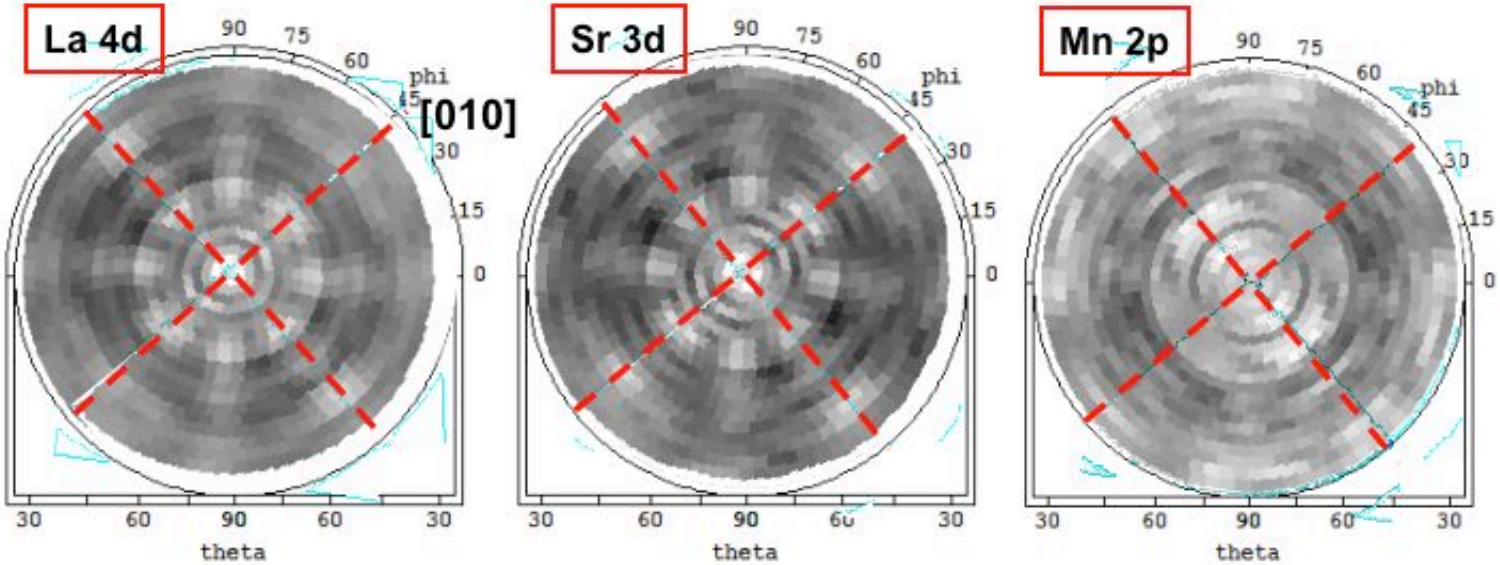


Atomic, Electronic Surface Structure





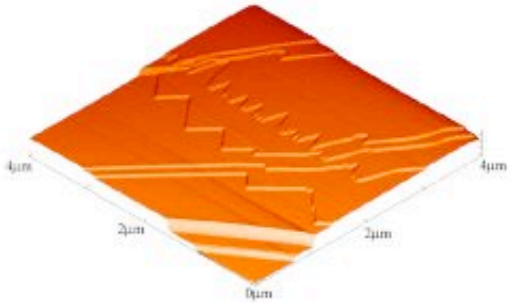
B. Sell, L. Pham, C. Fadley

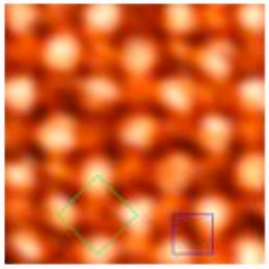


Future Direction: Origin of Insulating Bilayer

Surface of Sr_2RuO_4

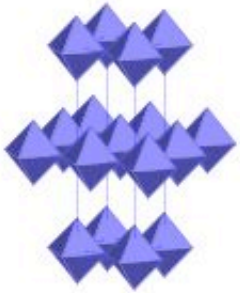
R. Matzdorf, et al., Science 289 (2000) 746.



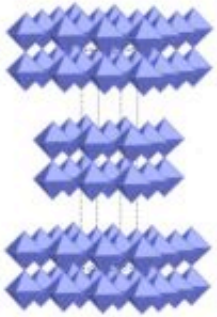


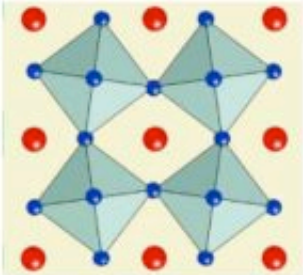
STM

LEED



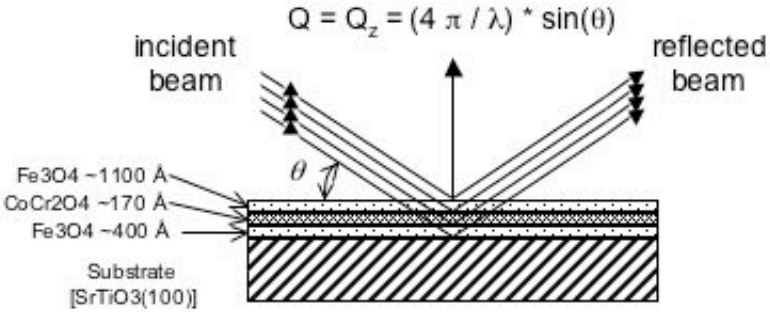
vs.

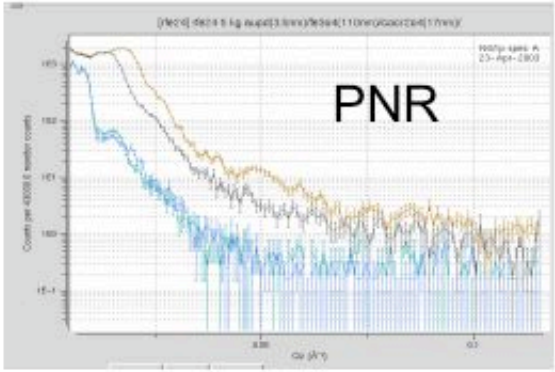




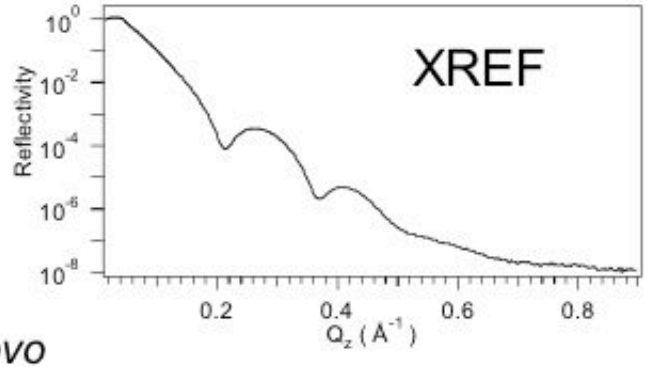
Surface reconstruction: in manganites could lead to M-I transition.

Future Direction: Characterization of Devices





Explore interface chemistry/magnetism
- Polarized Neutrons: magnetism
- X-ray reflectivity: chemistry



Y. Suzuki, J. Freeland, D. Arena, E. Vescovo

Other Future Activities

- Comparison of bilayer films and crystals (LANL, LBL + ANL)
- MTJ's from bilayer crystals, films (ANL, LBL, ORNL)
- X-ray standing wave studies of buried interfaces (LBL, UIUC, others)
- Spin polarized photoemission (BNL, LBL, LLNL)
- Search for surface charge order (ORNL + ANL)
- X-ray imaging of phase inhomogeneity, avalanches (ANL, LBL)
- Dynamics of magnetism at grain interfaces (LANL)
- etc.