Proximity and vortex pinning in YBCO/LSMO bilayers

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Outline

I. Introduction

High-Tc Superconductor

Colossal magnetoresistive manganite

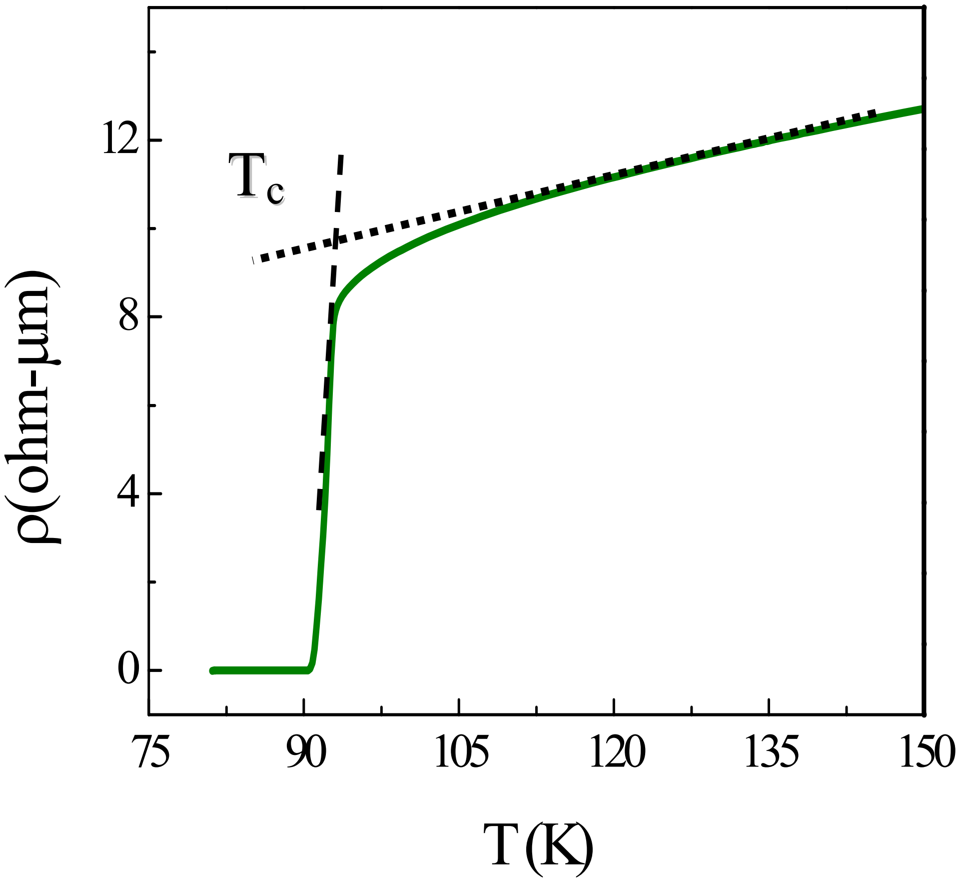
Proximity and vortex pinning

II. Experiment

III. Results & discussion

IV. Conclusion

Zero resistance in YBCO



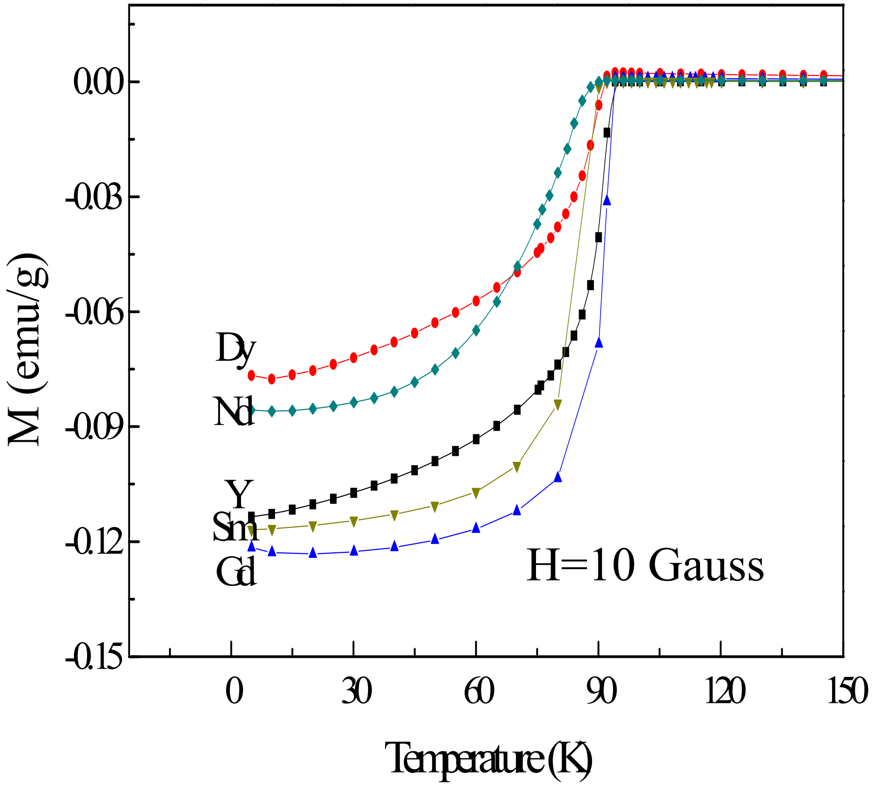
M.K. Wu & C.W..Chu, PRL 58 (1987)

$YBa_2Cu_3O_7$
T_c = 93 K
H_{c2} ~ 165 T

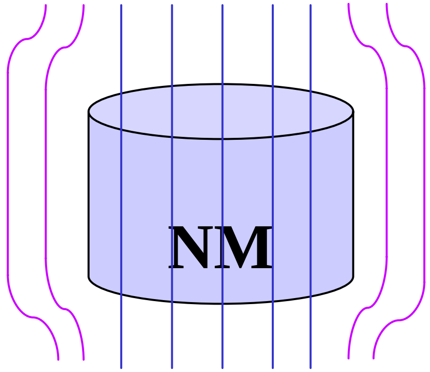
$T > T_c$:
$\rho = \rho_o + AT$

$T < T_c$:
$\rho = 0$

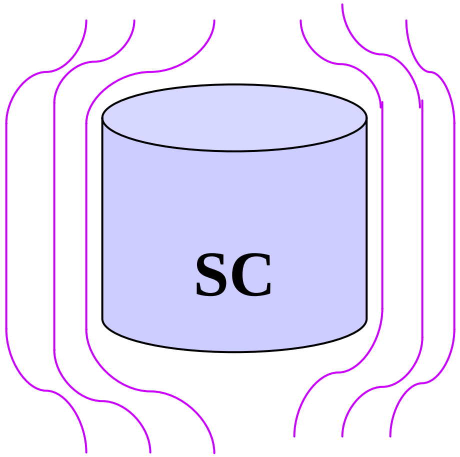
Meissner effect in RBCO, R = rare earth ions



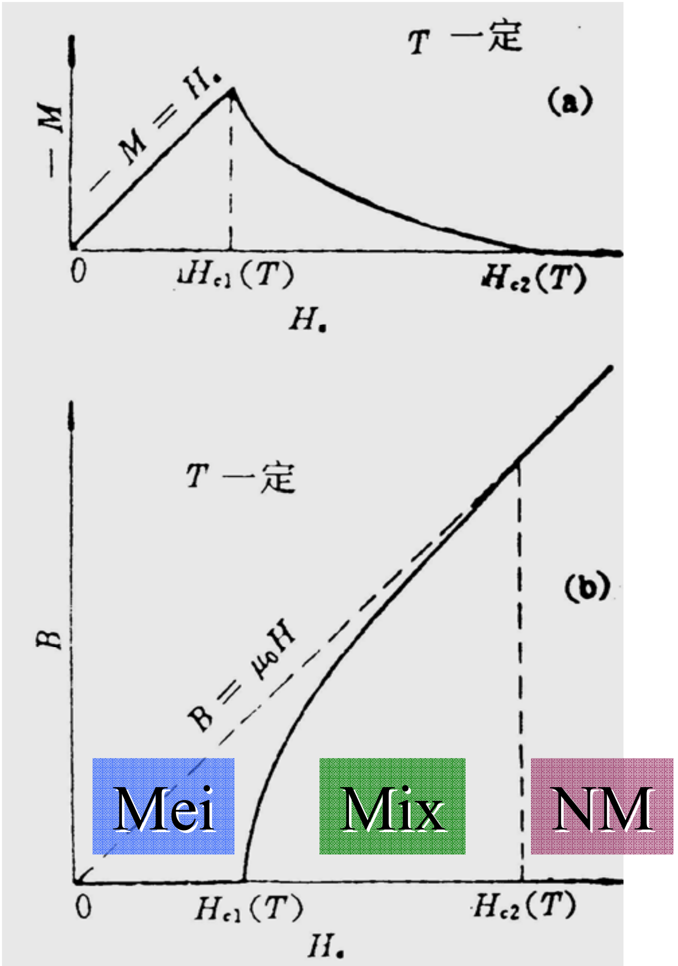
T > Tc

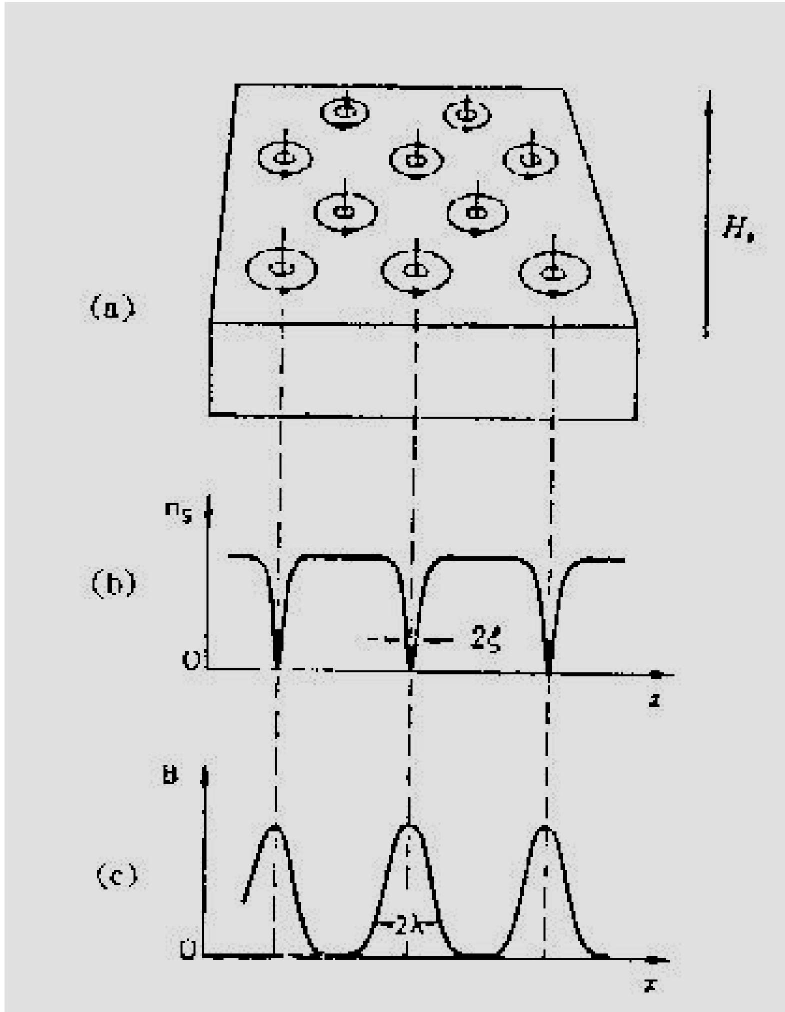


T < Tc

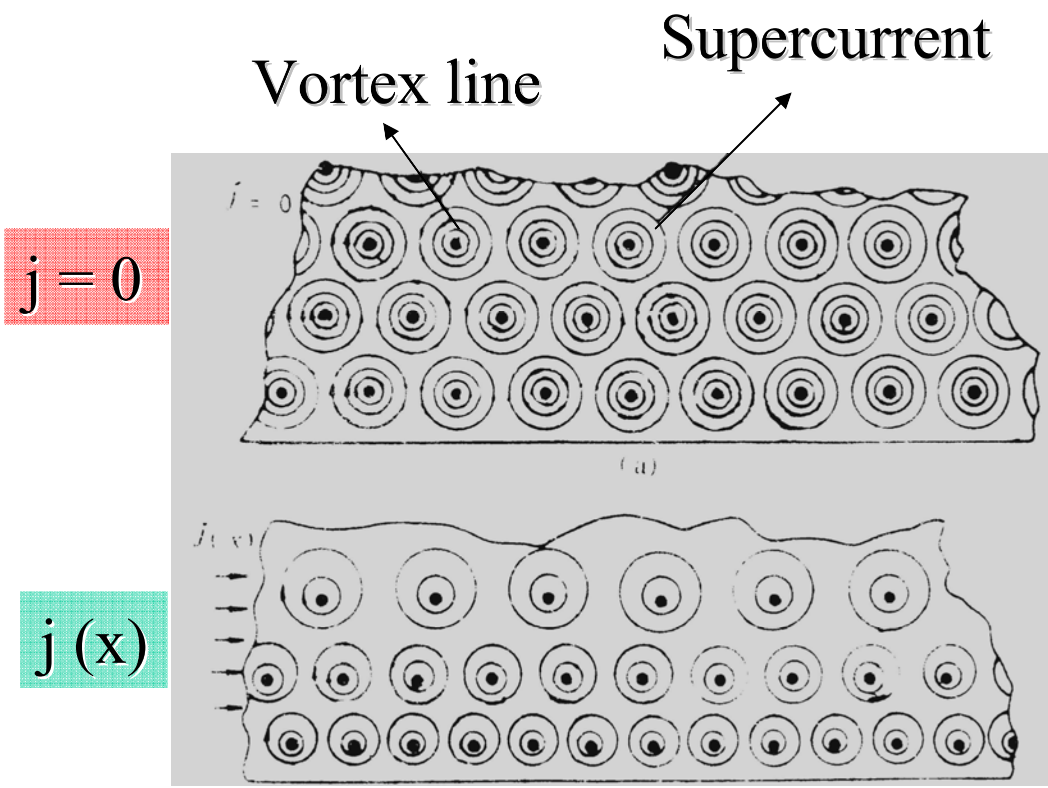


Vortex structure in type II superconductor



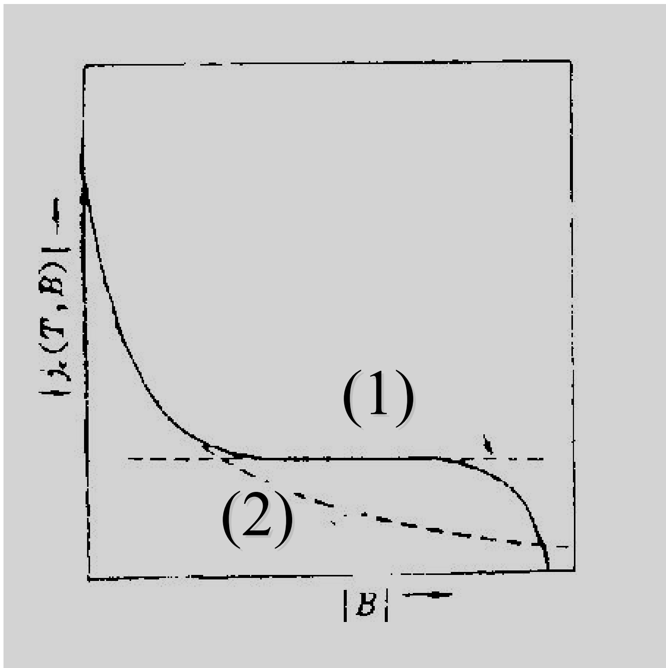


Vortex pining in type II superconductor



Bean: $\alpha = Bj_c$ --- (1)

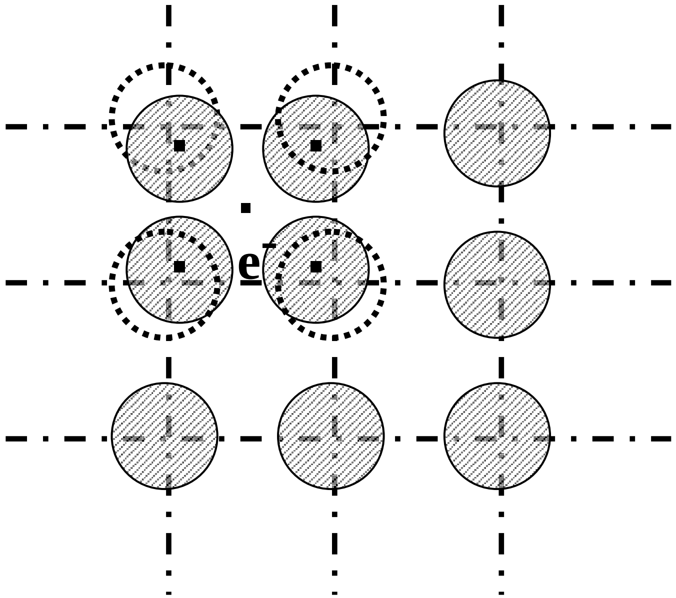
K-A: $\alpha = j_c(B+B_o)$ --- (2)



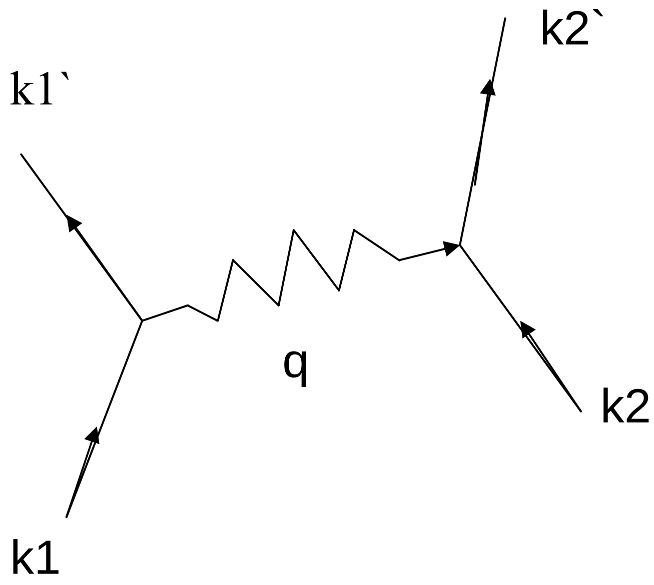
BCS Theory Work?

$k_B T_c \sim h\omega \exp[-1/g]$

$g = N(0)V$



Phonon-electron interaction



Cooper pair

Models for High-T_c materials

BCS-like $k_B T_c = E_{char} \exp[-(1+\lambda)/\lambda]$

RVB $k_B T_c = C\,\delta\,(t_\perp{}^2/t_{||}{}^2)U$ (Anderson, 1987)

Hubbard model

$$k_B T_c = t_{||}\,\delta \exp(-U\delta / t_{||})$$ (Cyrot, 1987)

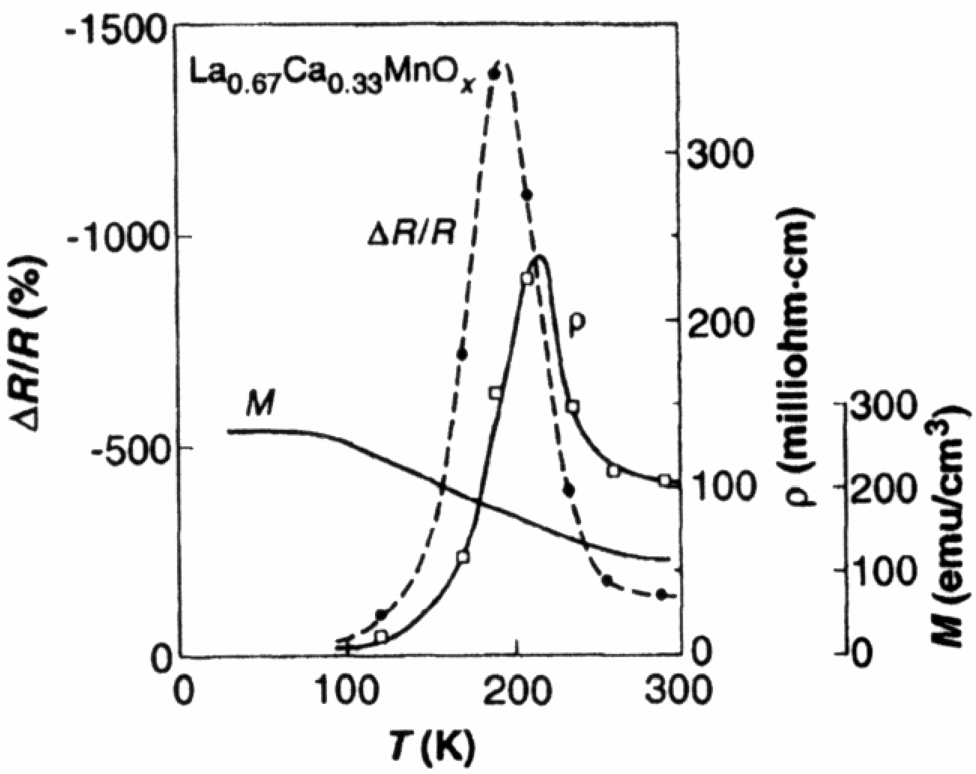
Charge-transfer/hole-depletion

$$T_c = T_{co} - A(n' - n_o)^2$$ (Liechtenstein, 1995)

BCS + d_{x2-y2} symmetry

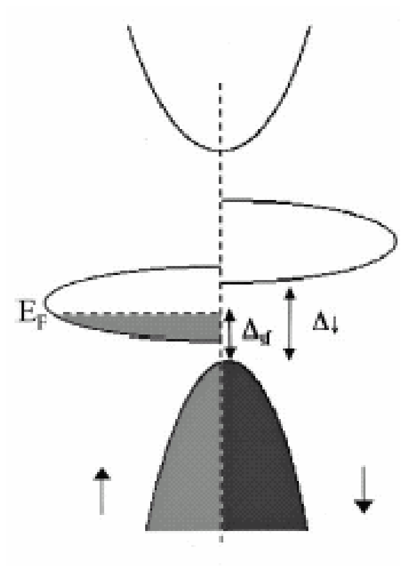
$$T_c = [n_H(P), V_{eff}(P)]$$ (Chen et al., 2000)

Colossal magnetoresistance (CMR)



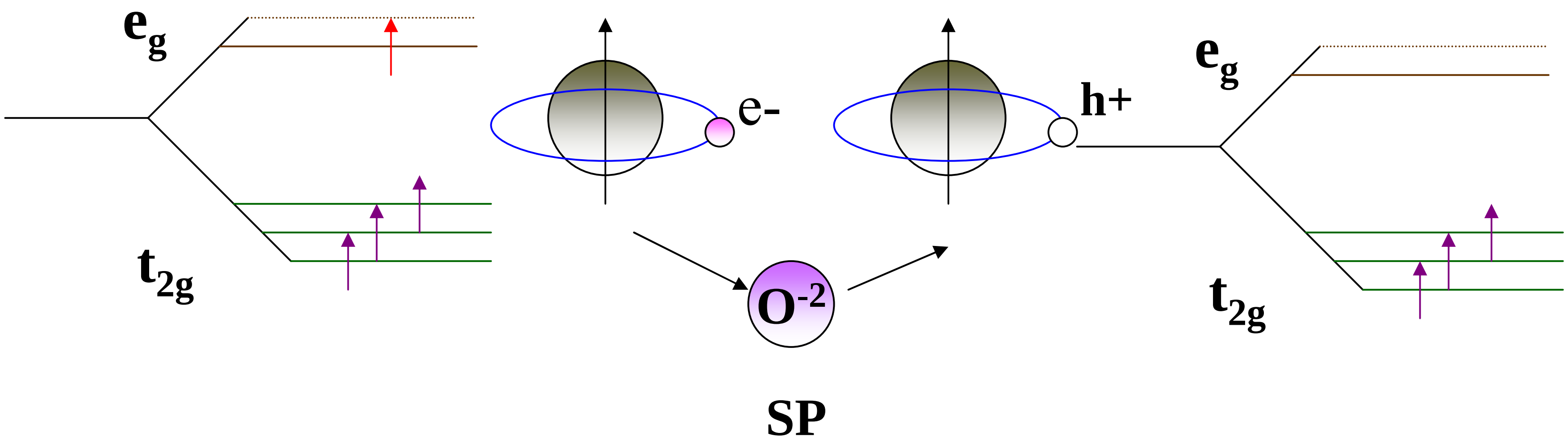
S. Jin et al. Science 265 (1994)

1) Very high magnetoresistance (-1500% at 200 K)
2) Polarization 100% (half metal)
3) Metal - Insulator (PM -FM) transition



Double exchange (1951, Zener)

(La,Sr,)MnO_3



Mn^{+3}: $3d^4$ $(t_{2g}{}^3\ e_g{}^1)$

Mn^{+4}: $3d^3$ $(t_{2g}{}^3\ e_g{}^0)$

Physical Review B, Volume 58, Number 17 1 November 1998-I

Phase diagram of manganese oxide

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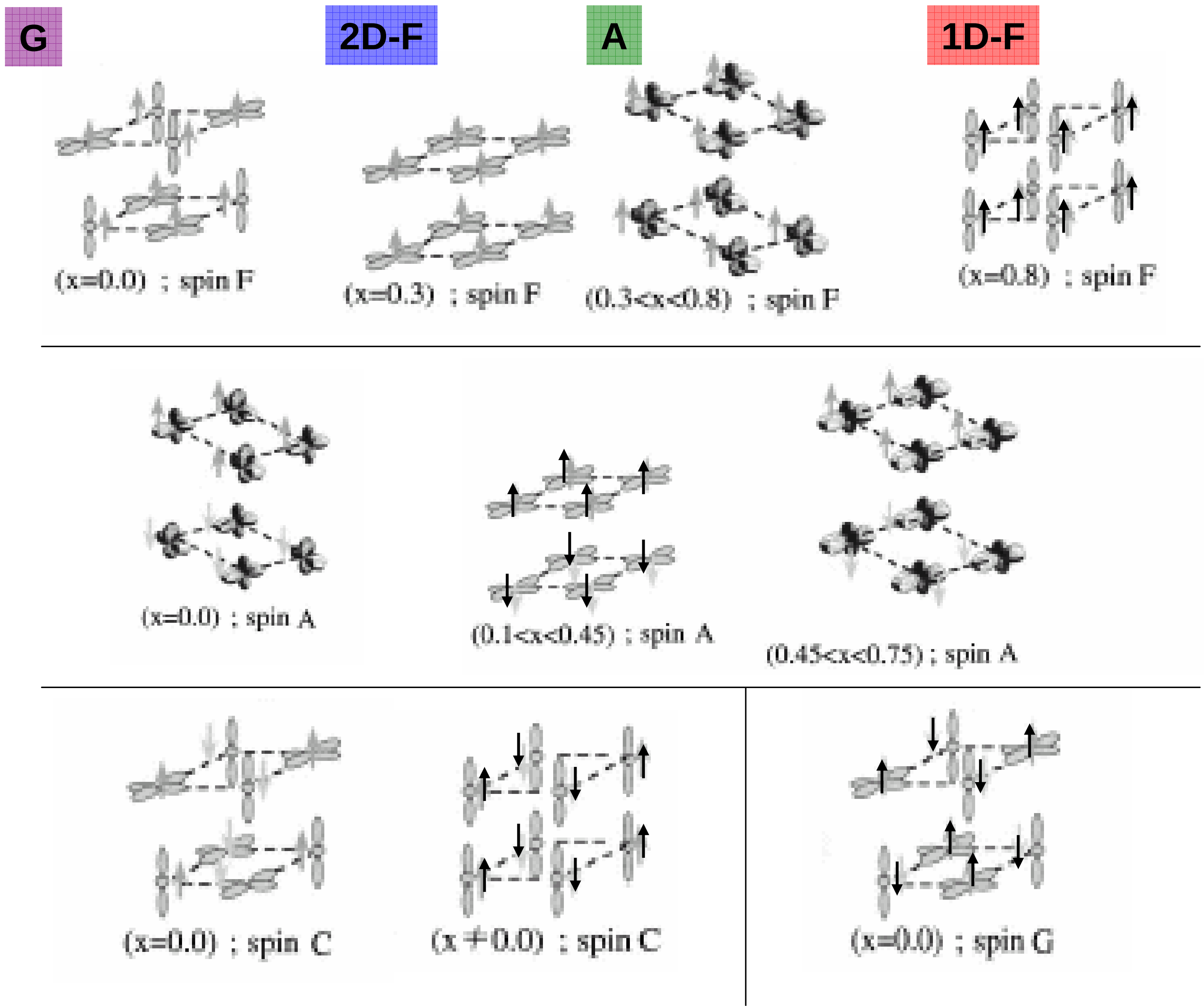
$$H = H_K + H_{Hund} + H_{on\,\mathrm{site}} + H_S$$

$$H_K = \sum_{\sigma\gamma\gamma'(ij)} t_{ij}^{\gamma\gamma'} d_{i\sigma\gamma}^{+} d_{j\sigma\gamma'}$$ (Kinetic energy of e_g electrons)

$$H_{Hund} = -J_H \sum_i \vec{S}_{t2gi} \cdot \vec{S}_{egi}$$ (Hund coupling between e_g & t_{2g} spins)

$$H_{\mathrm{on\,site}} = -\sum_{\mathrm{i}} (\tilde{\beta} T_i^2 + \tilde{\alpha} S_{egi}^2)$$ (Coulomb interaction between e_g-electrons)

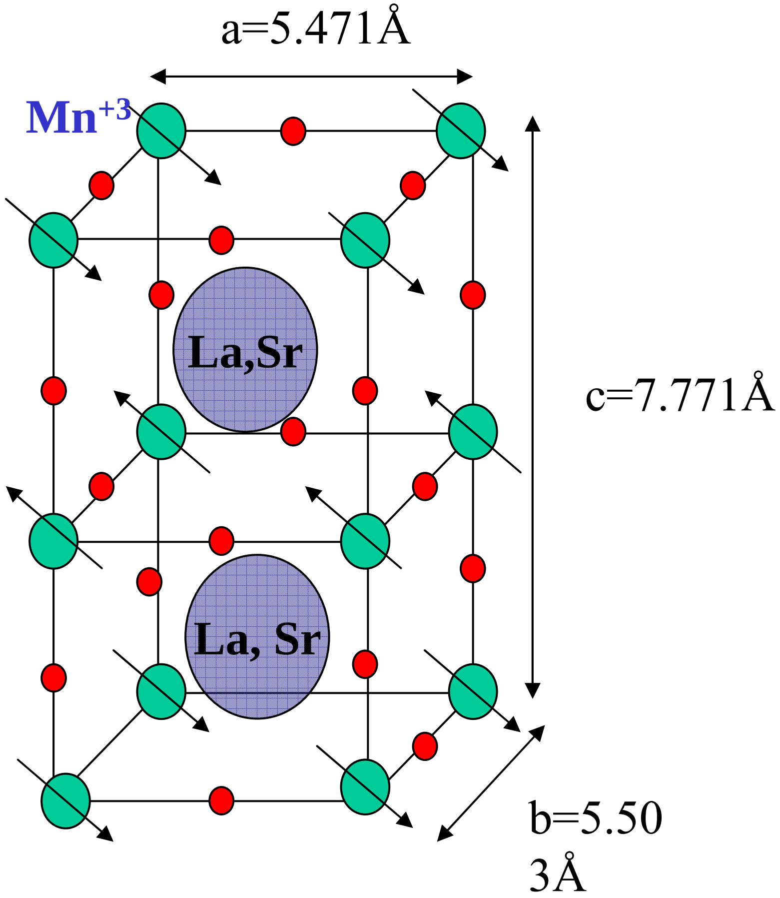
$$H_S = J_S \sum_{(ij)} \vec{S}_{t2gi} \cdot \vec{S}_{t2gj}$$ (Super exchange t_{2g} spins)



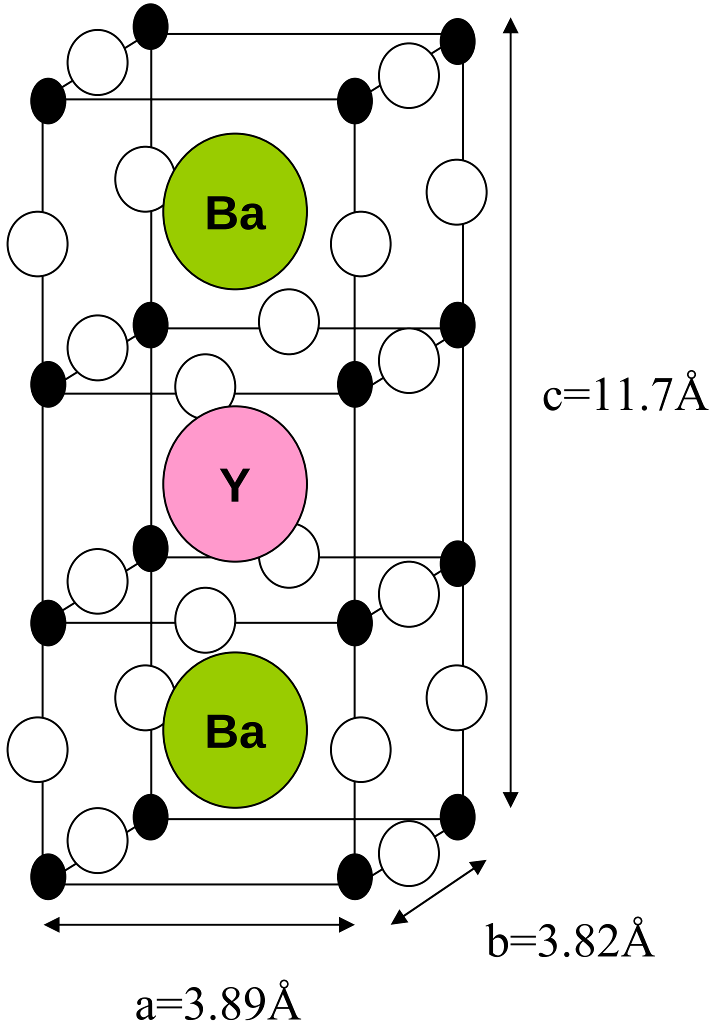
G
2D-F
A
1D-F
(x=0.0) ; spin F
(x=0.3) ; spin F
(0.3<x<0.8) ; spin F
(x=0.8) ; spin F
(x=0.0) ; spin A
(0.1<x<0.45) ; spin A
(0.45<x<0.75) ; spin A
(x=0.0) ; spin C
(x ≠ 0.0) ; spin C
(x=0.0) ; spin G

CMR effect toward to spintronic applications

Type	MR	Field	Temp.	Material
OMR	0.01%	~Tesla	RT	Cu,Al
AMR	2 %	10 Oe	RT	Fe,Co,Ni
GMR	5~10 %	2 Oe	RT	Fe/Cr
TMR	20 %	10 Oe	RT	Co/AlO/Co
CMR	10 (99.9)%	2 T	RT(200K)	La-Sr-Mn-O

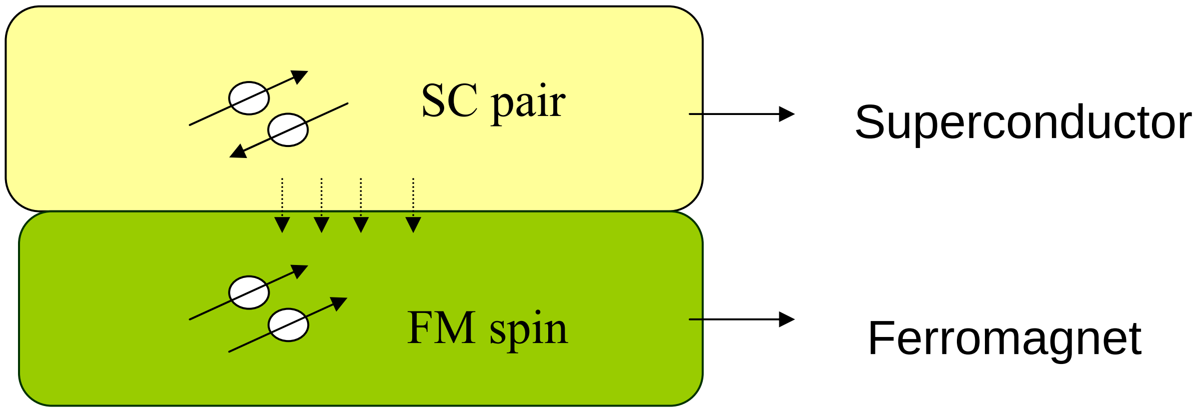


$La_{0.7}Sr_{0.3}MnO_3$



$YBa_2Cu_3O_7$

Interesting physics in SC/FM



Boundary conditions $\rightarrow$

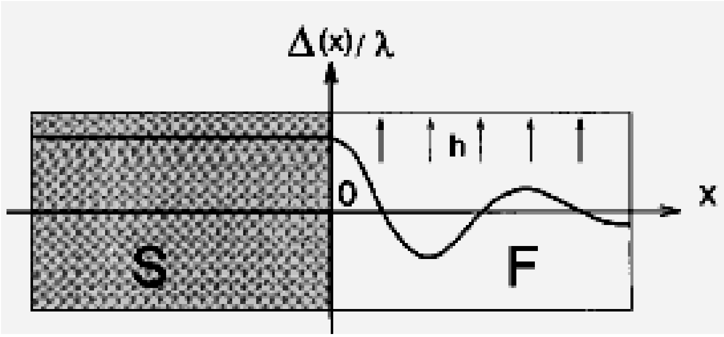
1) Proximity effects
2) Magnetic vortex pinning
3) π –phase shift
4) Spin injection
5) Spin-accumulation
6) Andreev reflection

Proximity effect

1) Influence of magnetism on supercond.

Intermixing $\Rightarrow$ effective exchange field

$H_{effect} = H_{ex} [d_F/(d_s+d_F)]$, **$T_c$ oscillation**

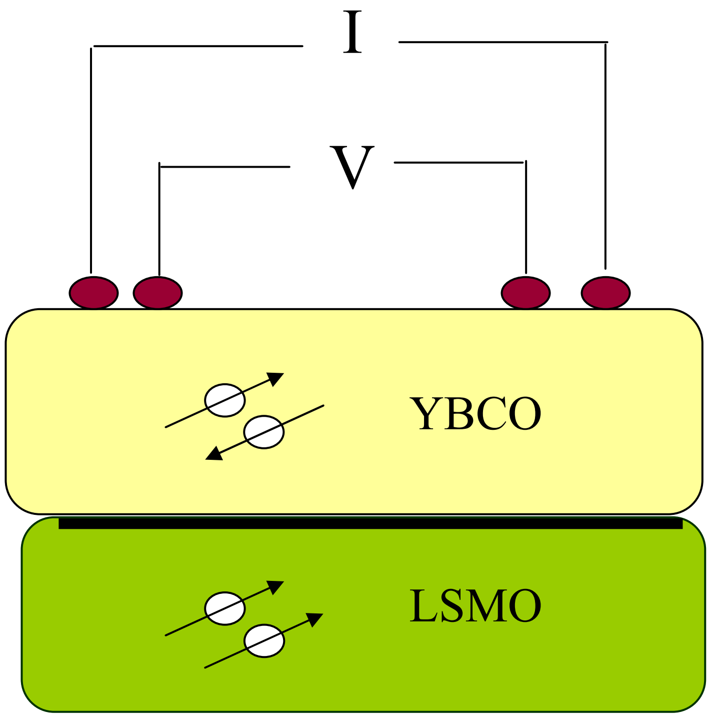


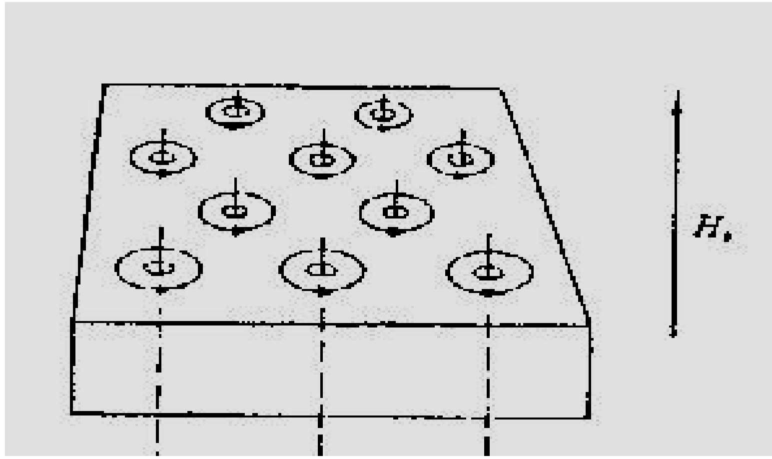
2) Influence of supercond. on magnetism

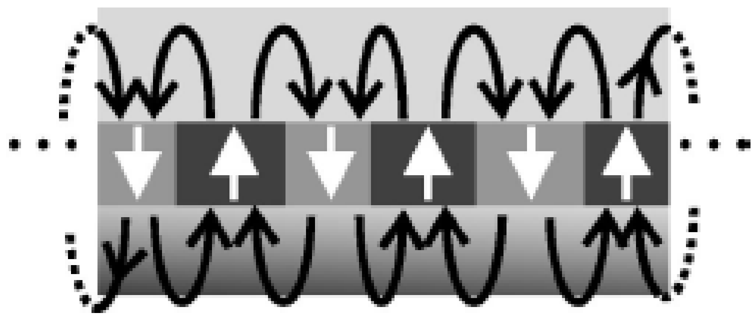
Intermixing $\Rightarrow$ reconstruction of magnetic order

T_{curie} oscillation

Vortex pining by domain wall







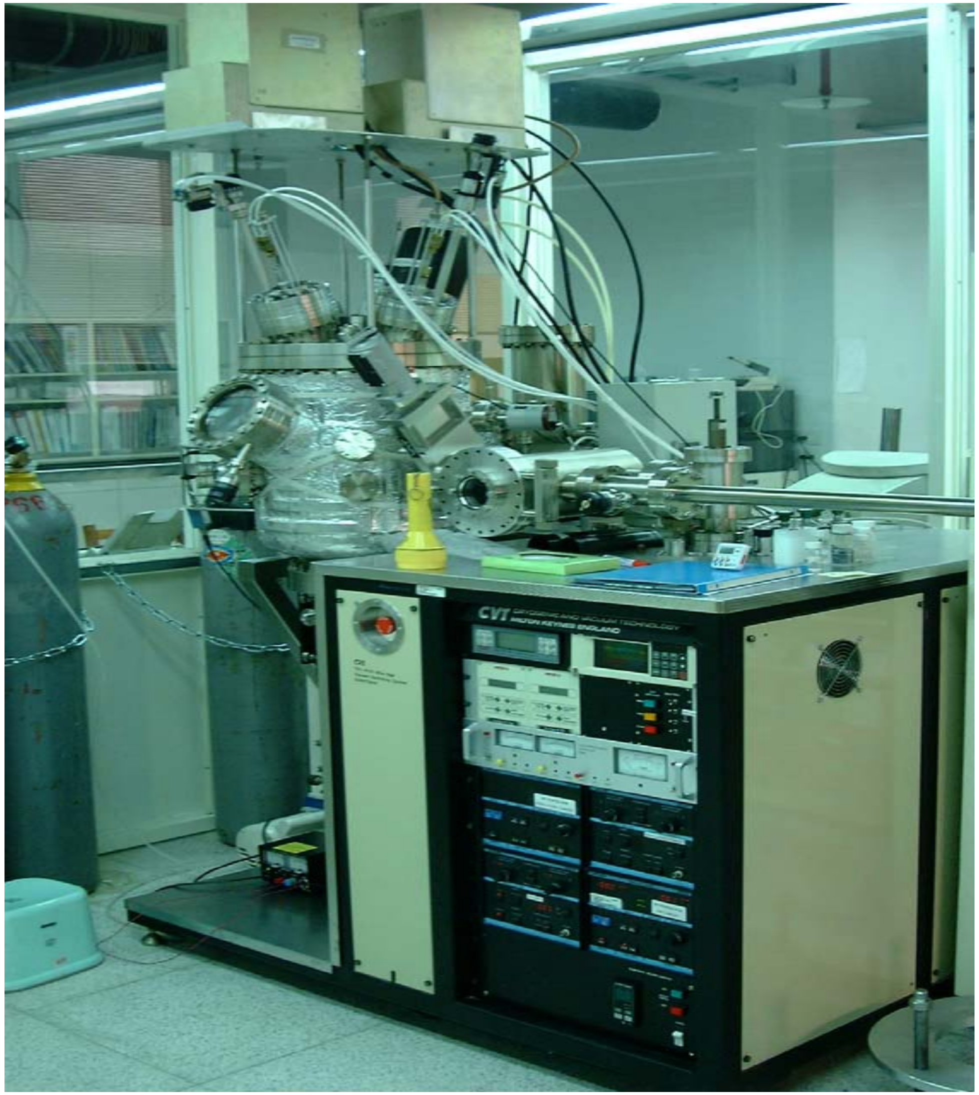
Attractive force by opposite directional magnetic-lines

a

t

t

Experimental set-up (I)



RF sputter system
(Millton CVT, 13.6 MHz)
Base pressure 10^{-8} torr
four guns
Substrate temp. 1000 °C

LSMO Target Making

Step 1 Pre-heating La_2O_3: 900℃/ 3 h .

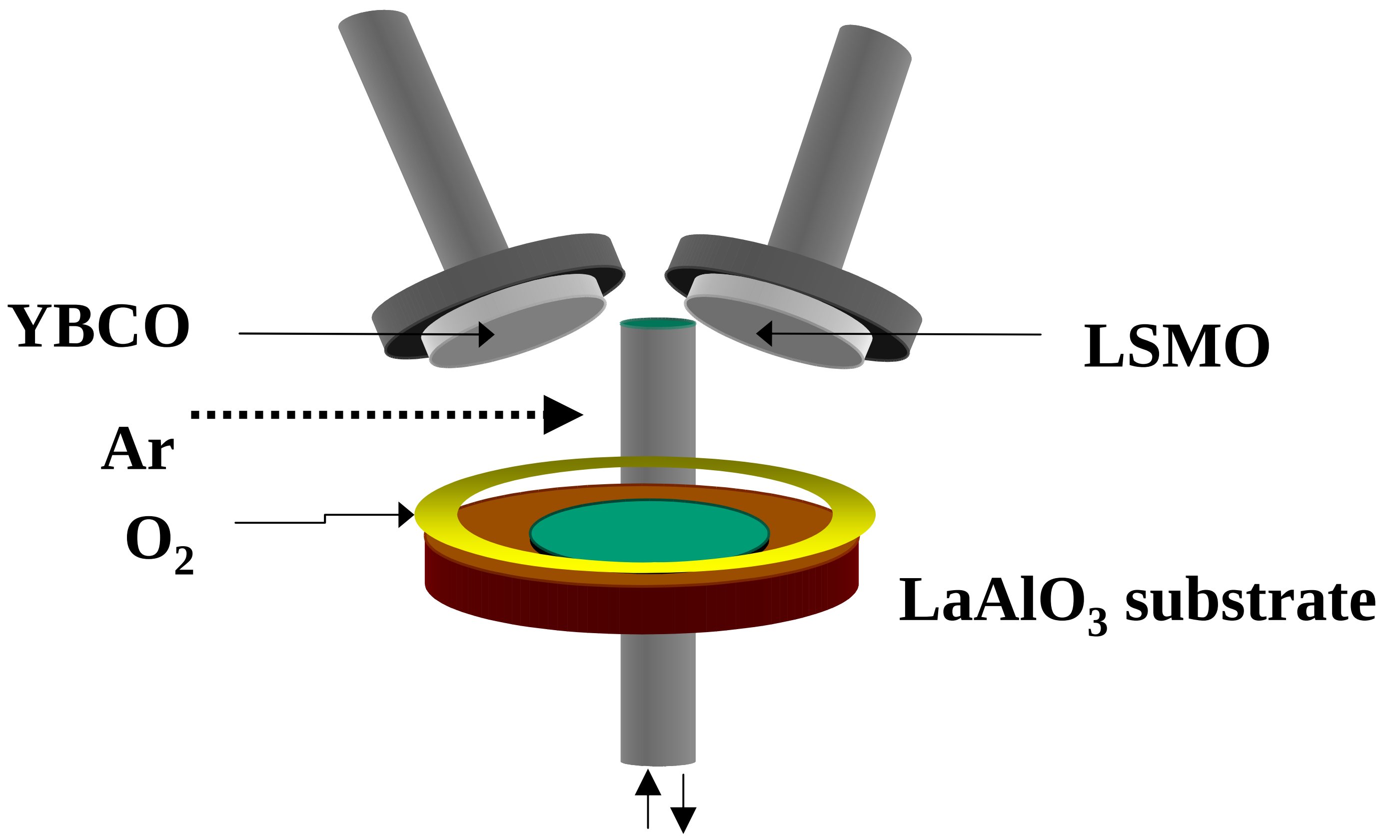
Step 2 Mix La_2O_3 , $SrCO_3$, $MnCO_3$

Step 3 Reaction: 1200℃/ 24 h

Step 4 Pellet :d = 5 cm, Thick =1 cm, 3 tons/ cm^{-2}

Step 5 Anneal: 1400℃ /16 h

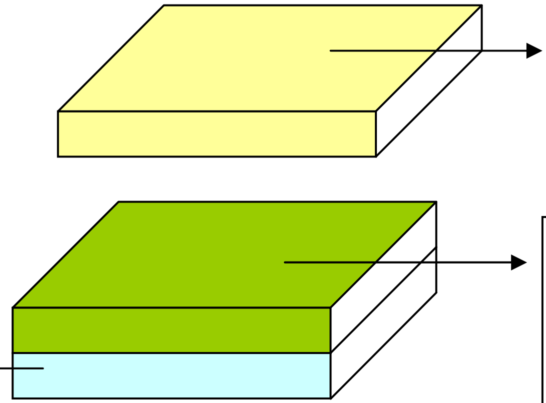
Film making



Reactive co-sputtering process

• Substrate ⇒	Si (100) , $LaAlO_3$(100)
• Target ⇒	YBCO, LSMO
• RF power ⇒	80 Watt
• Base pressure ⇒	3×10^{-7} torr
• Mixed gas ⇒	$Ar:O_2=98:2$
• Sputtering pressure	70 mtorr
• Base temperature ⇒	Room temperature
• pre-sputtering ⇒	3 minutes
• Working distance ⇒	10 cm
• Annealing tempert.	800 – 920 ℃ (700 ℃)
• Annealing time ⇒	1 hrs

Post-annealing conditions



Experimental set-up (I)

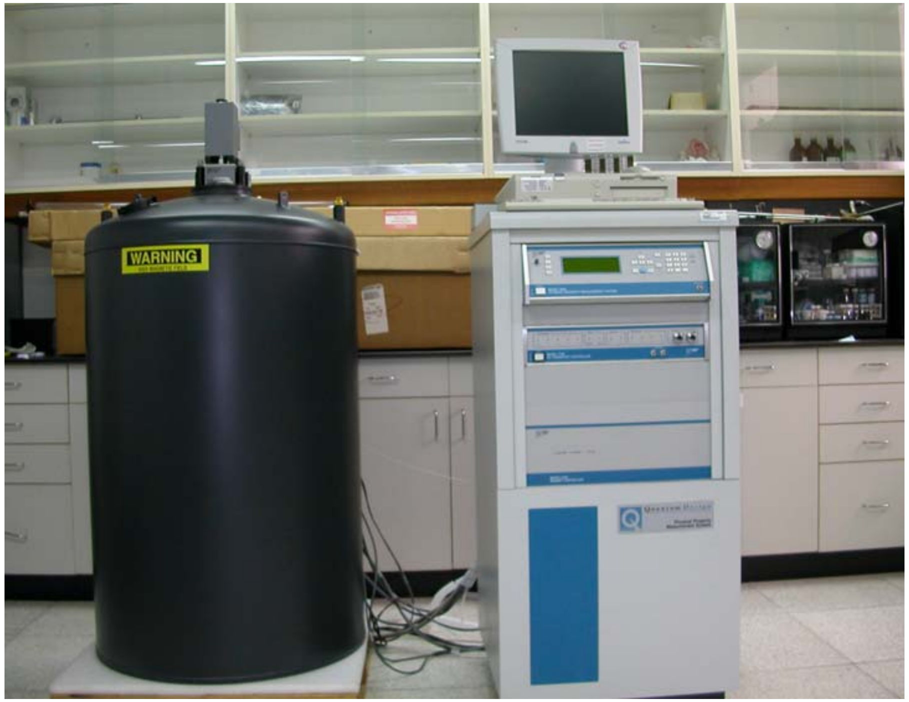
- **X-Ray Powder Diffractometer**

  (Japan MAC Sience, model MXP18)

- **AFM** (Solver P47)

- **Physical Property Measur. System**

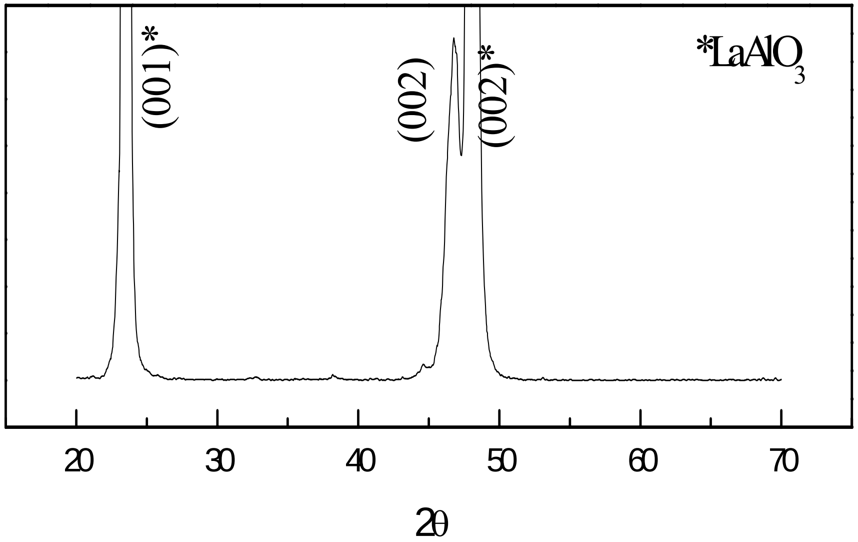
  (Quantum design)
  7 Tesla, 1.4 – 400 K
  Resisitivity, I-V curve
  AC/DC susceptibility



Structures of LSMO layer

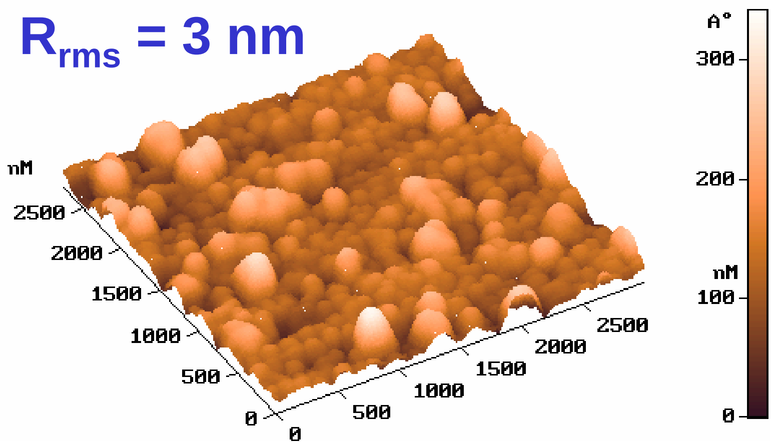
XRD – orthorhombic

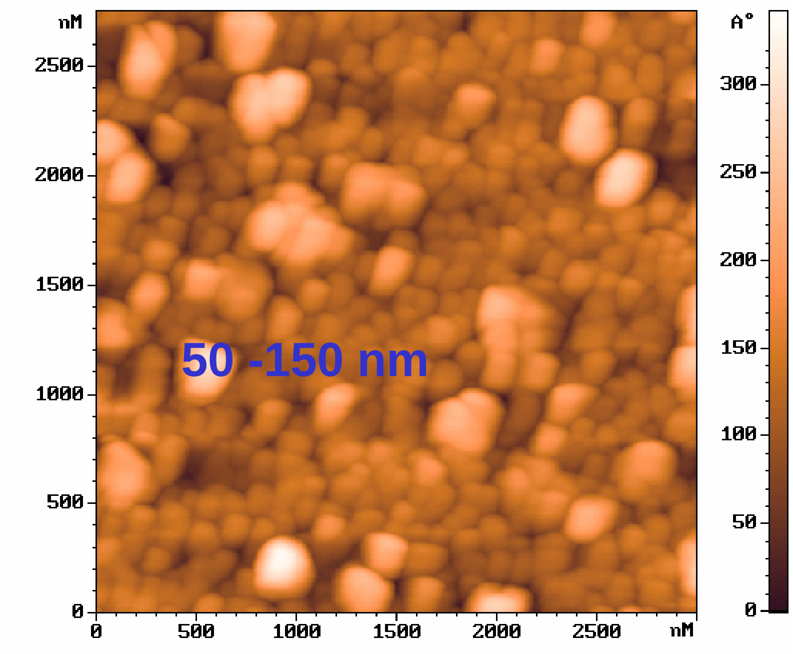
c-oriented



AFM - granular

R_{rms} = 3 nm

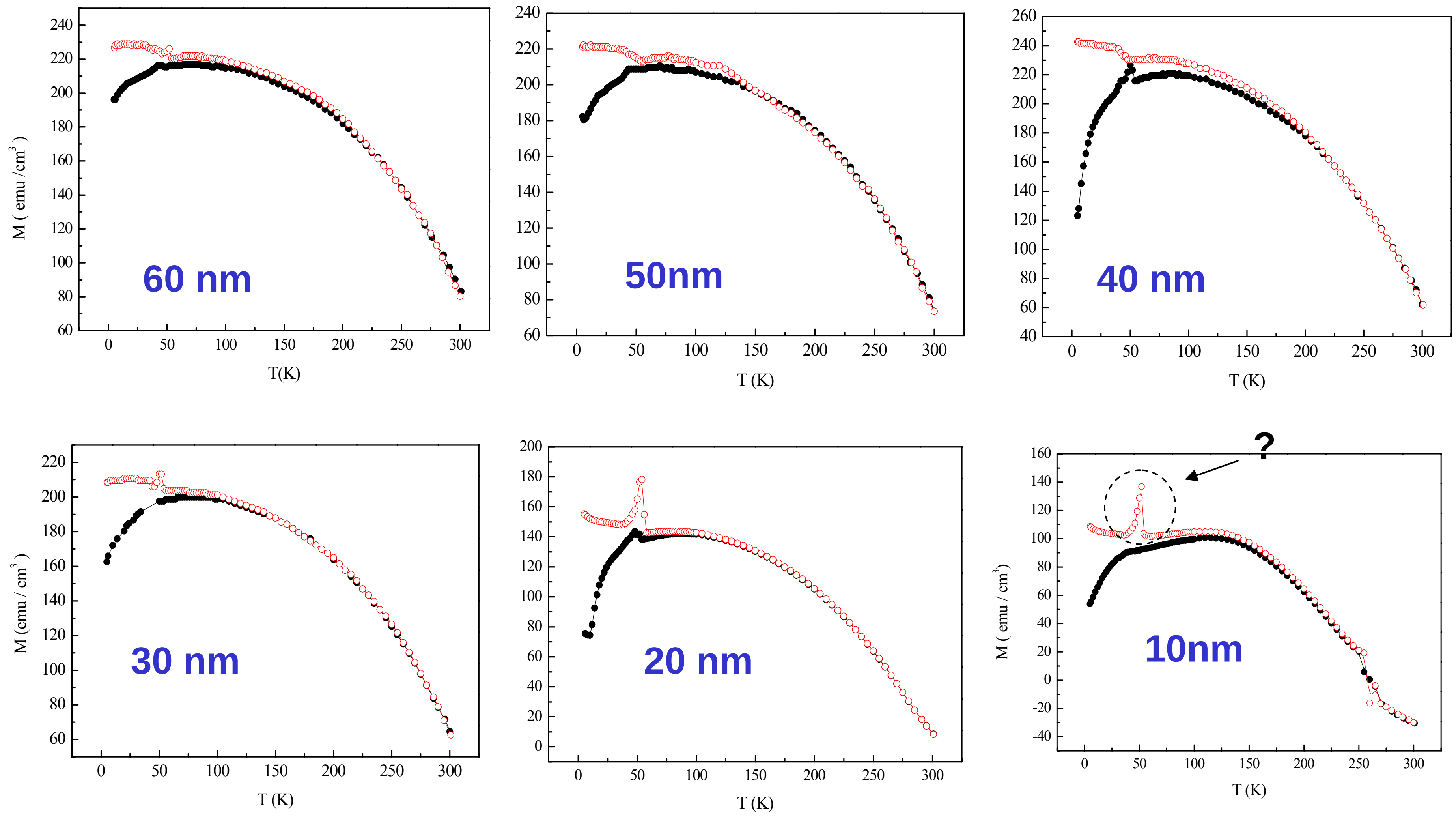




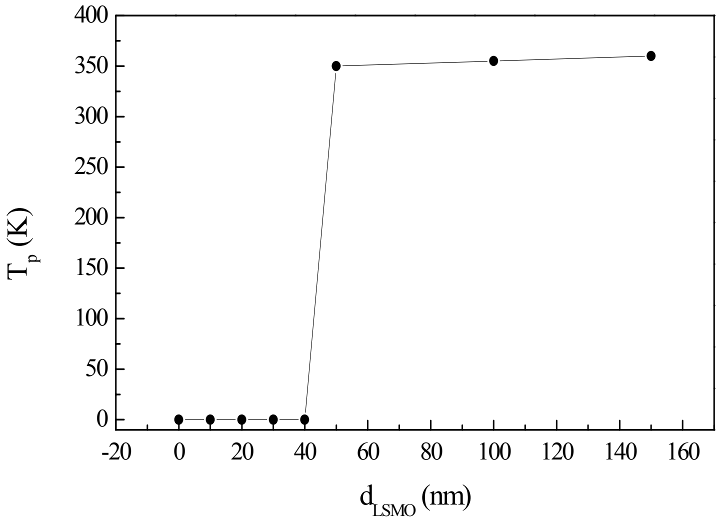
Magnetization for LSMO

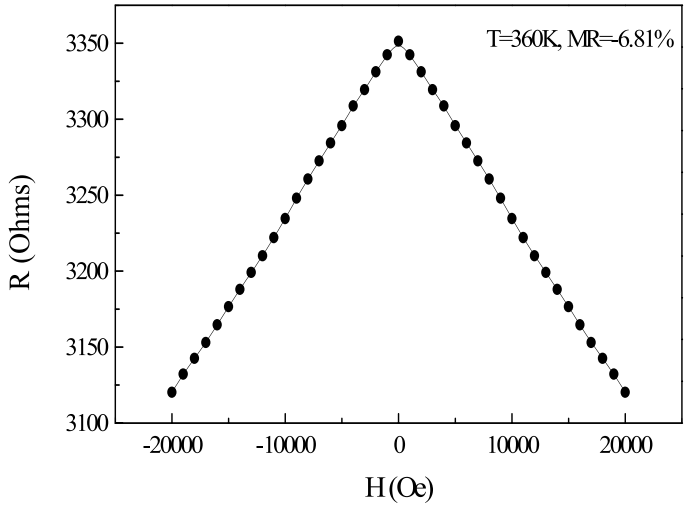
H = 500 Gauss

ZFC(black line); FC (red line)



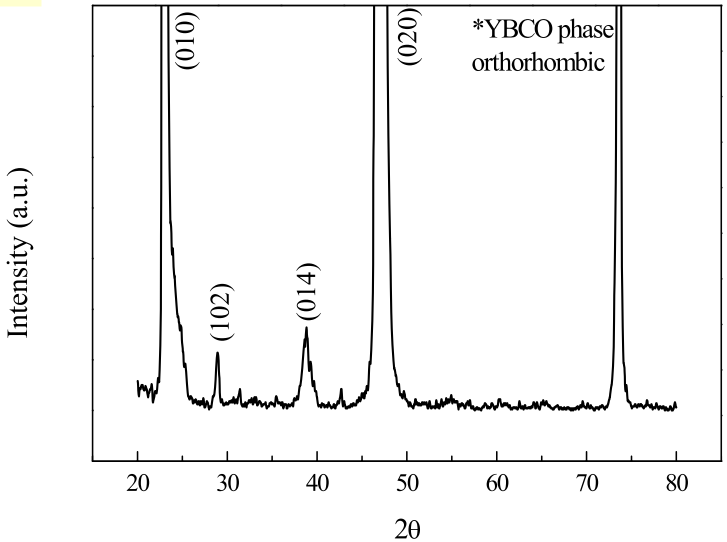
$La_{0.7}Sr_{0.3}MnO_3$ (LSMO)

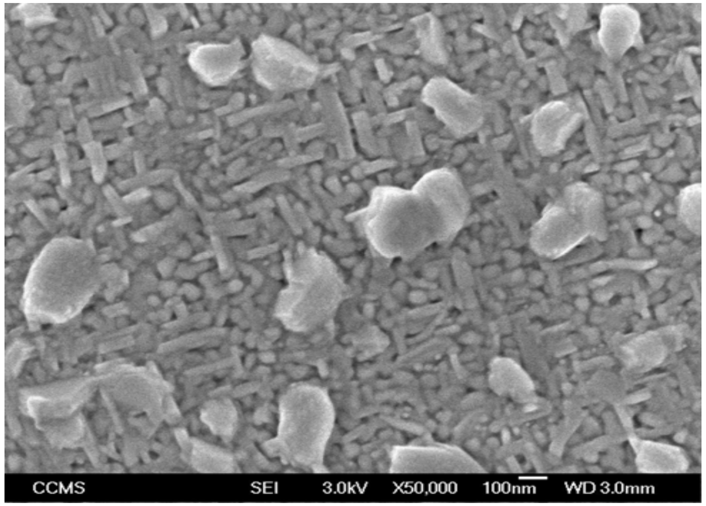




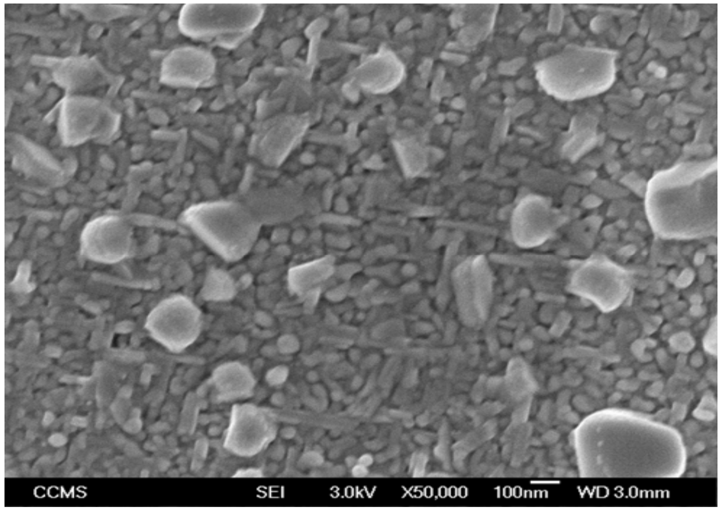
- For $t_{LSMO} < 50$ nm
  Ferromagnetic insulator
- For $t_{LSMO} \geq 50$ nm
  $T_{M\text{-}I} = 360$ K
  Ferromagnetic metal
  MR = -6.81%
  (at room temperature)

Morphology of YBCO/ LSMO (t)

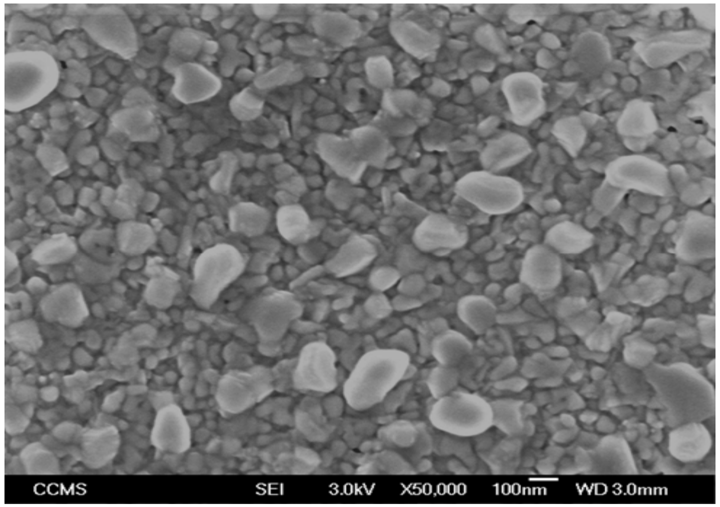




Pure YBCO

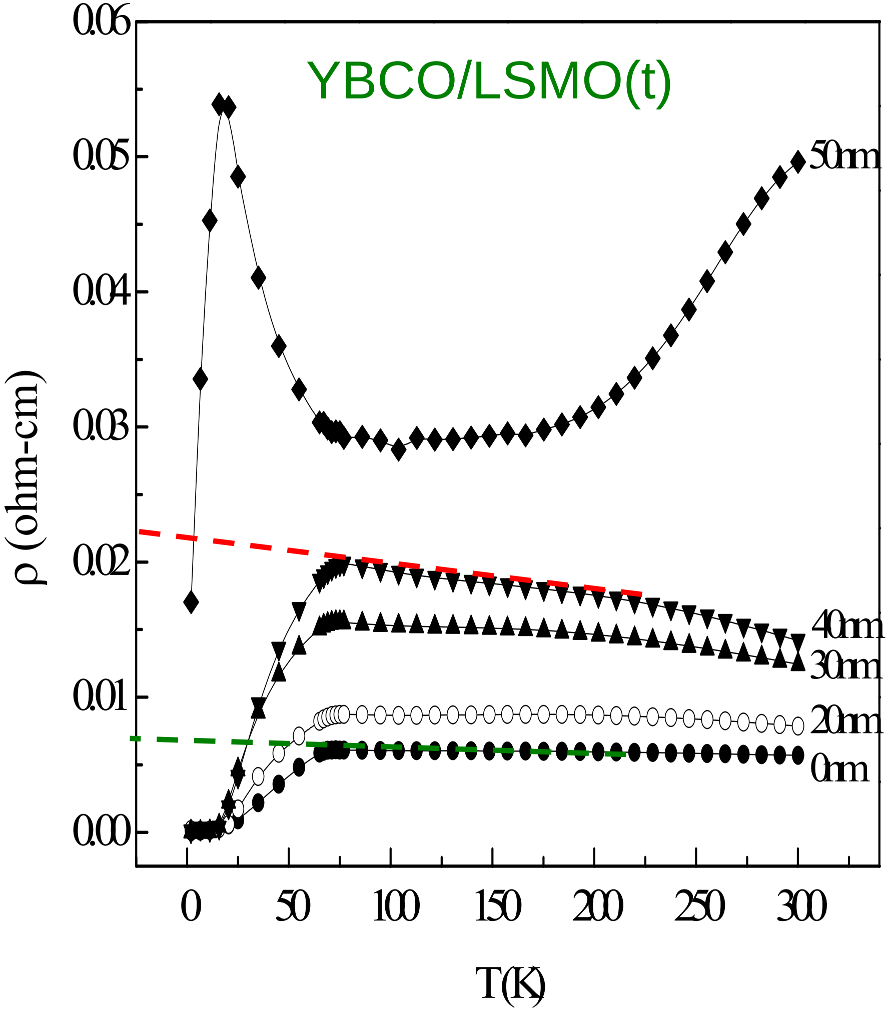


Y/L(30nm)

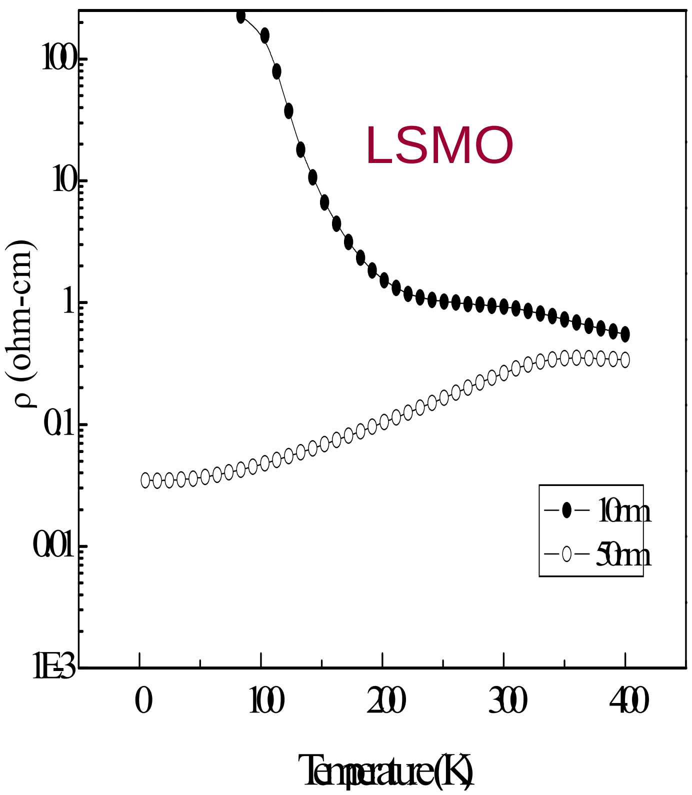


Y/L(50nm)

Resistivity for YBCO(150nm)/LSMO(t)

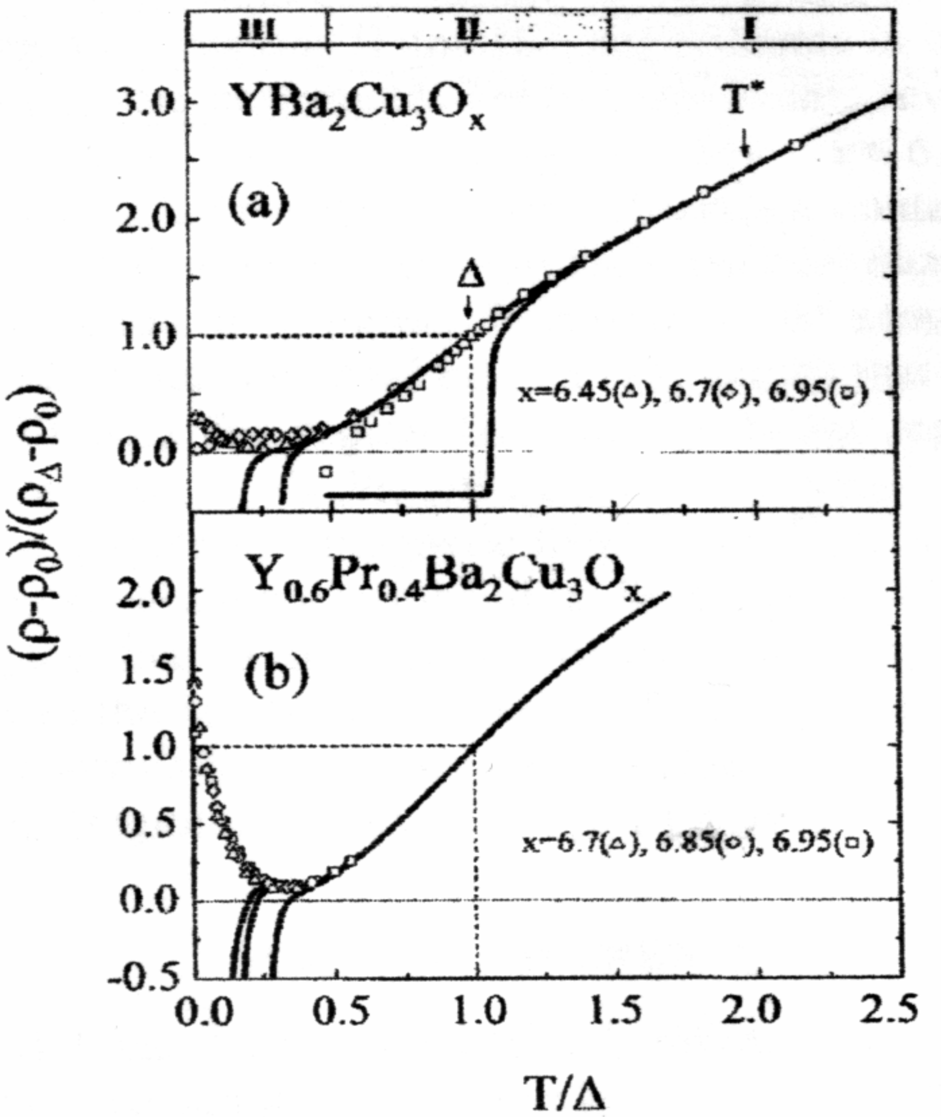


LSMO(50nm)- FM Metal
LSMO(10nm)- FM Insulator



Ground state of high-T_c superconductor is an insulator ?

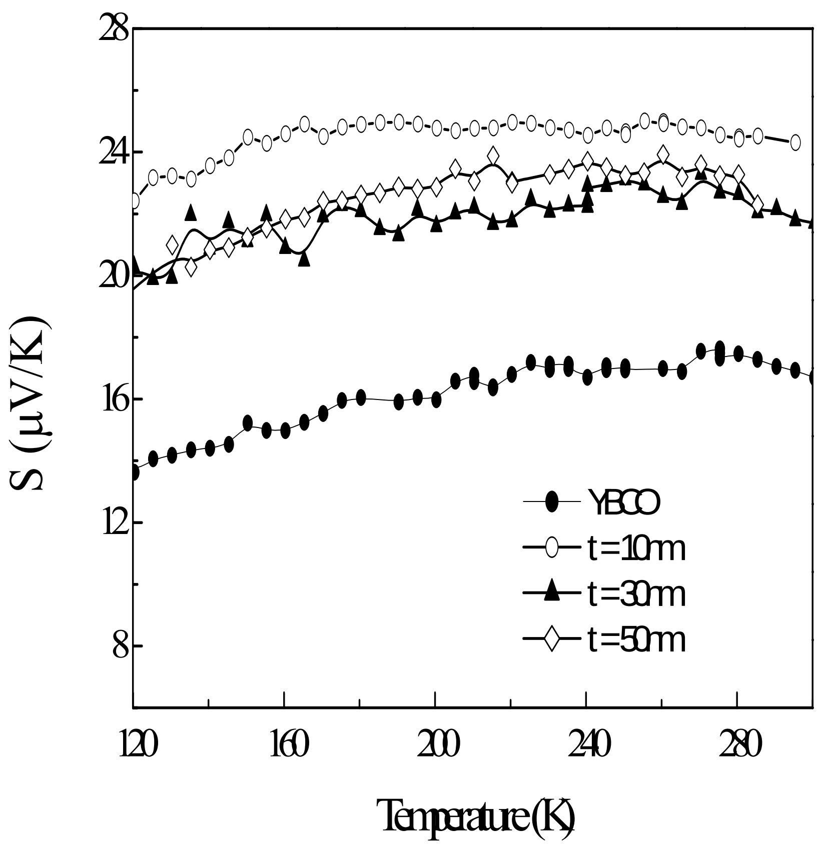
Solid lines:
without field
Open symbols:
at 50 tesla



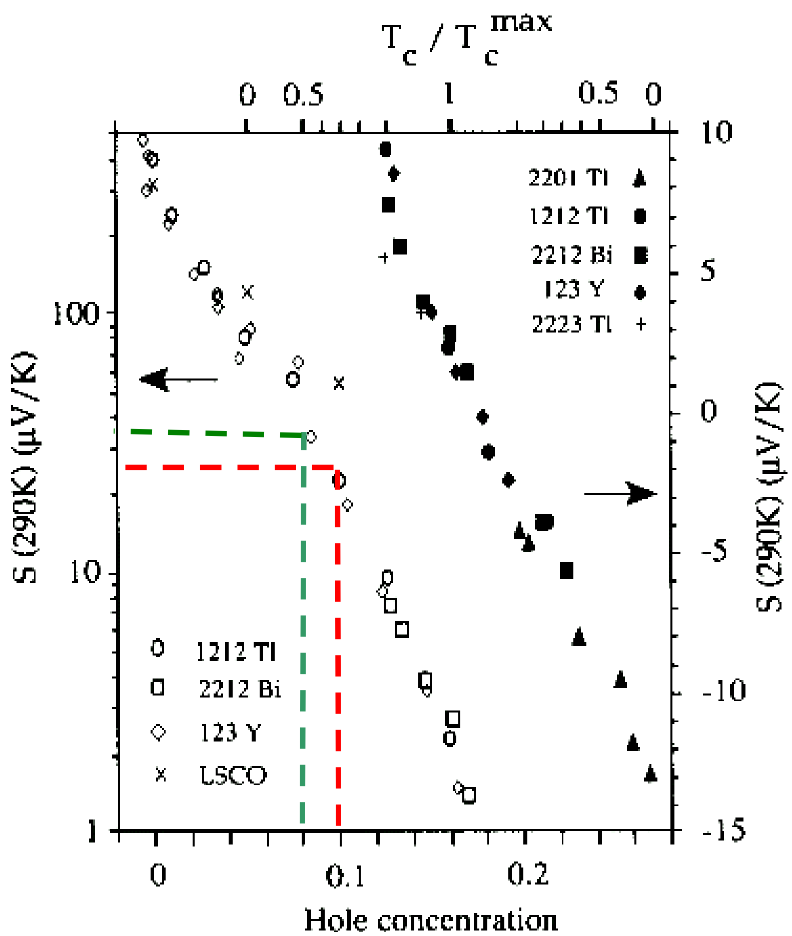
Vanacken et al., PRB 64 (2001)

Thermoelectric power

Our data

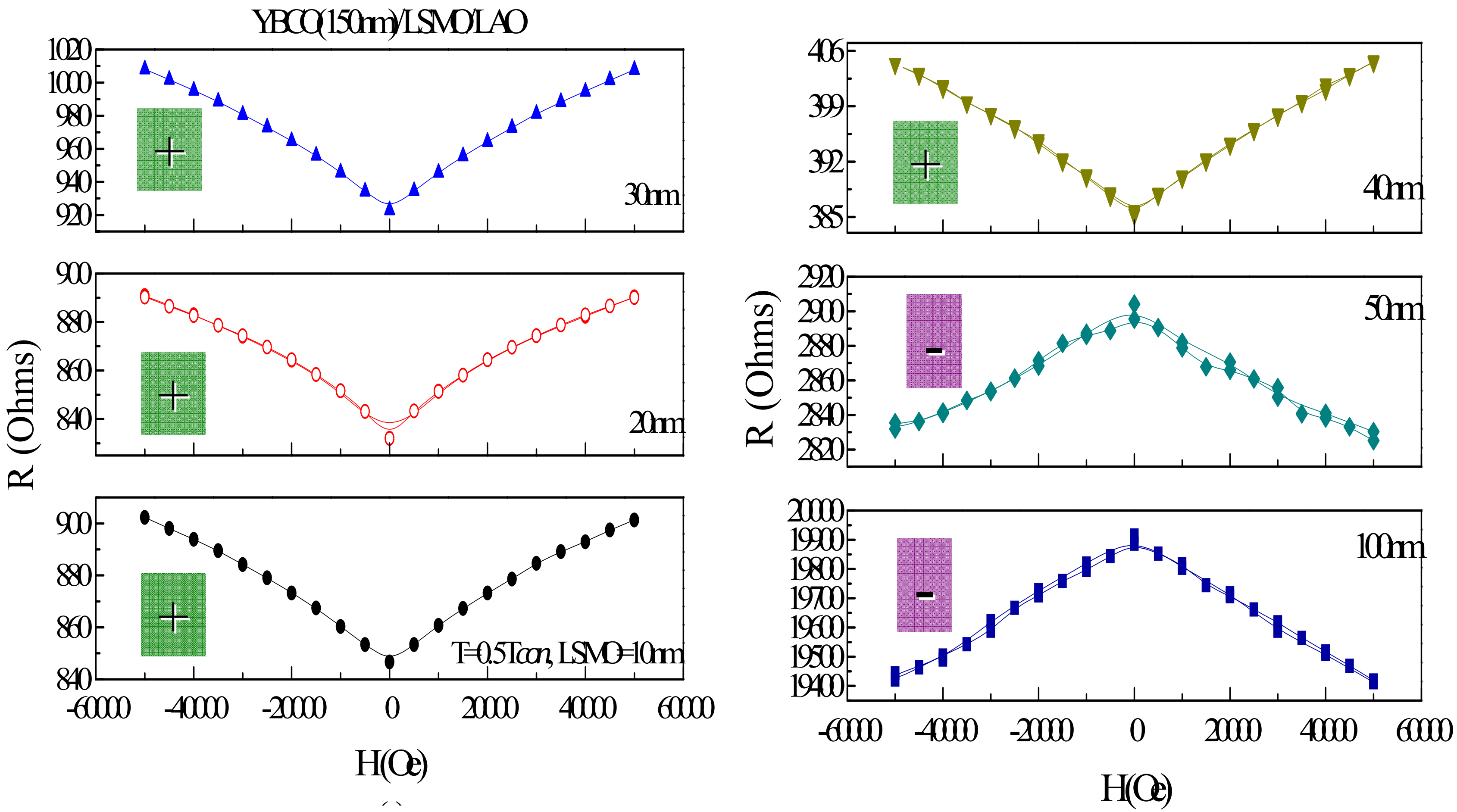


Obertelli et al., PBR 46 (1992)



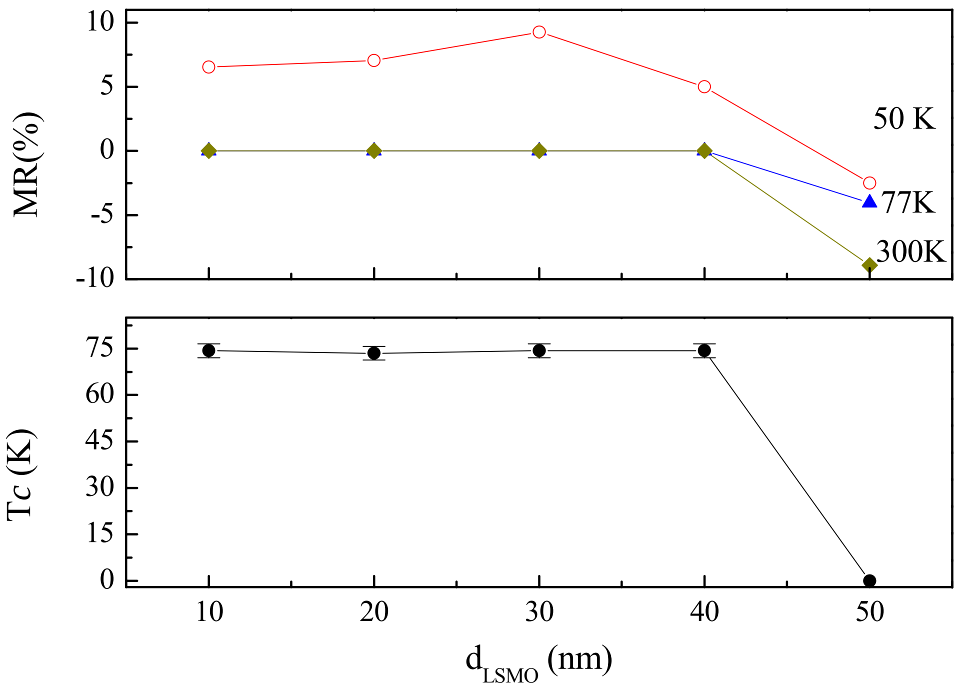
0.09 < n[Y/L(10-50 nm)] < 0.1 (YBCO)

R-H curves at mixed state (50K) for Y/L(t) bilayers

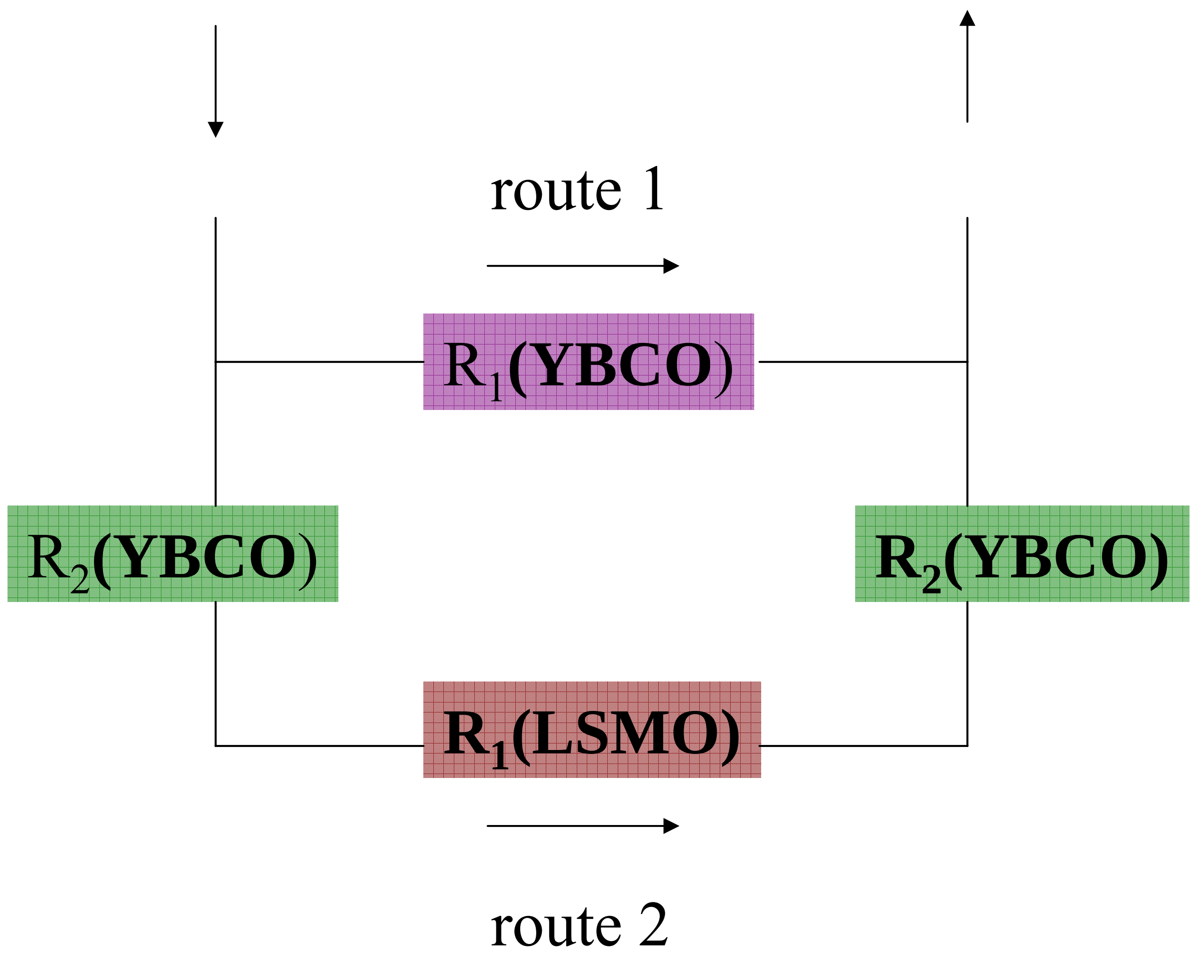


(a) (b)

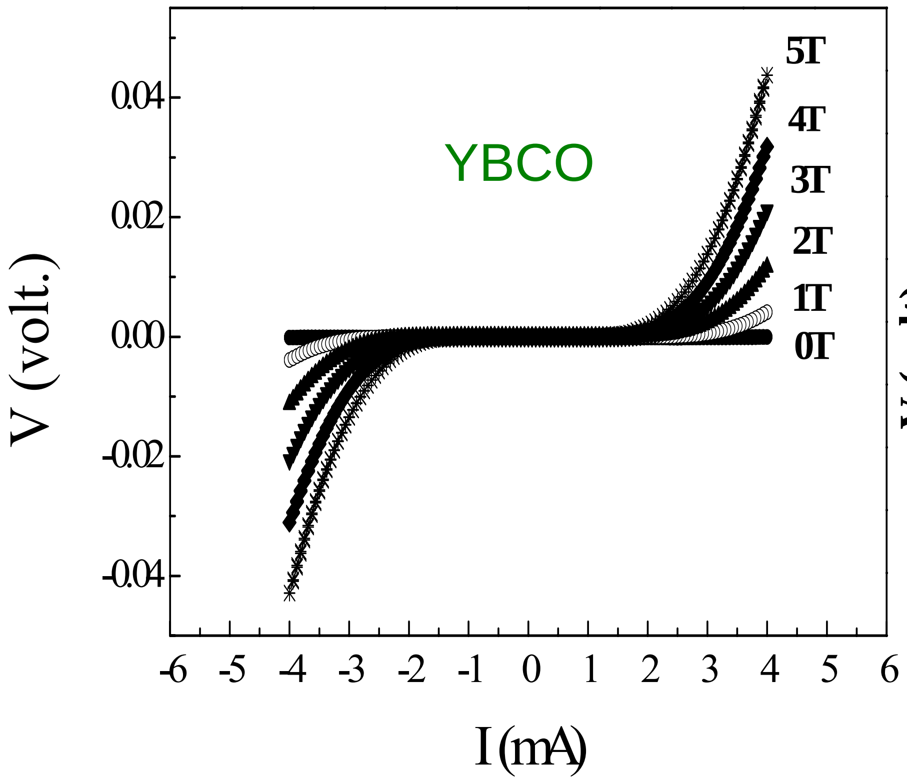
Summary of MR in YBCO/LSMO(t) bilayers

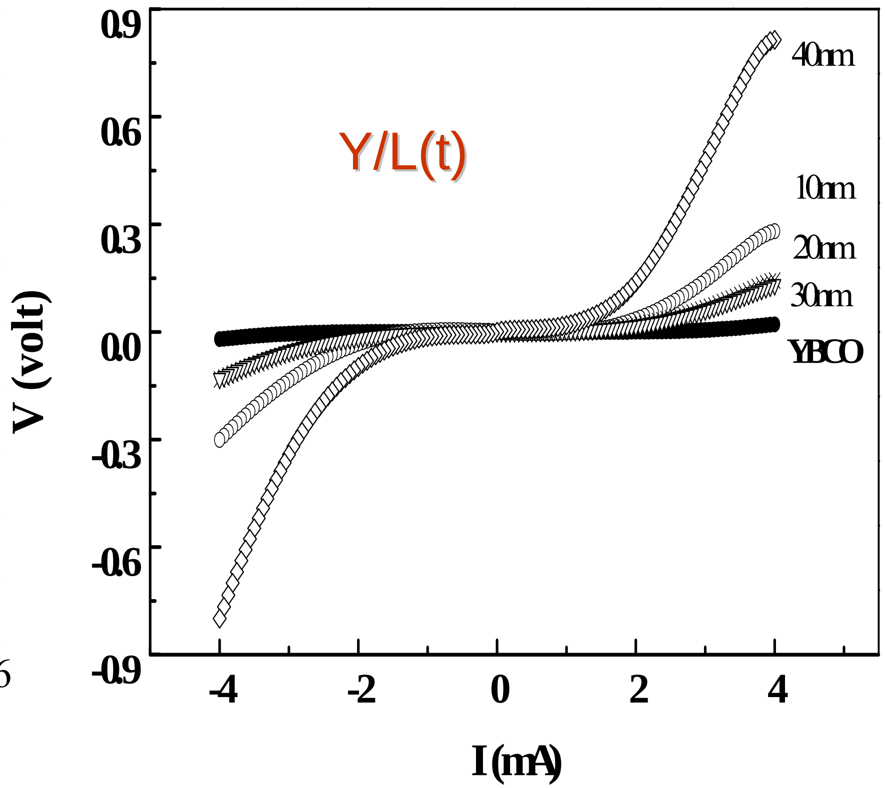


Proposed effective circuit



I- V Characteristic (2 K)

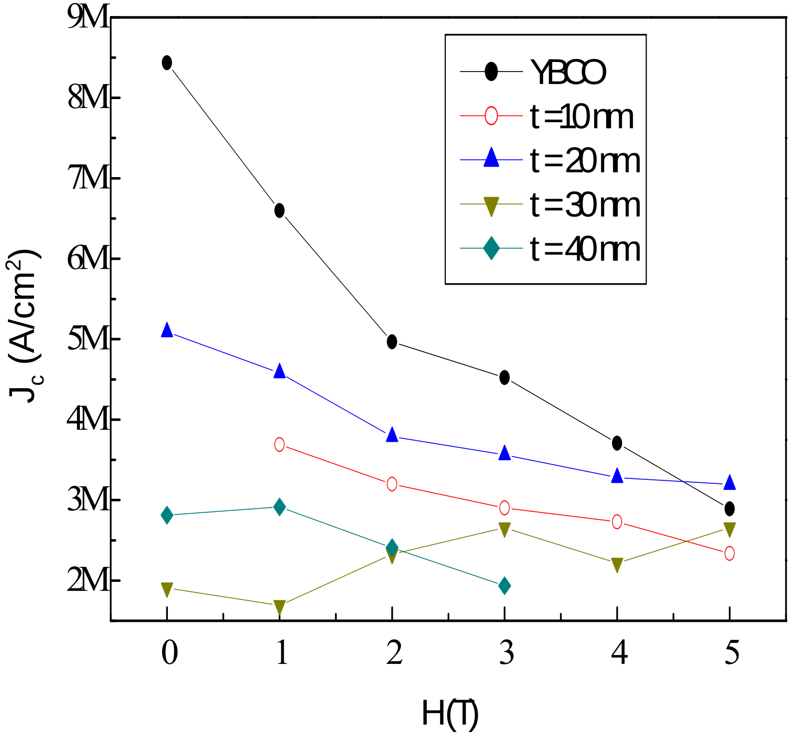


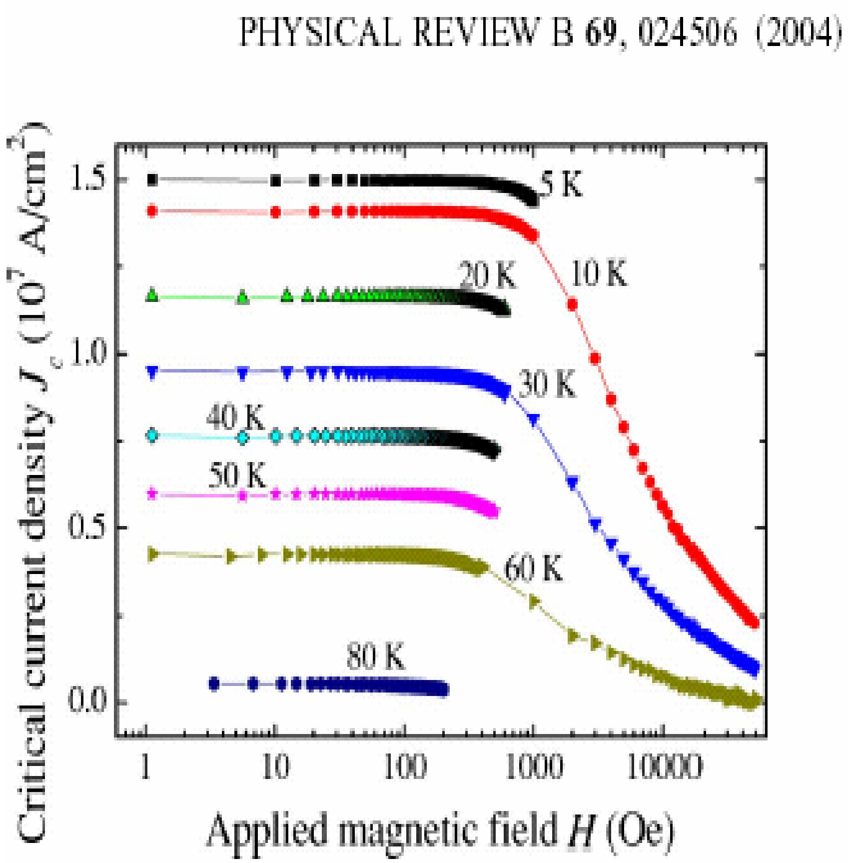


I_c is defined as the current value where V = 1 μvolt.

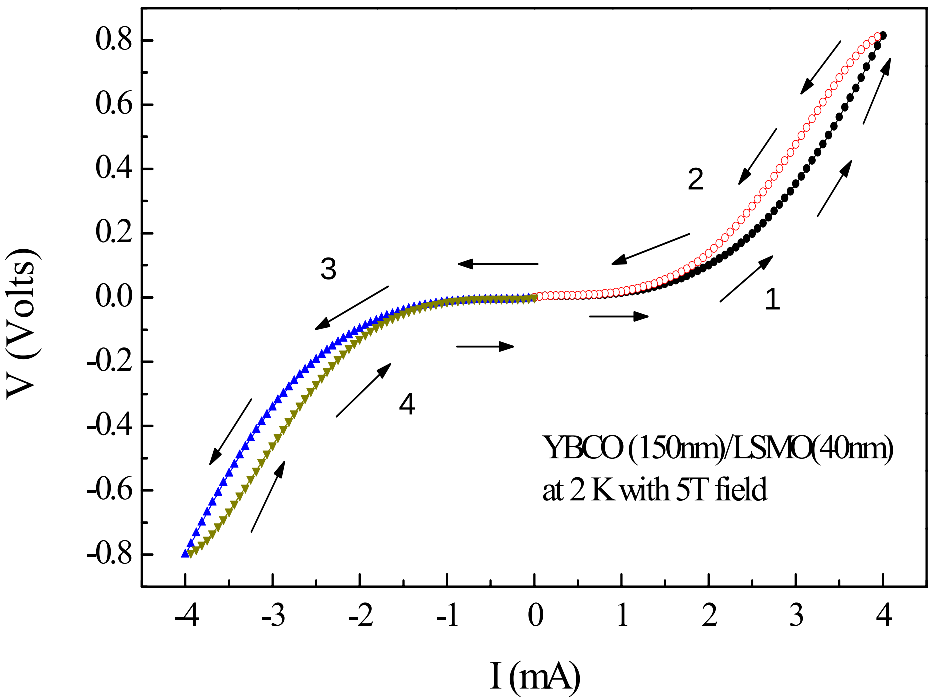
Magnetic dependent critical current density

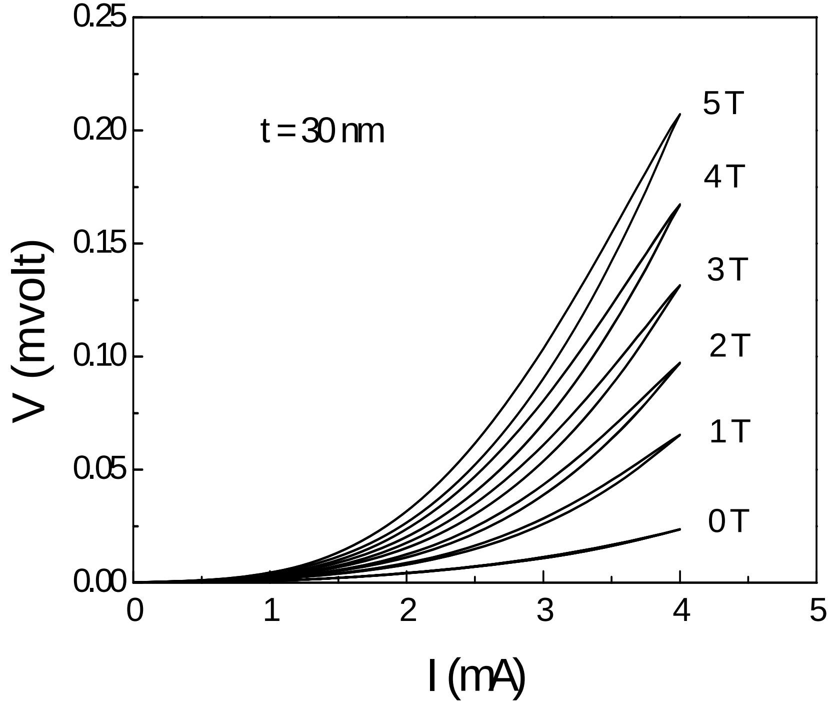
$J_c = I_c$/cross-section
Bean: $\alpha = Bj_c$
K-A: $\alpha = j_c(B+B_o)$





Hysteresis in V- I Characteristic





- Observing anti-clockwise hysteresis in YBCO/LSMO bilayers

PHYSICAL REVIEW B VOLUME 52, NUMBER 1 1 JULY 1995-I

Flux-flow fingerprint of disorder: Melting versus tearing of a flux-line lattice

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(Received 25 April 1994)

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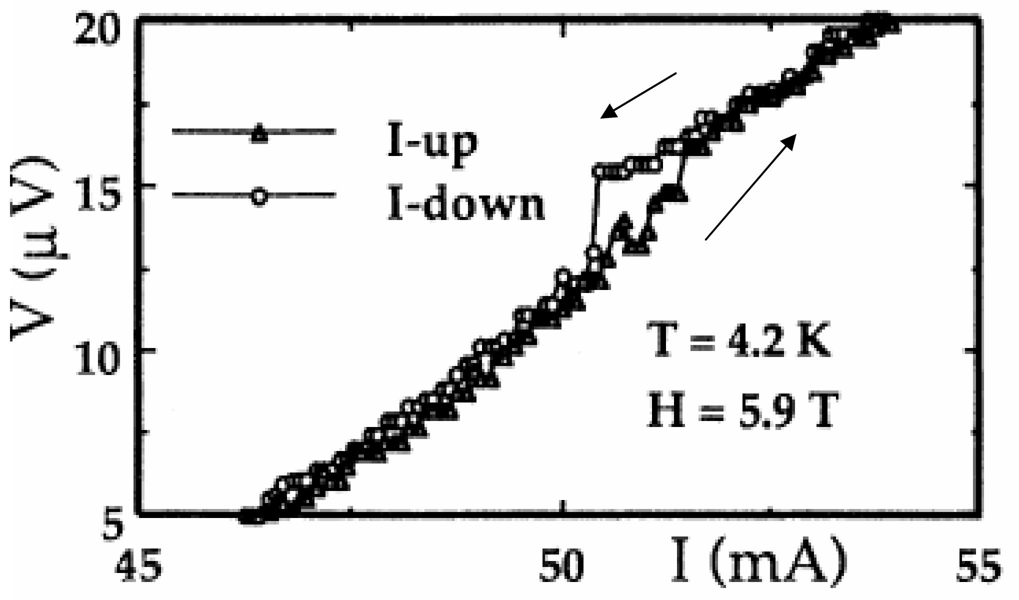
1. Fingerprint of dynamics generated disorder via interaction between flux-line lattice & pinning centers.
2. A "tearing" of a soft lattice in a narrow regime of (H, T).
3. A first order depinning transition.

2H – $NbSe_2$ single crystal
(T_c = 7.1 K, H_{c2} ~ 2.3 T)



VOLUME 85, NUMBER 15 PHYSICAL REVIEW LETTERS 9 OCTOBER 2000

Equilibration and Dynamic Phase Transitions of a Driven Vortex Lattice

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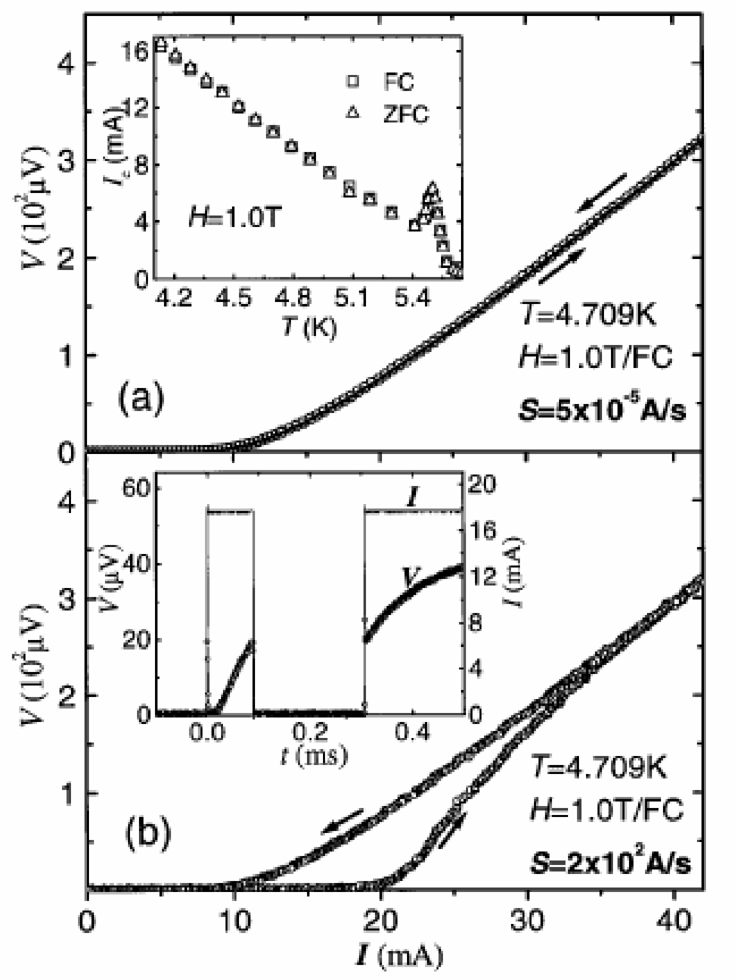
(Received 31 January 2000)



$2H – NbSe_2$ at 4. 7 K, 1 Tesla
T_c = 7.1 K, H_{c2} ~ 2.3 T

Only fast rate I-sweep produces Hysteresis (S = 2×10^2 A/s)

When I increases, the flux-line lattice transits from a metastable to a stable state, followed by a dynamic crystallization transition at high currents.

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History effect in inhomogeneous superconductors

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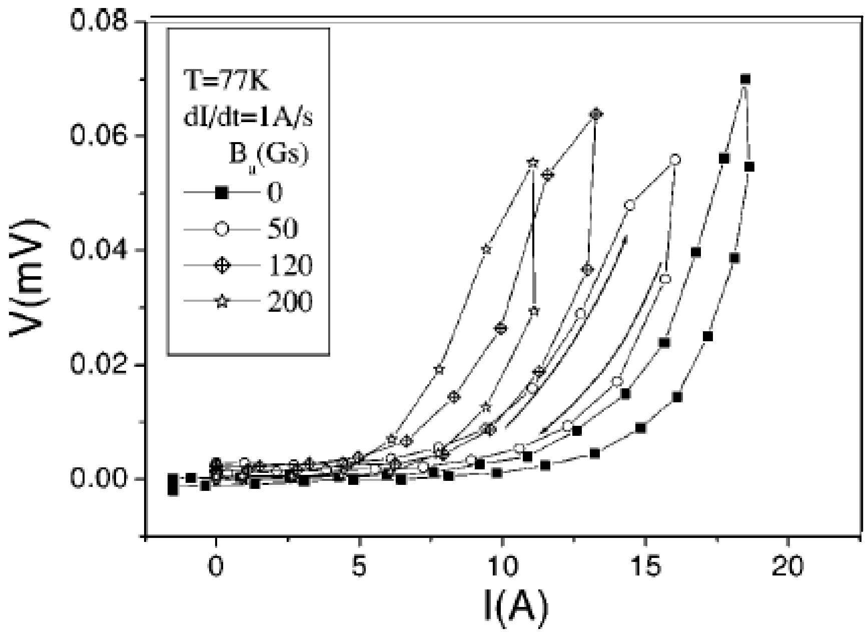
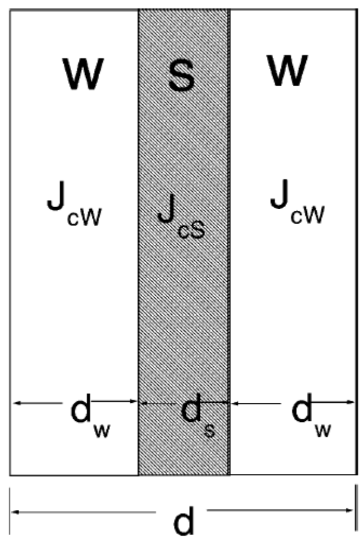
1. Ag-Bi2223 tape at 77 K; fast sweep
2. Considering flux creep and inhomogenous Flux pinning;
3. Clockwise hysteresis.





Conclusion

- *Suppression of T_c in YBCO/LSMO(t) bilayer is observed at t = 50 nm, which should be originate from intrinsic proximity effect.*
- *Reversal of the sign of MR ratio in 50-nm YBCO/LSMO bilayer indicates the competition between superconductivity and ferromagnetism.*
- *We have observed magnetic pinning effect and hysteresis in V-I curves of YBCO/LSMO bilayers.*