SAND2016-4952C

Magneto-Photoluminescence and Giant Magneto-Resistance in Self-Assembled Vertically-Aligned $(ZnO)_{0.5}$:$(La_{0.7}Sr_{0.3}MnO_3)_{0.5}$ Nanopillars

Wei Pan
Sandia National Labs

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Collaborators:

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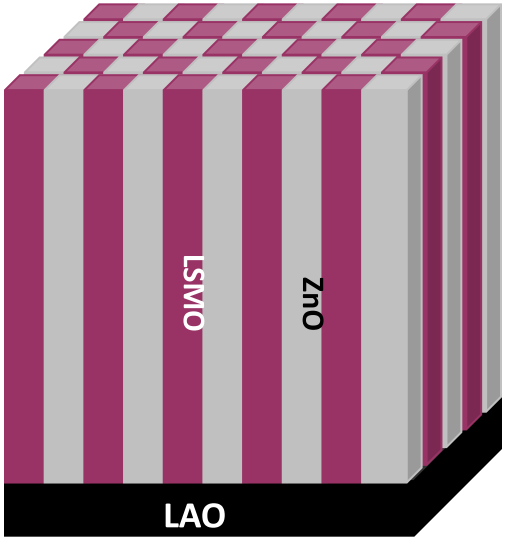
LANL: Q.X. Jia

NHMFL: T.D. Tokumoto and S.A. McGill

Outline:

- Motivation
- Growth
- TEM and XRD
- Magneto-PL
- Magneto-resistance

Profound interface effect in vertically aligned nanostructures



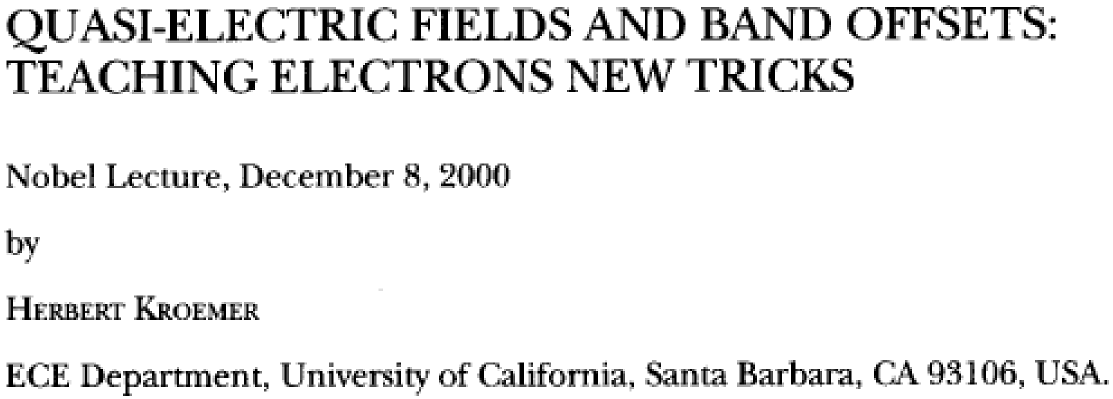
- **Due to a reduction in dimensionality, the large interface area plays an important role in determining the structural and functional properties of nanocomposite film.**

- **The coupling of different functionalities in two dissimilar components provides a vast parameter space for exploiting interface properties and functionalities.**

- **Epitaxial nanocomposites provide new opportunities for novel/improved functionality not available from bulk crystals.**

The Interface is the device

-- Herbert Kroemer, UCSB



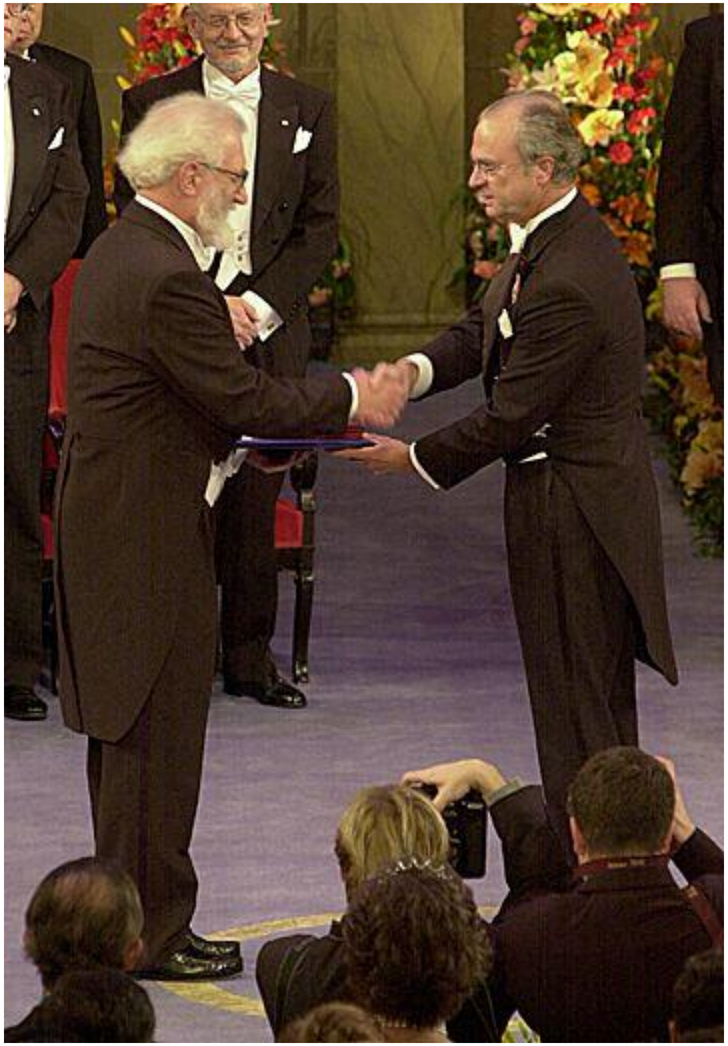
QUASI-ELECTRIC FIELDS AND BAND OFFSETS:
TEACHING ELECTRONS NEW TRICKS

Nobel Lecture, December 8, 2000

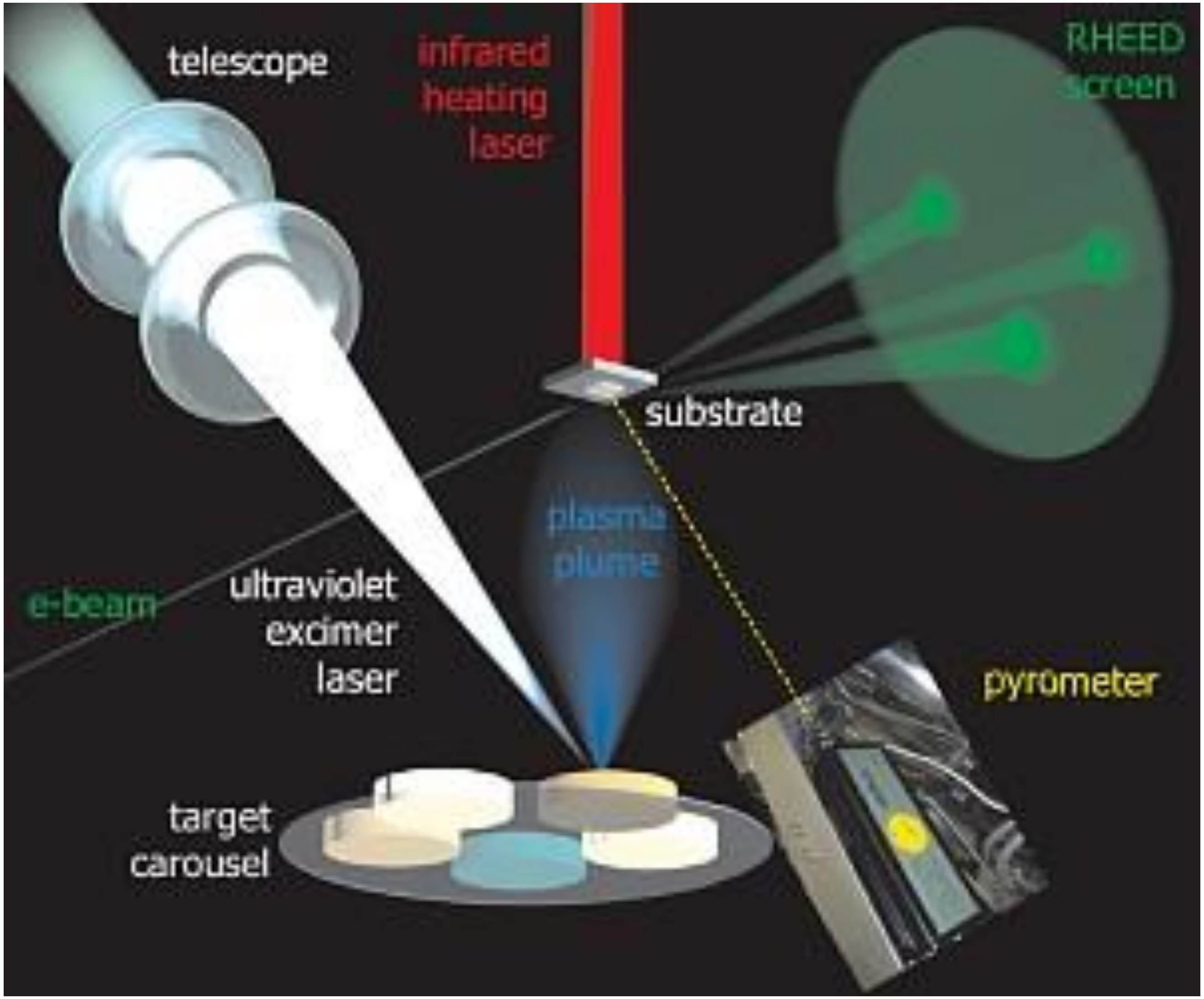
by

HERBERT KROEMER

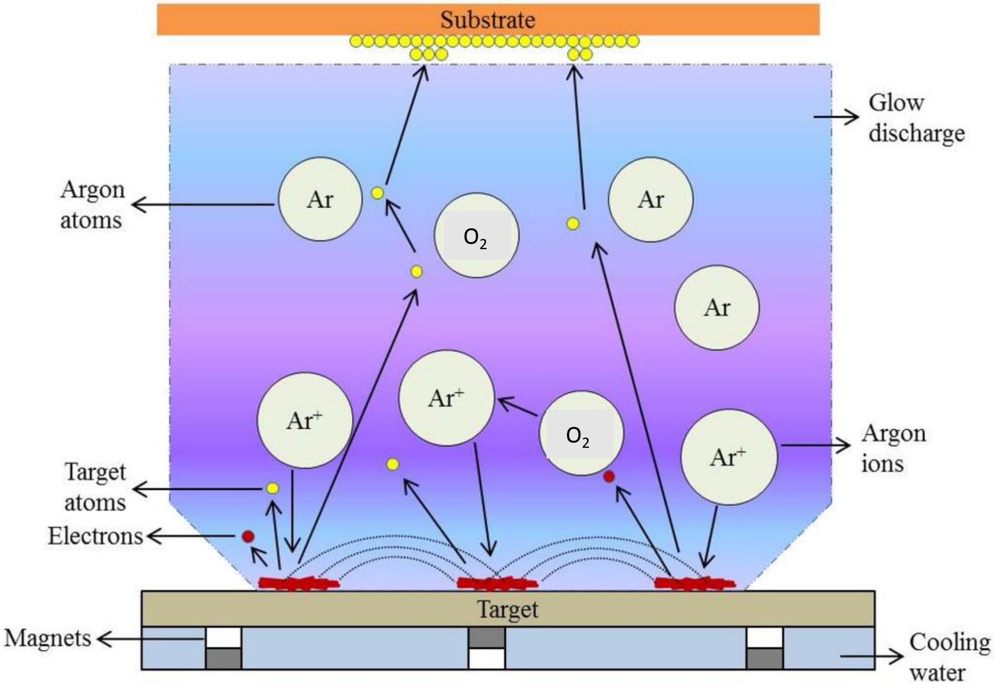
ECE Department, University of California, Santa Barbara, CA 93106, USA.



PLD growth


telescope
infrared heating laser
RHEED screen
substrate
plasma plume
e-beam
ultraviolet excimer laser
pyrometer
target carousel

Sample growth – rf magnetron sputtering



growth parameters:

30W, 20 mTorr

5:1 for Ar:O_2

Substrate Temp: 700 or 750 °C

Outline:

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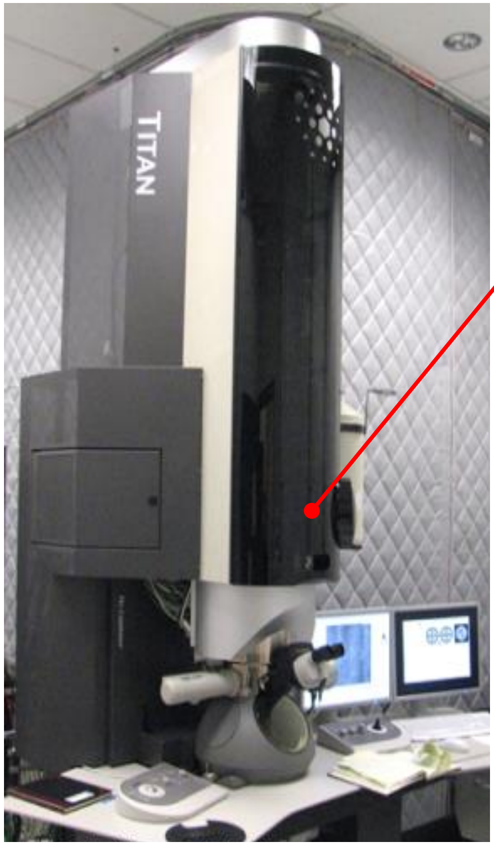
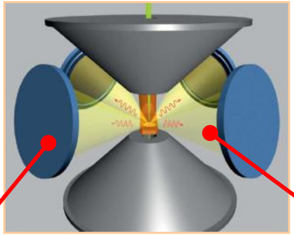
- **TEM and XRD**
- Magneto-PL
- Magneto-Resistance
- Summary

Sandia's AC-STEM provides unprecedented capabilities for interface characterization



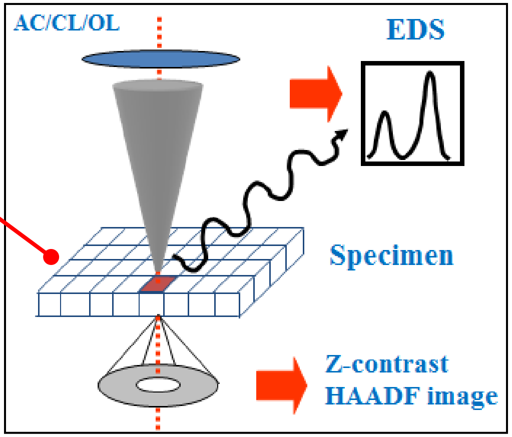
Titan P ChemiSTEM

Super-EDS



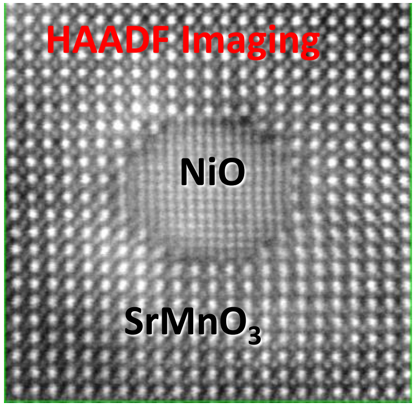
- 4 SDD geometry around the sample

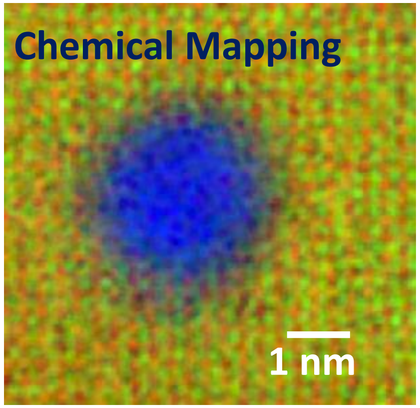
Aberration correction and four in-lens EDS X-ray detector technologies.



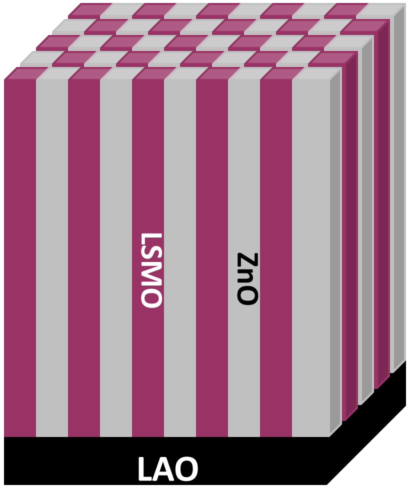
Small, intense electron probe
+
Super efficient EDS detector

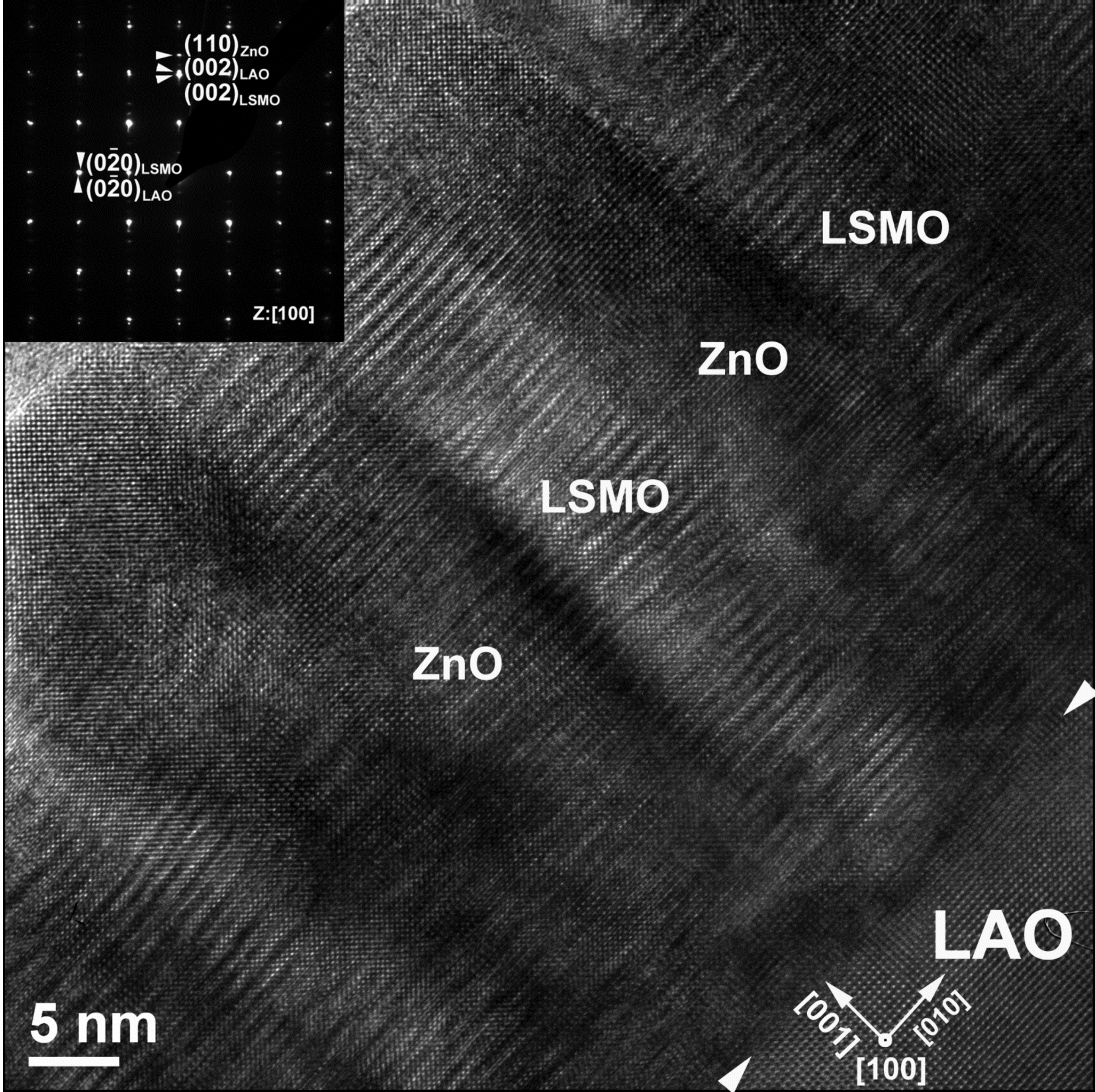
➔ Sub-atomic-scale imaging (0.8Å at 200 kV) & Atomic-scale chemical mapping by EDS

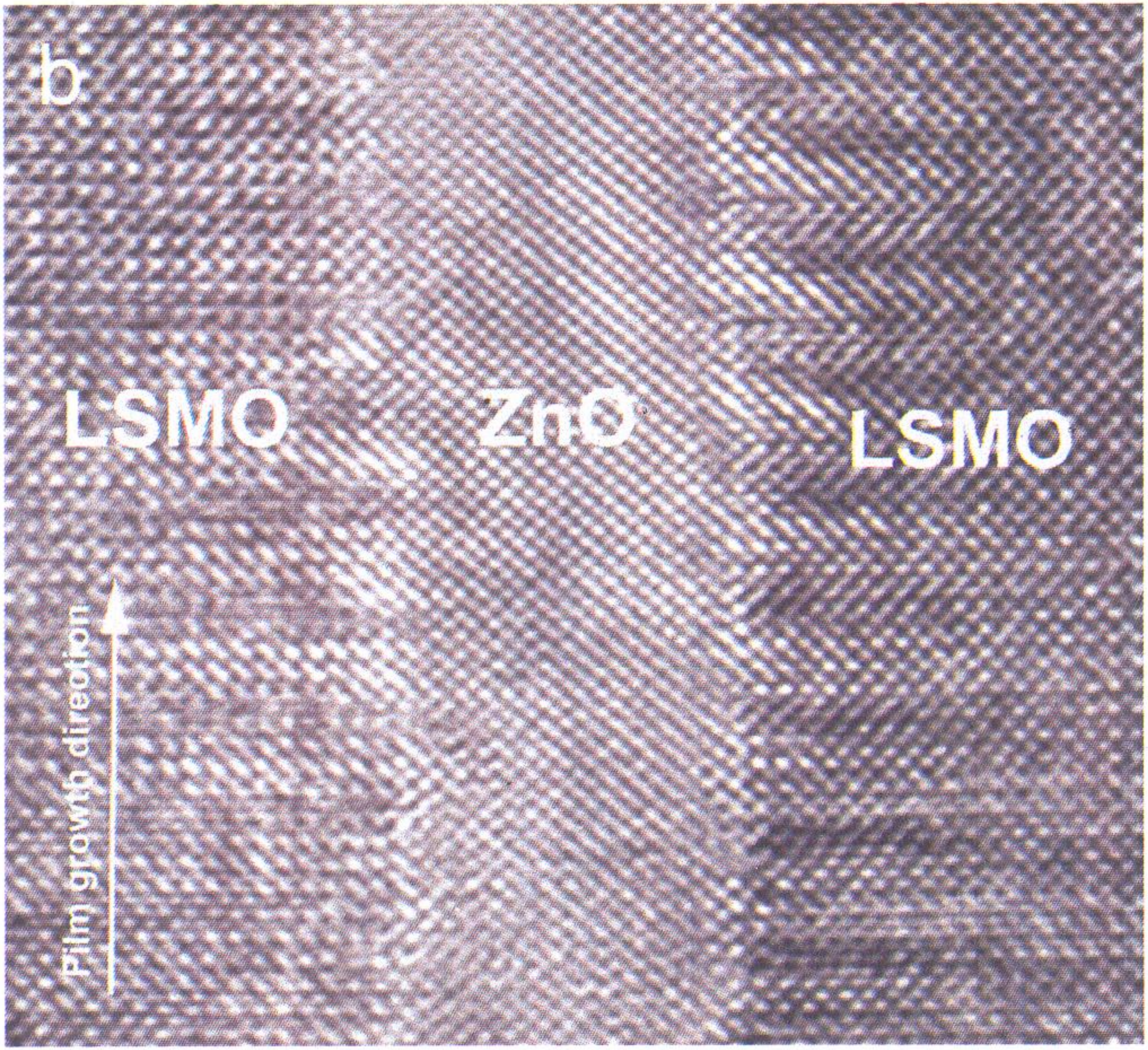




Sr – Red
Mn – Green
Ni – Blue

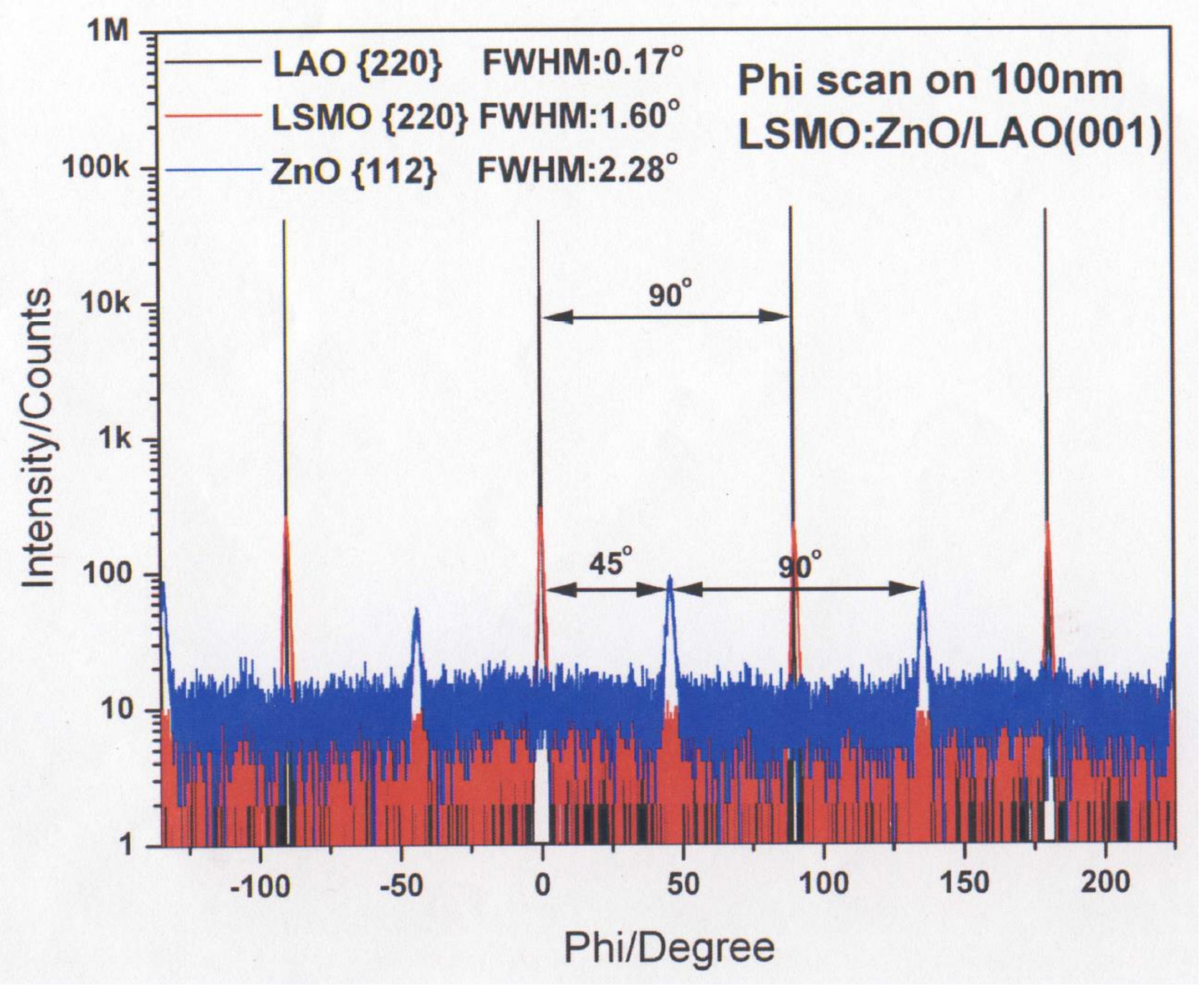

LSMO
ZnO
LAO


(110)ZnO
(002)LAO
(002)LSMO
(0$\bar{2}$0)LSMO
(0$\bar{2}$0)LAO
Z:[100]
LSMO
ZnO
LSMO
ZnO
LAO
[001]
[010]
[100]
5 nm



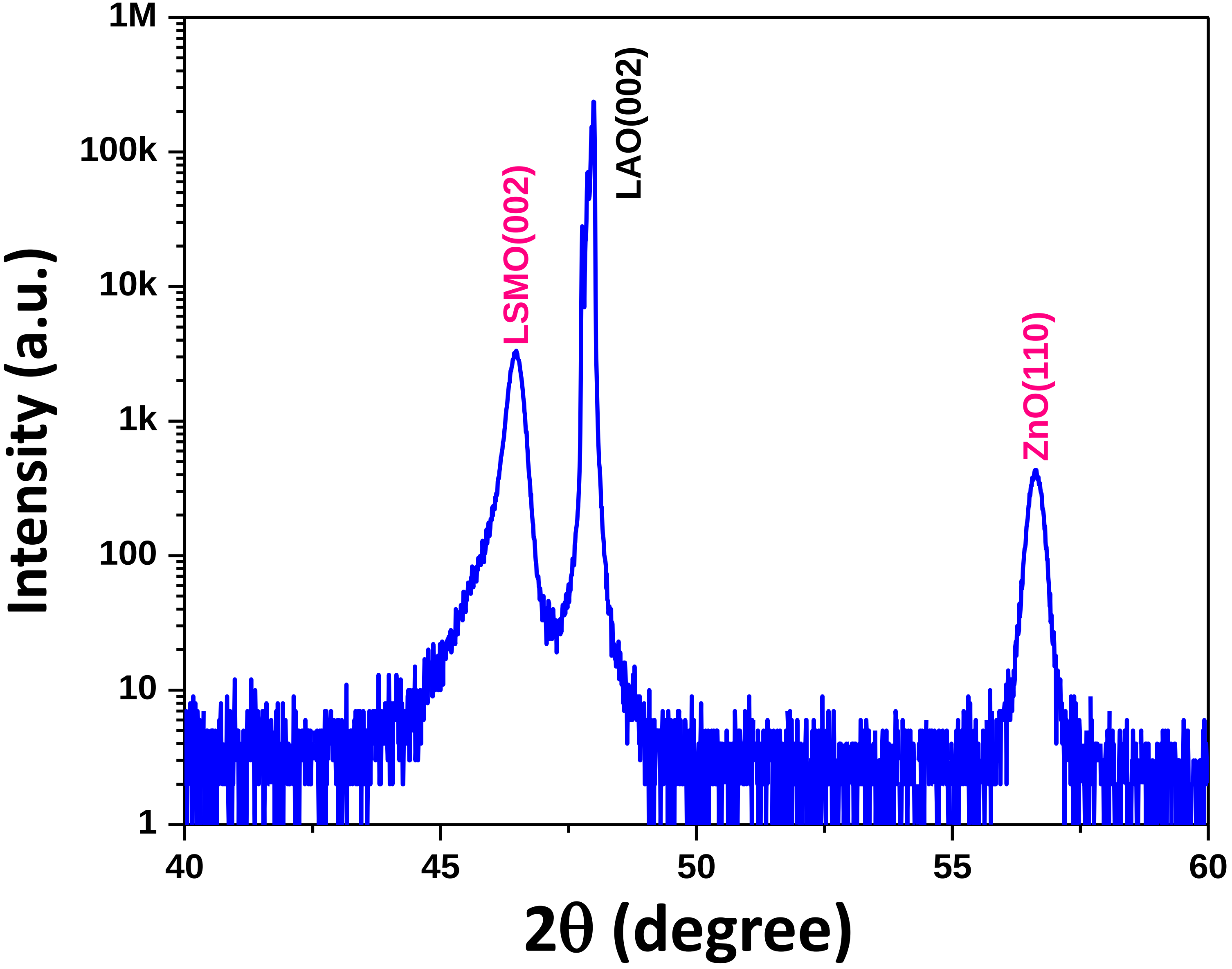
HRTEM image shows vertical lattice matching between LSMO and ZnO columns

In-plane Phi scan

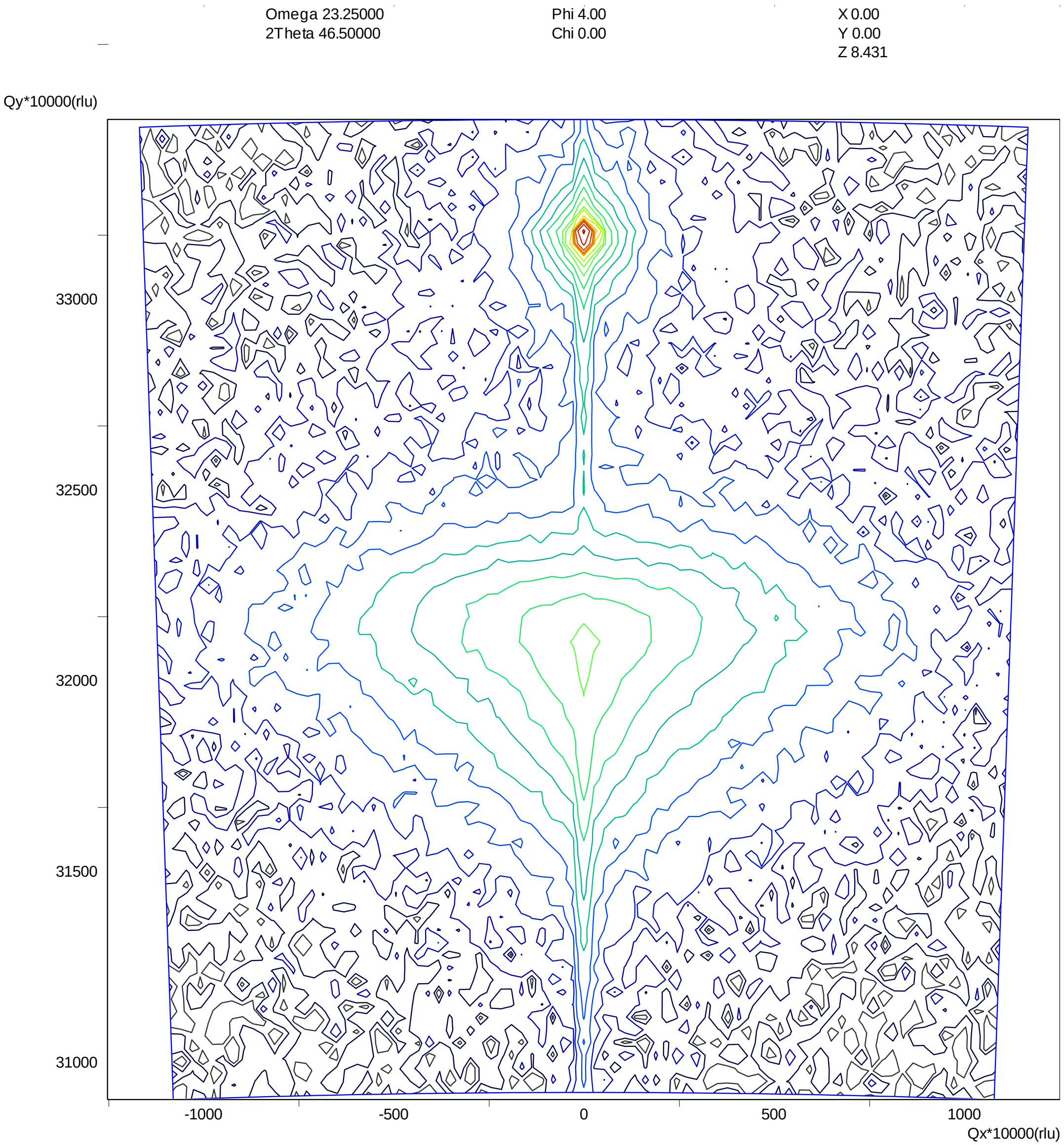


- **epitaxial growth of both LSMO and ZnO phases on LAO substrate.**

- **film/substrate crystal orientation can be determined to be:**
  - **LSMO(001)//LAO(001), LSMO (010)//LAO(010);**
  - **ZnO(110)//LAO(001), ZnO(001)//LAO(110)**


Intensity (a.u.)
1M
100k
10k
1k
100
10
1
40
45
50
55
60
2θ (degree)
LSMO(002)
LAO(002)
ZnO(110)

XRD reciprocal-space analysis



Sample 021815A
LSMO/ZnO on LAO

(002) LAO:
2theta=47.985°
Q_y=3.3171 (1/Å)

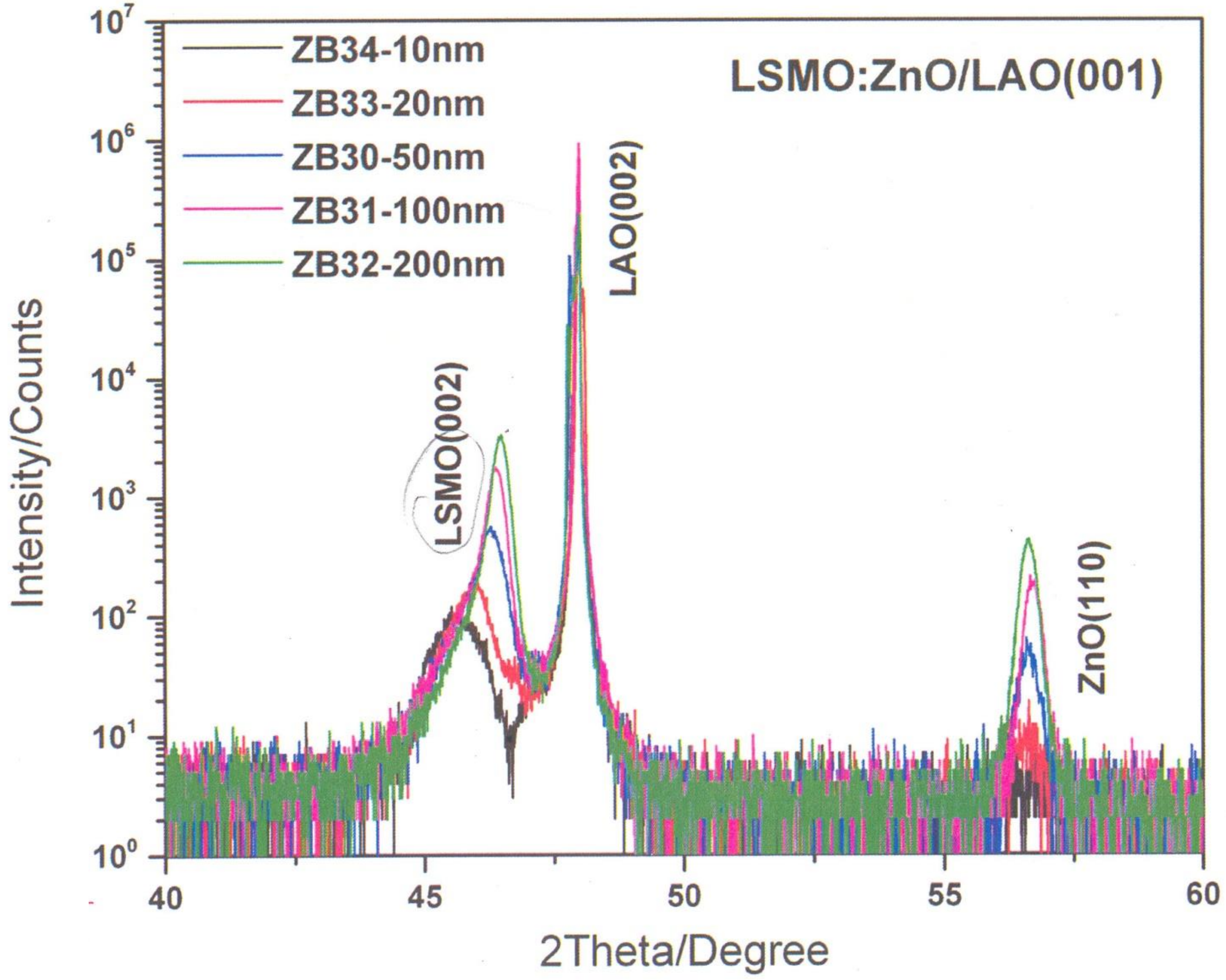
(002) LSMO:
2theta=46.368°
Q_y=3.2099 (1/Å)

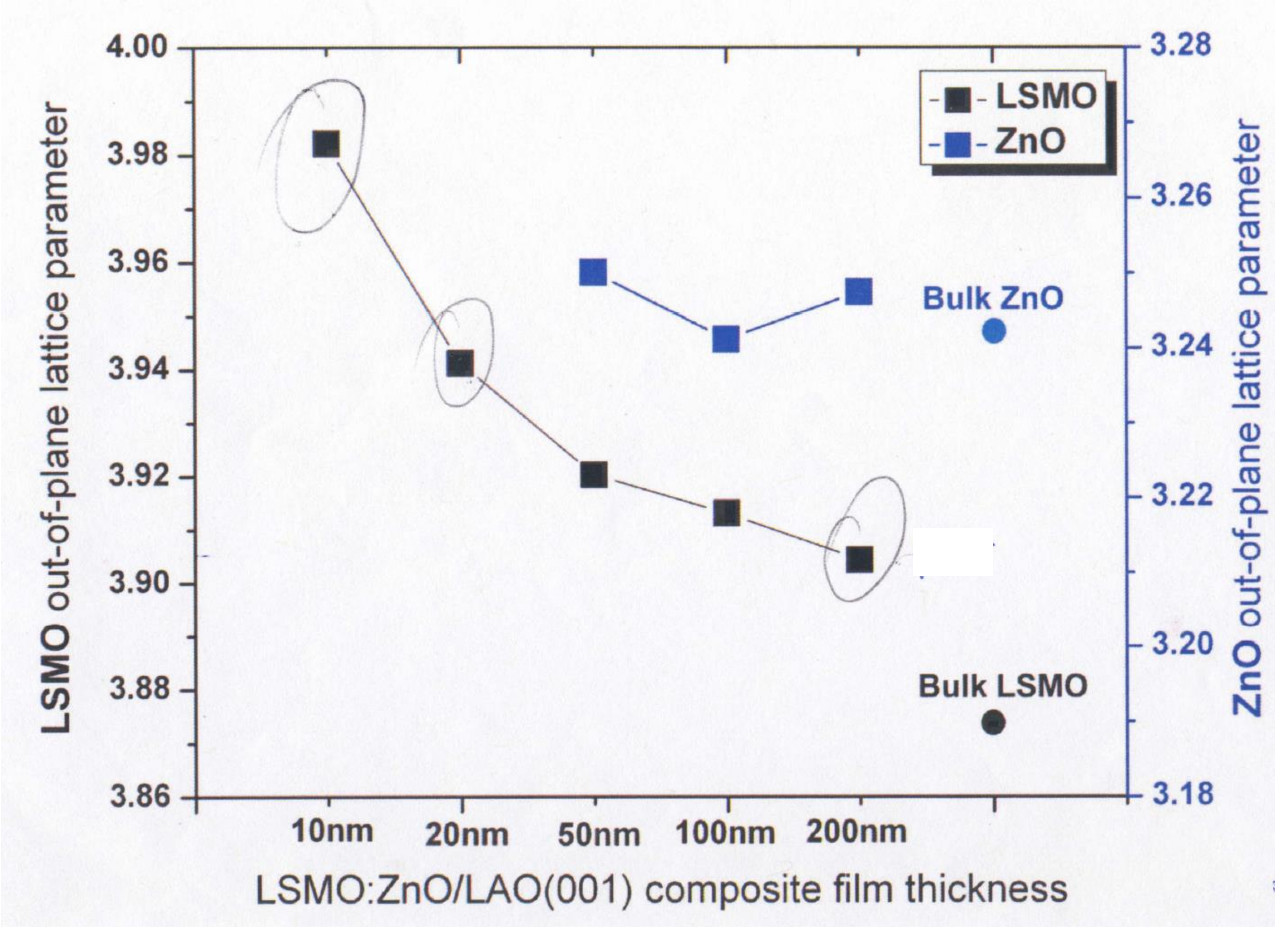
The broad LSMO peak shape reflects the presence of both misfit dislocations and the quasi-periodic columnar holes in the epilayer (filled with ZnO) .

Lao.

LSMO:ZnO/LAO(001)

- $LSMO_{0.5}$:$ZnO_{0.5}$ composite films have been grown on LAO(001) substrate with different film thickness (10nm, 20nm, 50nm, 100nm and 200nm).
- As film thickness increase, the LSMO(002) peak shifted to higher 2theta angle while ZnO(110) peak maintained stable.

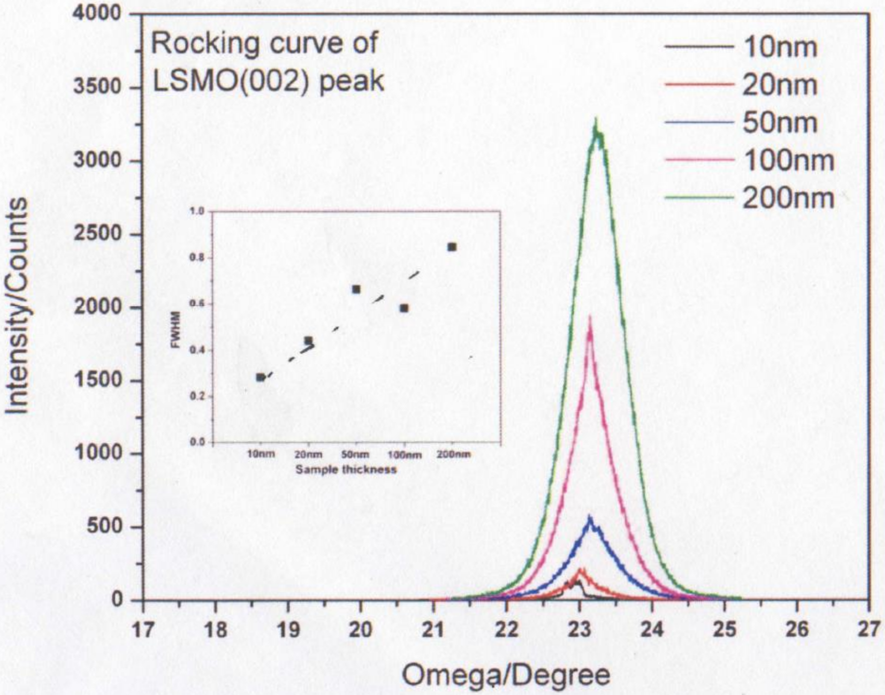


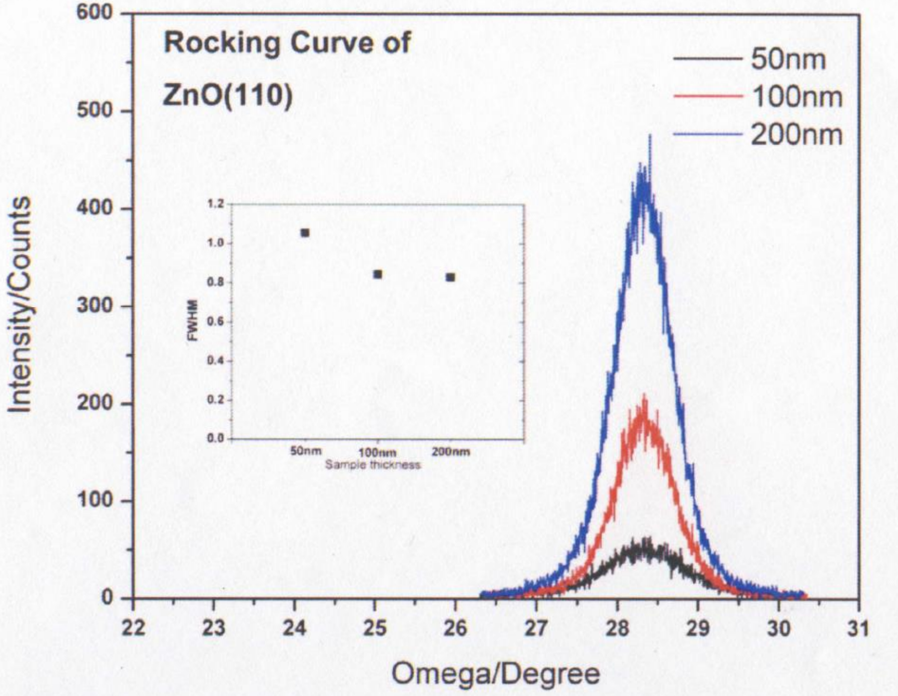


- As film thickness increases from 10 to 200nm, the LAO (a = 3.79Å) substrate induced strain in LSMO (tension out-of-plane) decreases, and the d-spacing of LSMO approaches to the bulk value of 3.87Å)

- No obvious strain tuning in ZnO can be observed. The d-spacing of ZnO is around its bulk value (a_{ZnO} = 3.242Å)

Rocking curve scan around LSMO(002) and ZnO(110) peaks



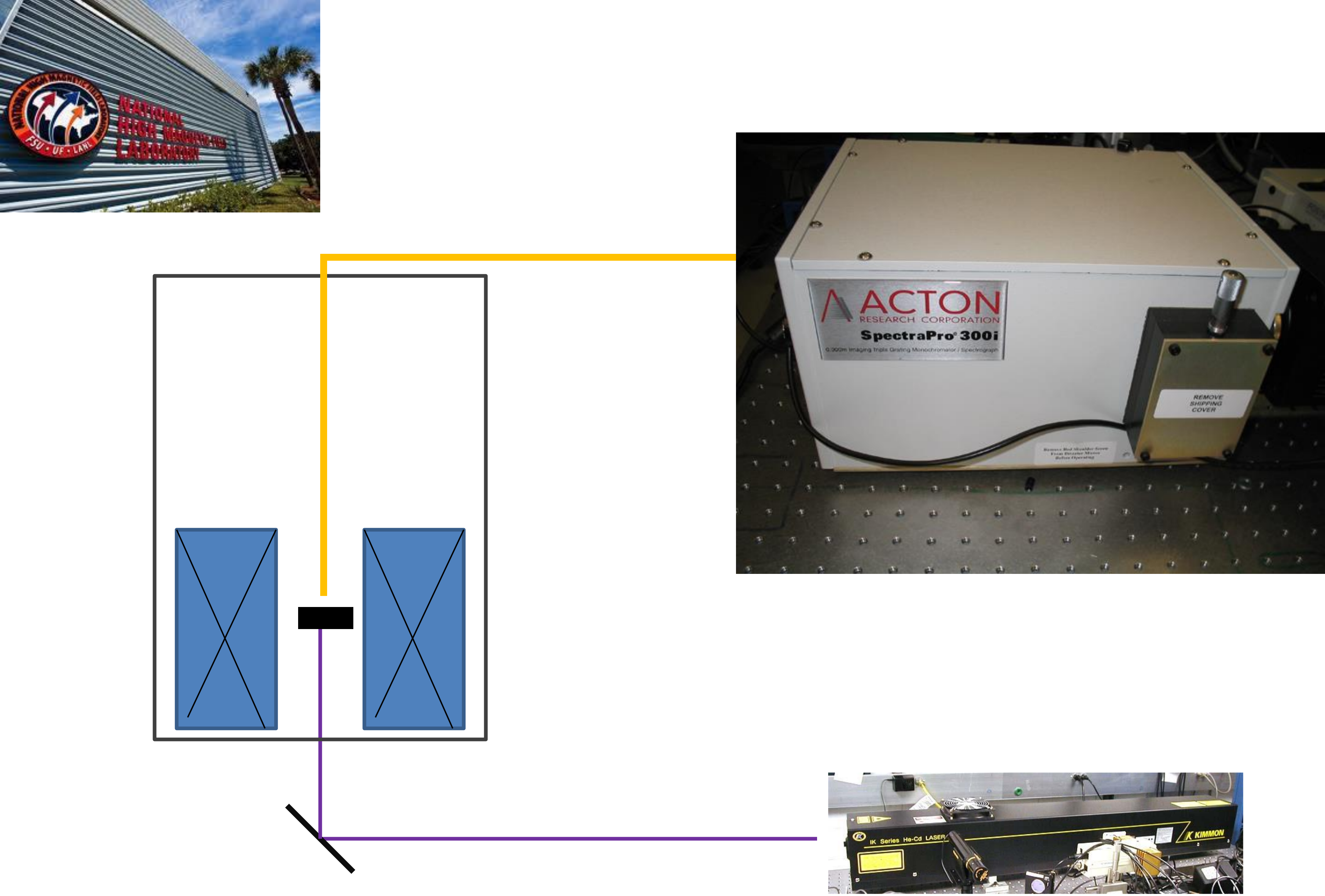


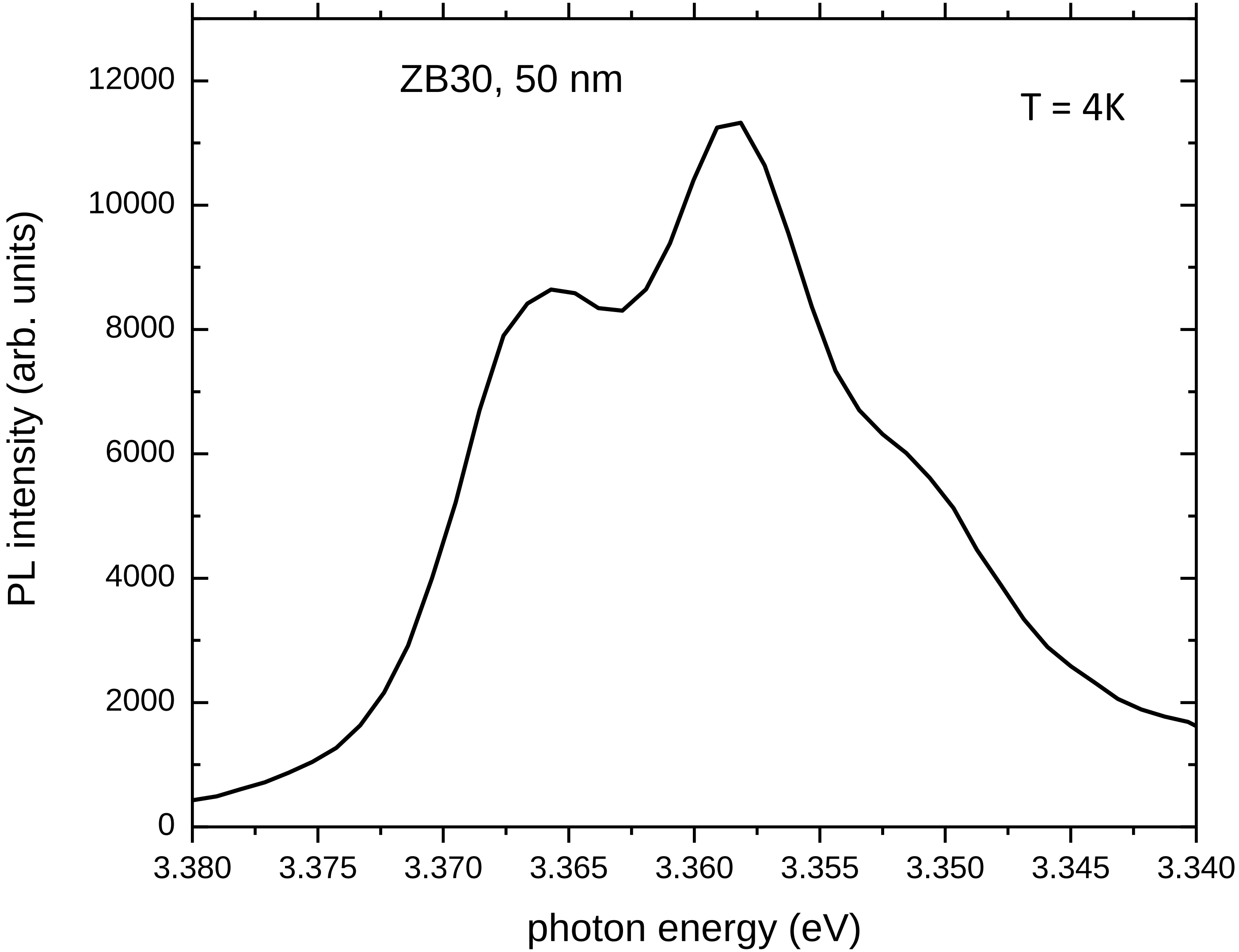
- **FWHM of LSMO(002) rocking curve increases from 0.3 to 0.8º as film thickness increases from 10 to 200nm, indicating in-plane crystal orientation uncertainty.**

- **Similar trend in FWHM of Zn(11) rocking curves as film thickness increases.**

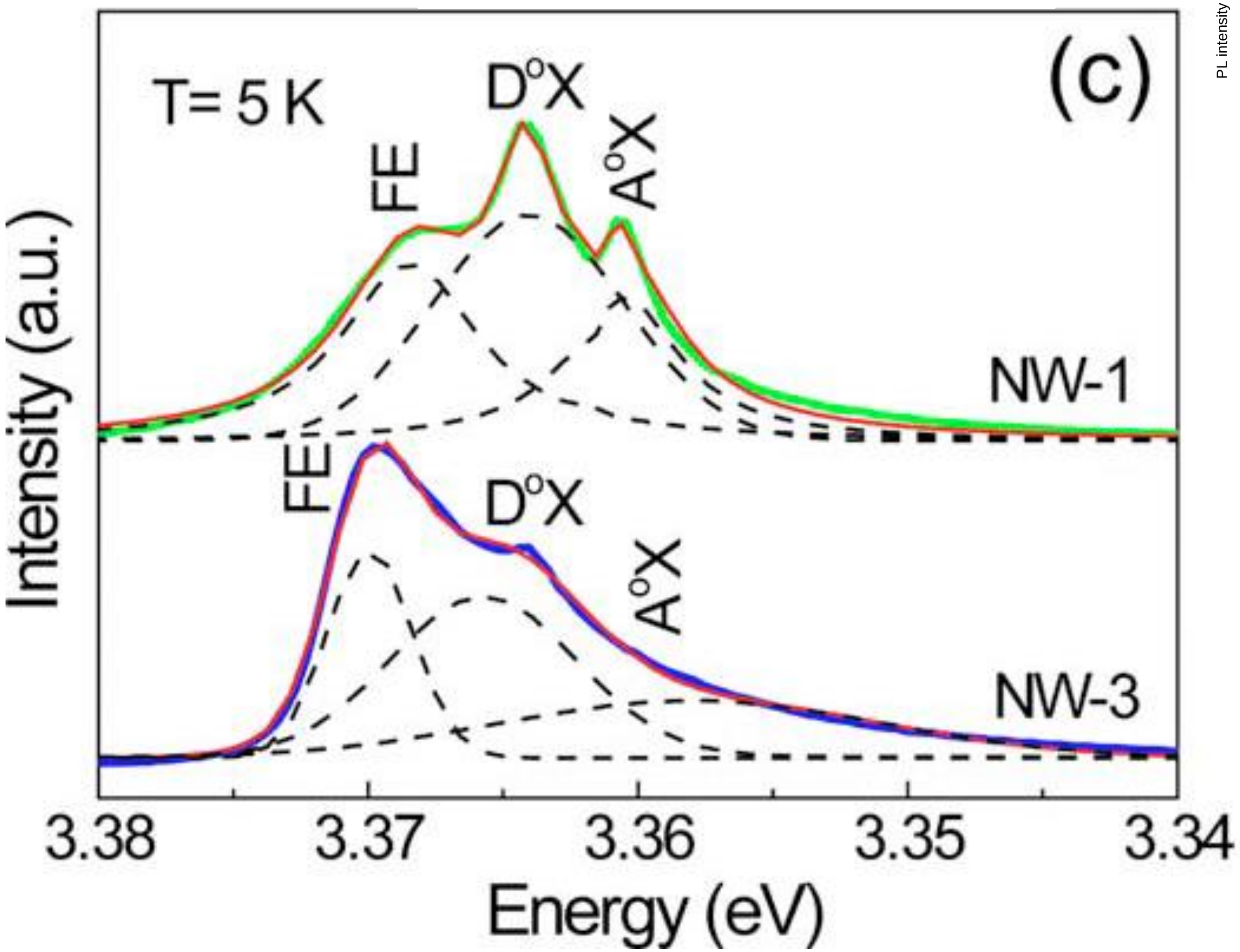
Outline:

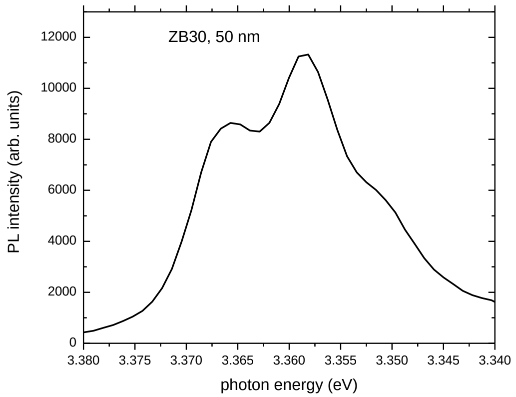
- Growth
- TEM and XRD
- **Magneto-PL**
- Magneto-Resistance
- Summary

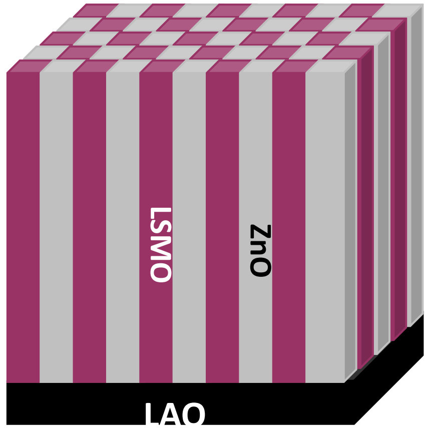

NATIONAL HIGH MAGNETIC FIELD LABORATORY
FSU • UF • LANL
ACTON RESEARCH CORPORATION
SpectraPro 300i
0.300m Imaging Triple Grating Monochromator / Spectrograph
REMOVE SHIPPING COVER
IK Series He-Cd LASER
KIMMON


ZB30, 50 nm
T = 4K
PL intensity (arb. units)
0
2000
4000
6000
8000
10000
12000
3.380
3.375
3.370
3.365
3.360
3.355
3.350
3.345
3.340
photon energy (eV)

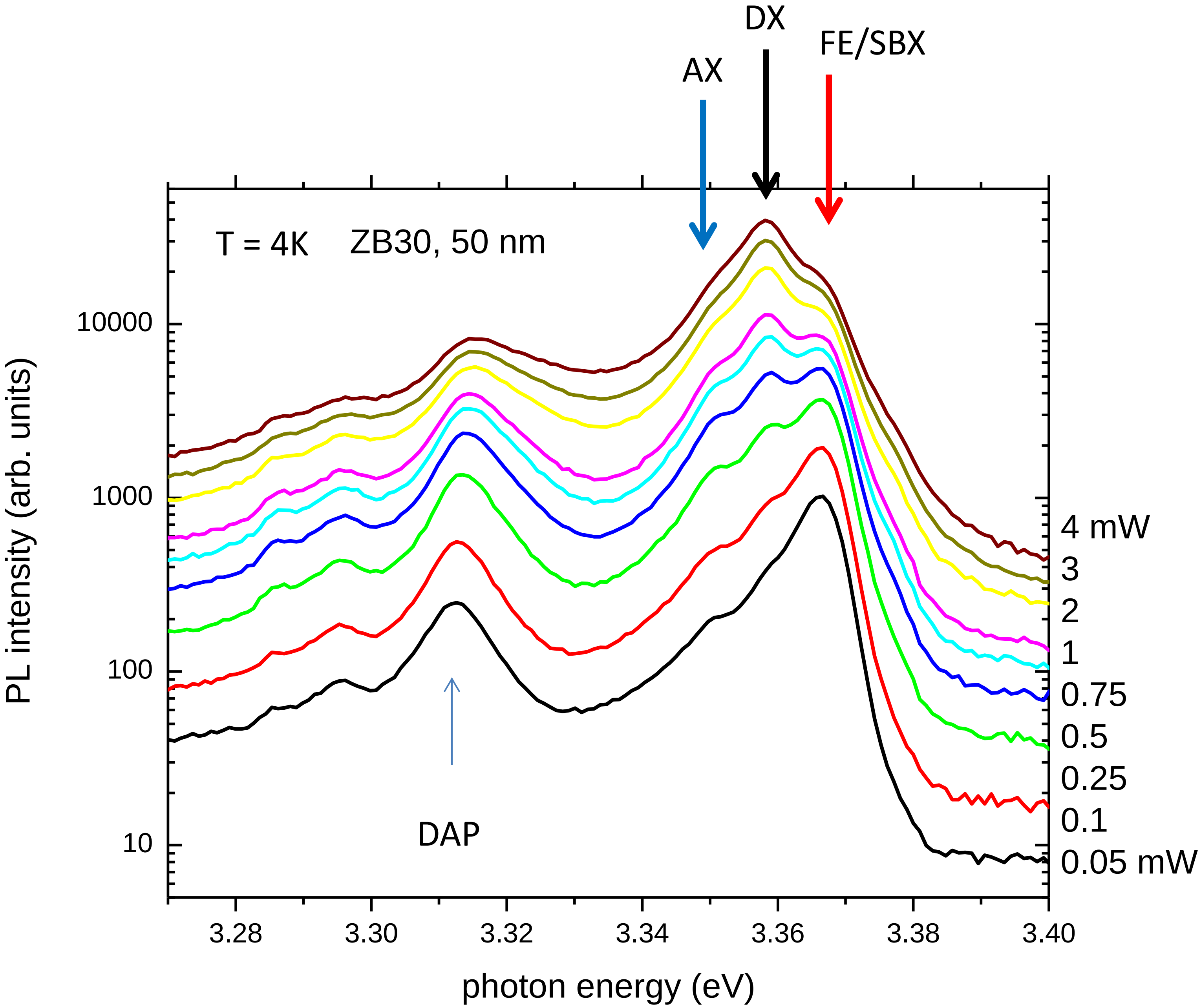
PL in ZnO nanowires

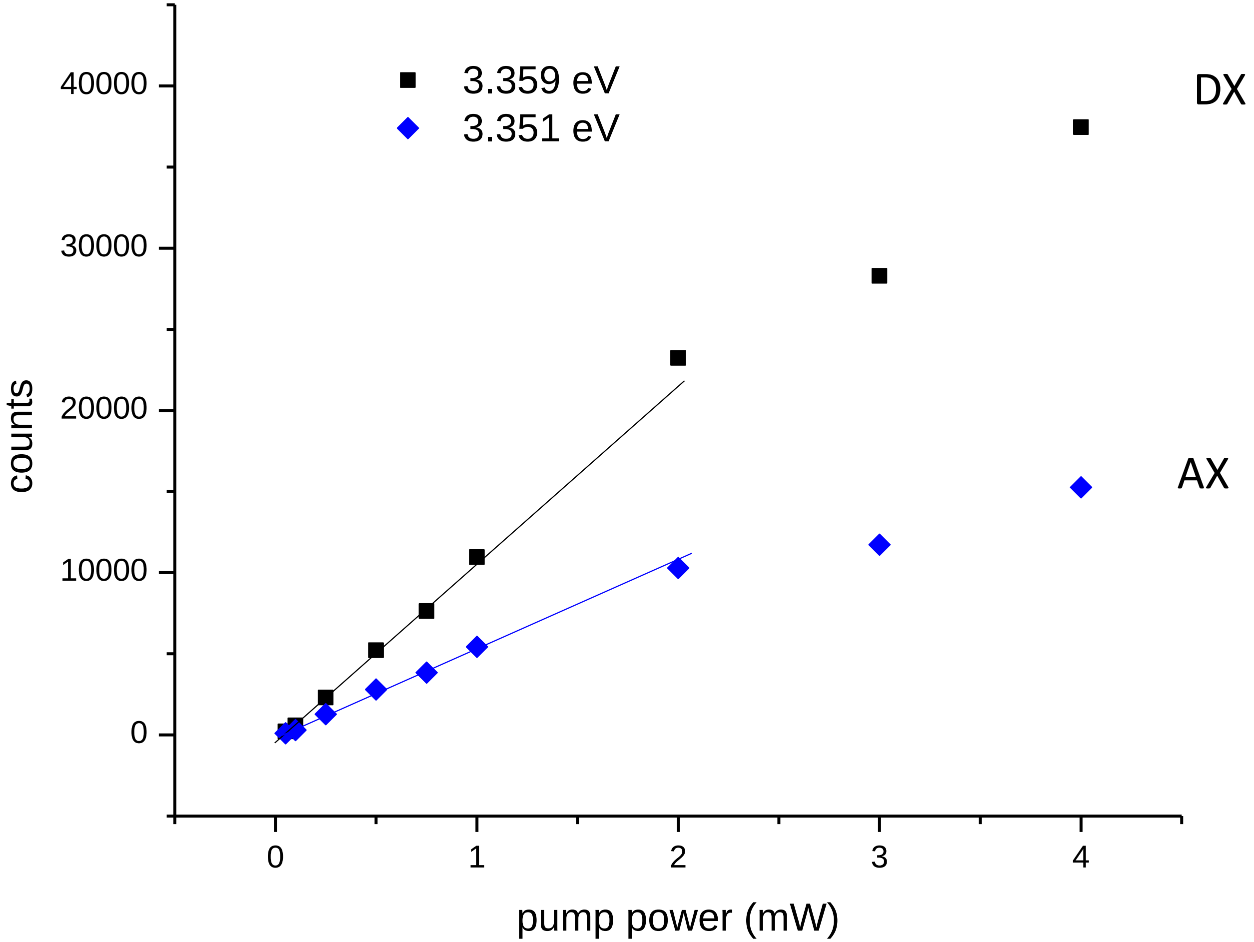


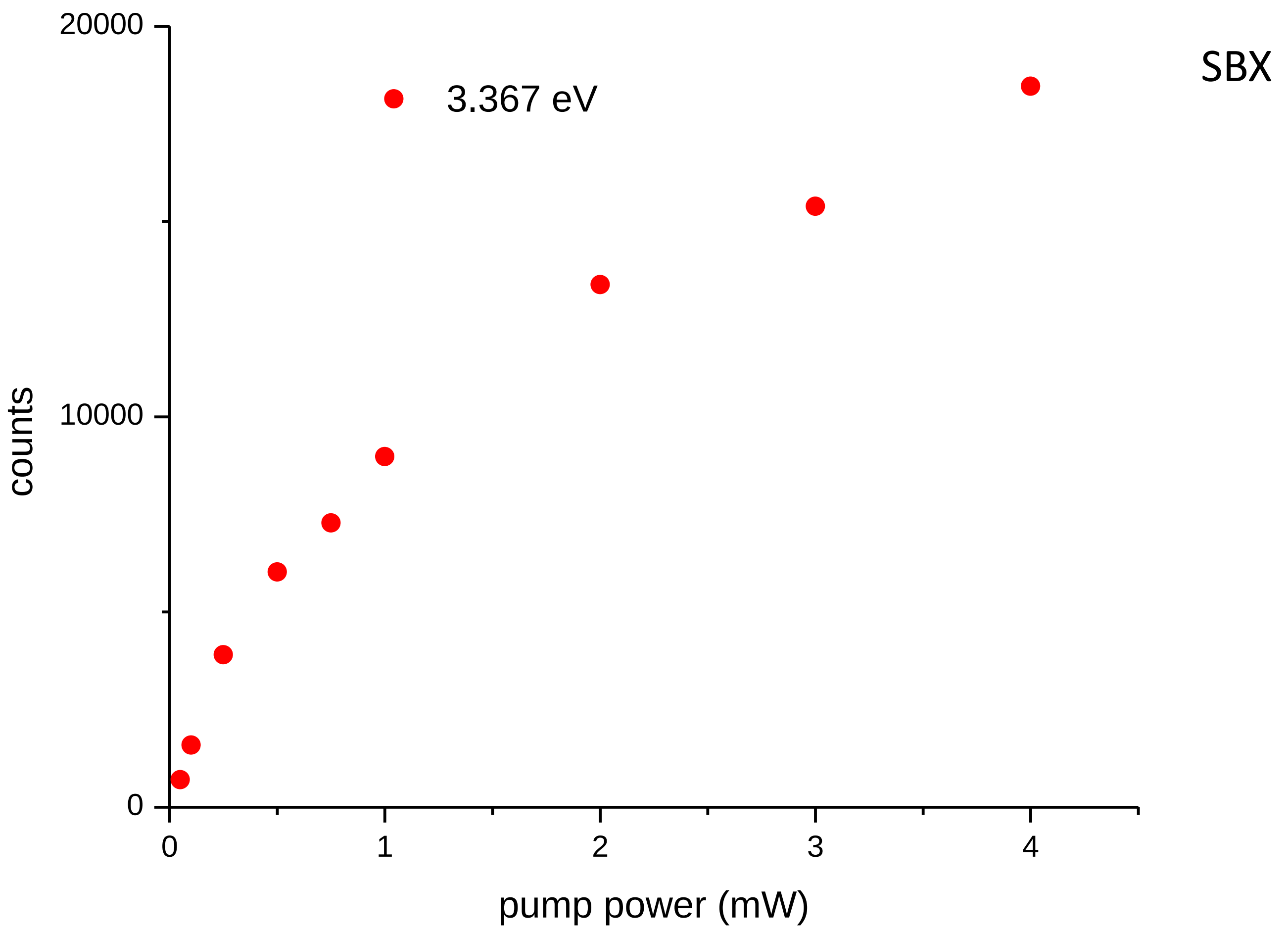




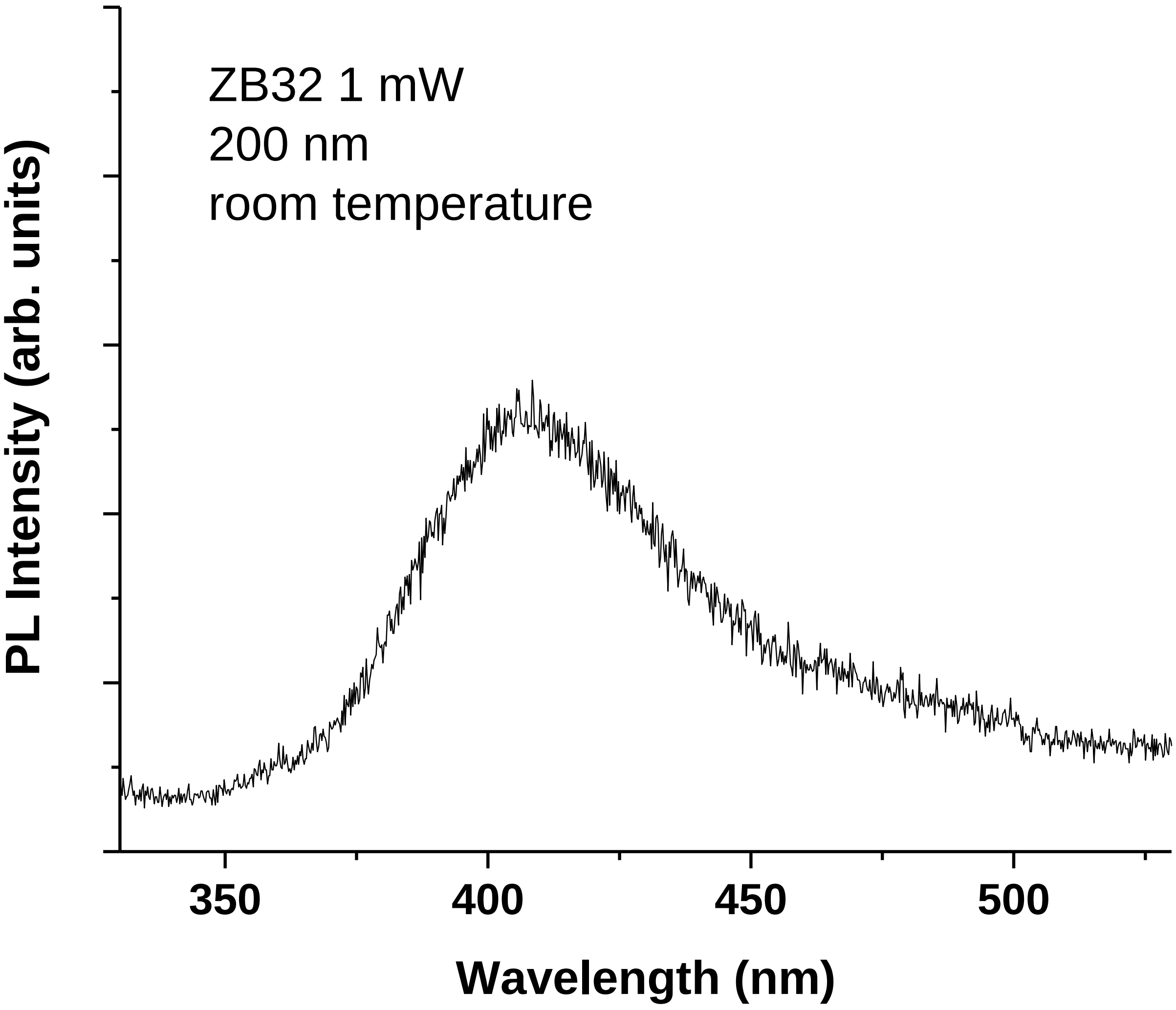
Xing et al, APL 96, 112511 (2010)


DX
FE/SBX
AX
T = 4K
ZB30, 50 nm
PL intensity (arb. units)
10000
1000
100
10
DAP
4 mW
3
2
1
0.75
0.5
0.25
0.1
0.05 mW
3.28
3.30
3.32
3.34
3.36
3.38
3.40
photon energy (eV)


■ 3.359 eV
◆ 3.351 eV
DX
AX
counts
pump power (mW)
0
10000
20000
30000
40000
0
1
2
3
4

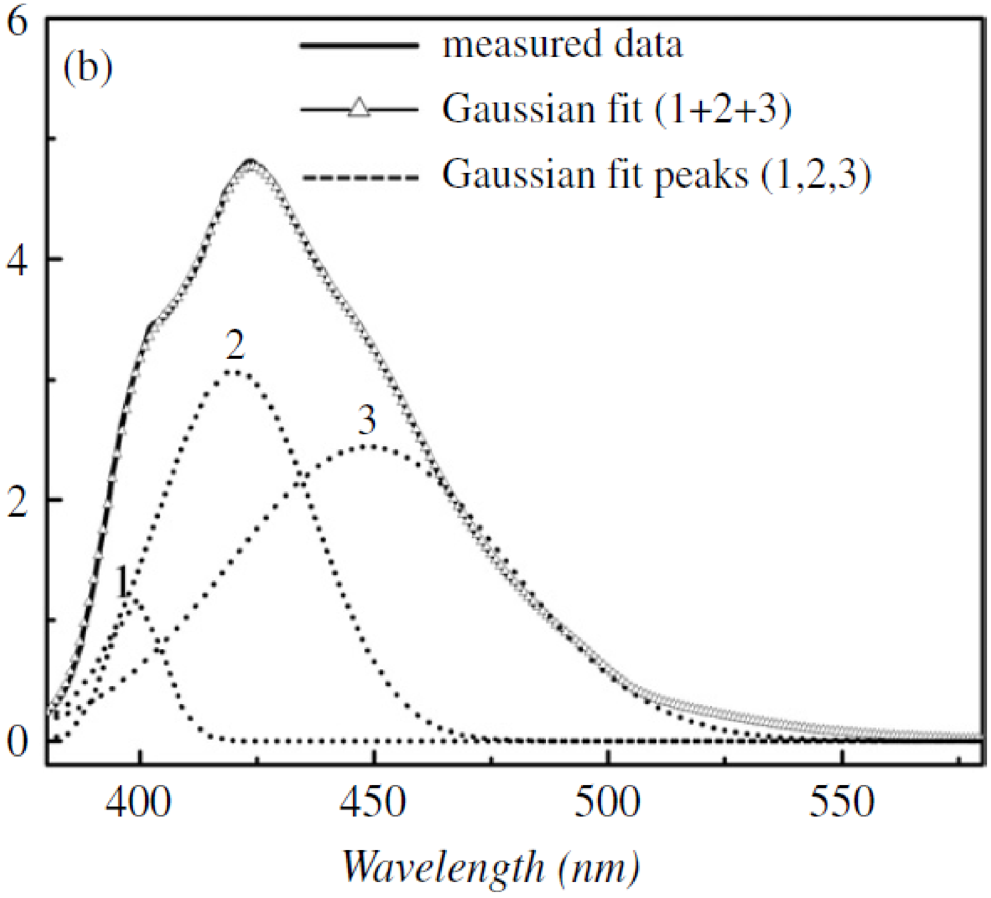

20000
10000
0
counts
● 3.367 eV
SBX
0
1
2
3
4
pump power (mW)

What about PL in LSMO?



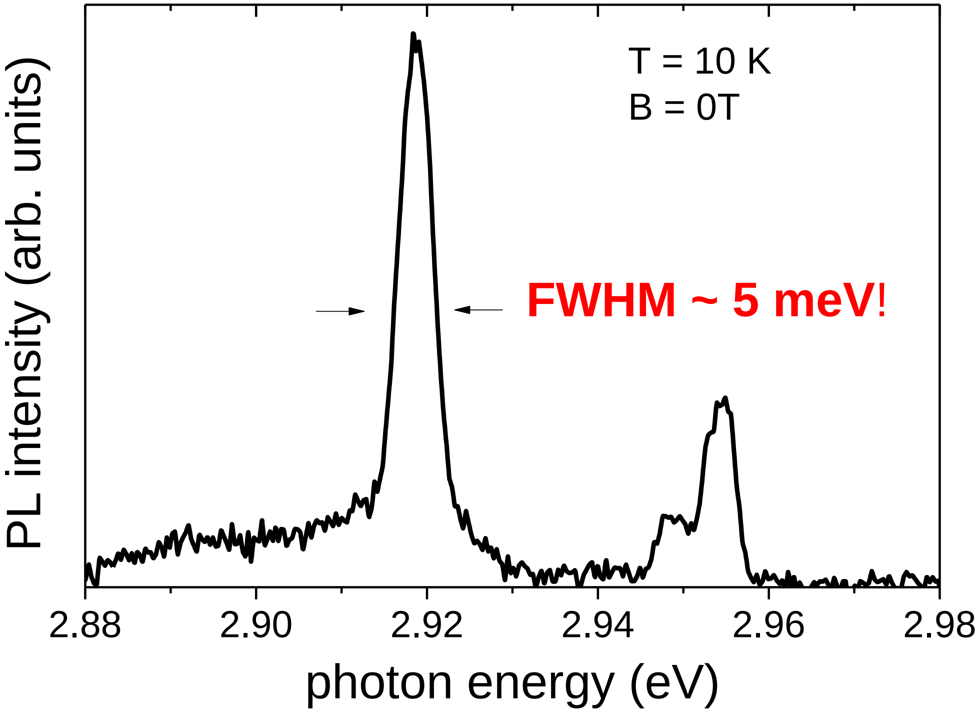
PL in LSMO nanowires

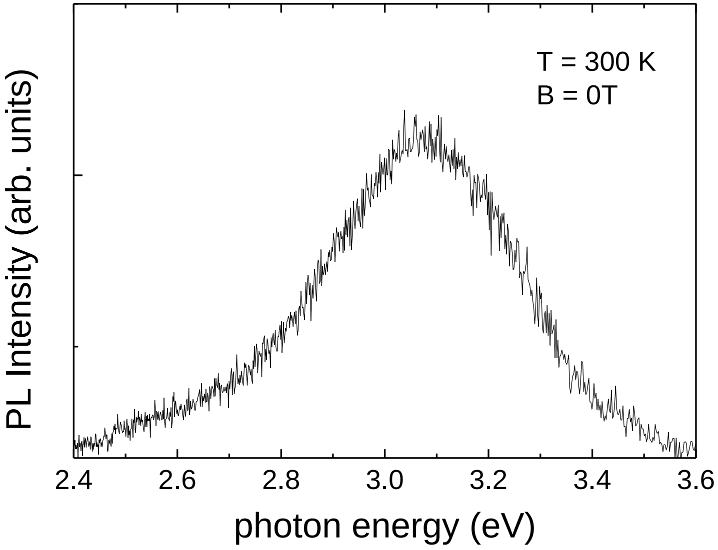
F. Chen et al, J. Phys. Cond. Matt. 17, 467 (2005)

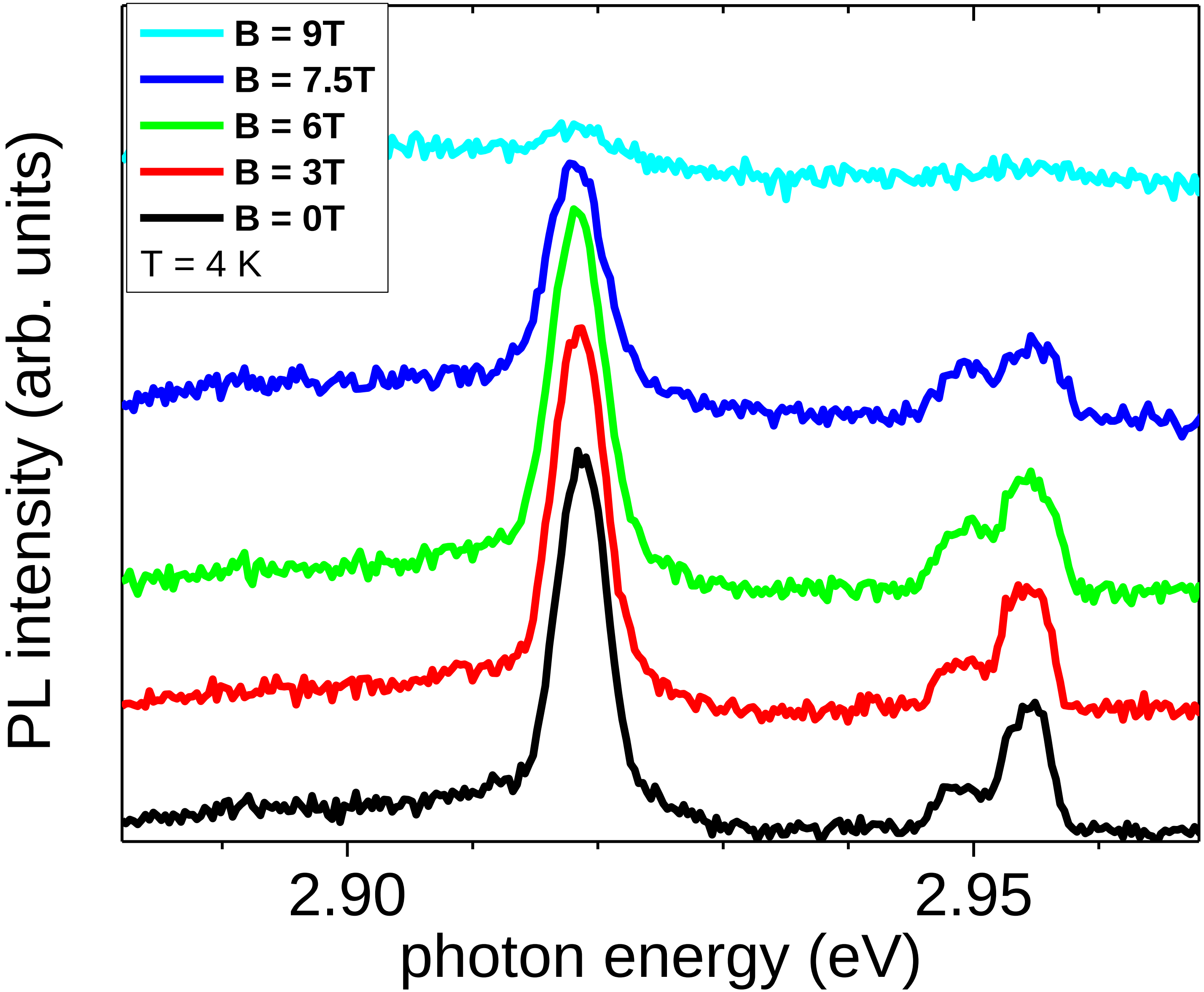


- self-trapped excitons localized on MnO6 octahedra
- oxygen vacancies on the surface of LSMO nanowires

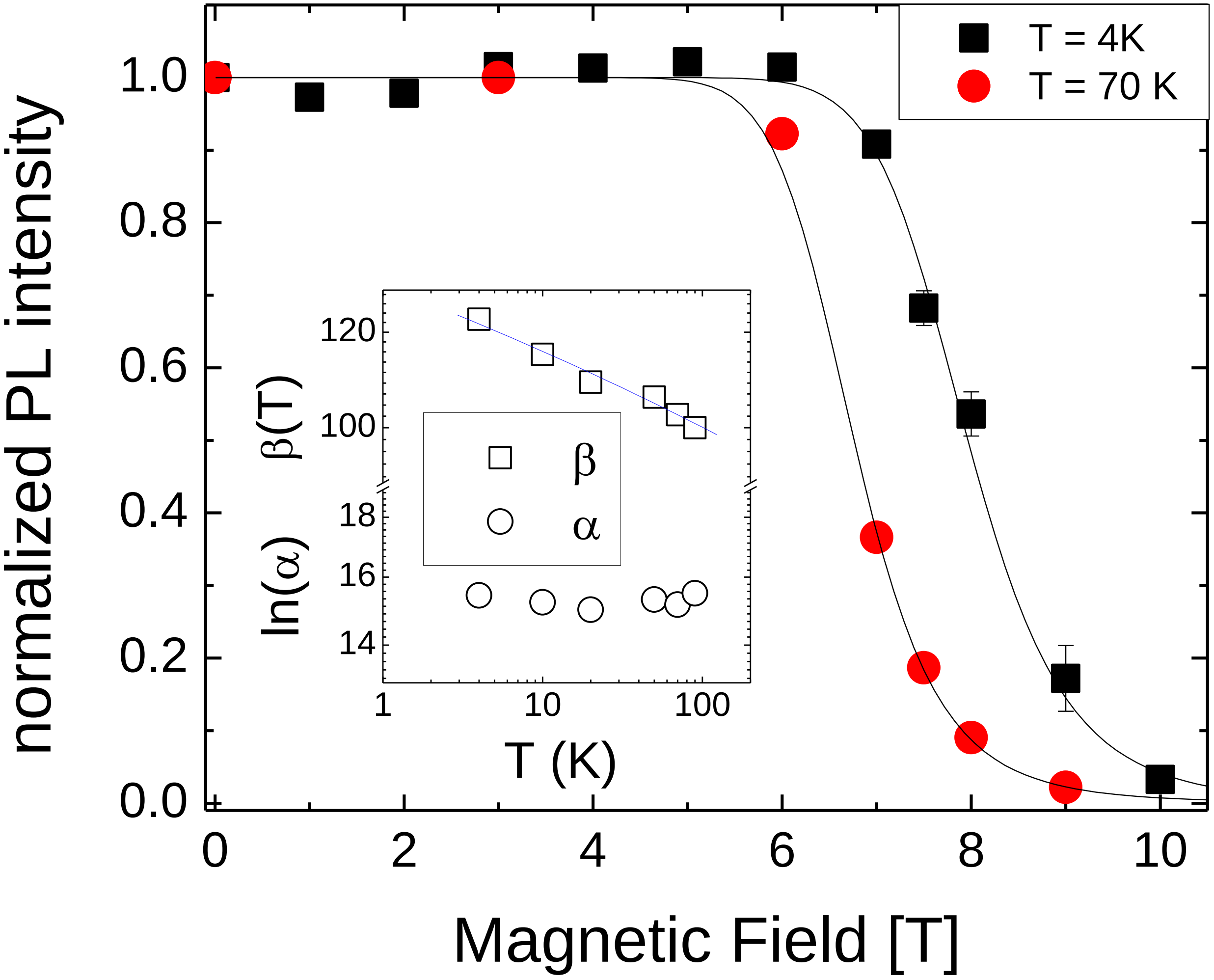
What about PL in LSMO at low temperature?





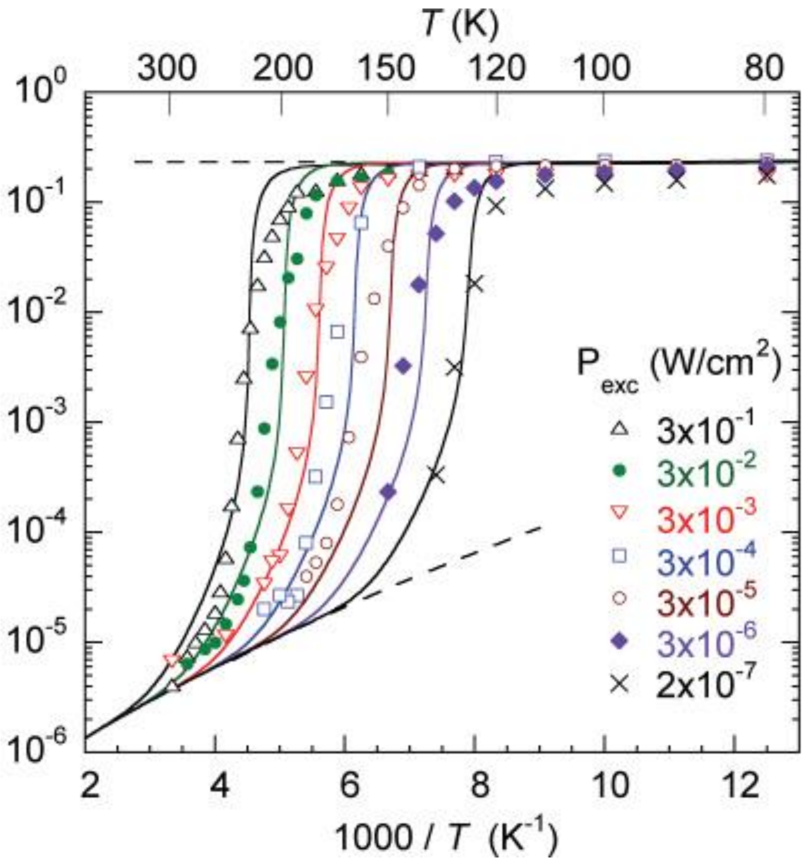

B = 9T
B = 7.5T
B = 6T
B = 3T
B = 0T
T = 4 K
PL intensity (arb. units)
2.90
2.95
photon energy (eV)

PL intensity ∝ 1/(1+αexp(-β/B))



Similar equation has been used to describe thermally induced quenching of photoluminescence.

PL intensity $\propto 1/(1+\alpha\exp(-\beta/T))$



Reshchikov et al, PRB (2011)

Under the thermal quenching model, the PL intensity is determined by the competition between localization and de-localization of carriers. Upon increasing temperatures, more carriers can thermally escape from localized states, thus quenching the photoluminescence.

Magnetic field induced quenching of the PL in our sample might be due to a magnetic field enhanced carrier escape rate from localized states.

It is known that a **magneto-strictive** effect exists in LSMO at high magnetic fields.

Size of unit cell changes with magnetic field, which, in turn, lead to a change in the Mn-O bond lengths and bond angles. This can modify the Jahn-Teller field in the MnO_6 octahedra.

Due to this modified Jahn-Teller field, the hopping of an electron along the Mn^{3+} — O^{2-} — Mn^{4+} chains is changed, which can lead to an increase in hopping amplitude or carrier escape rate .

This increased escape rate, similar to that upon heating in the thermal quenching model, then gives rise to the quenching of PL intensity.

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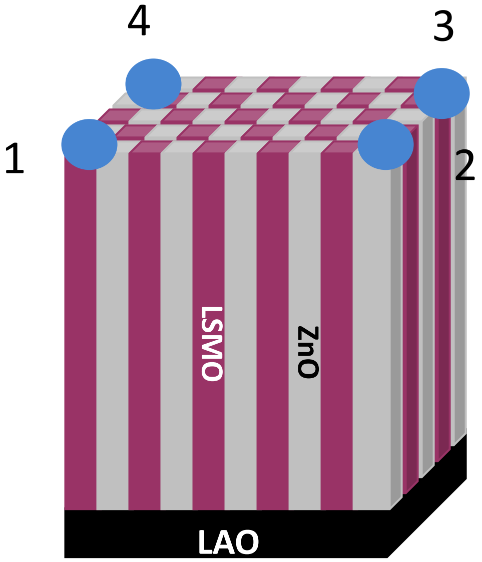
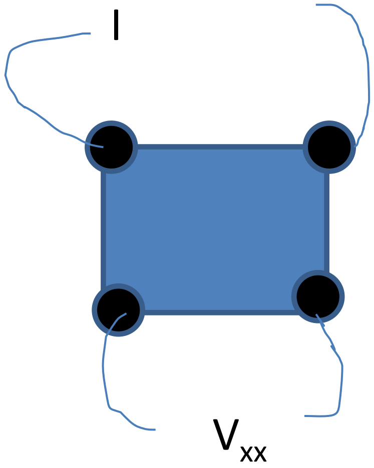
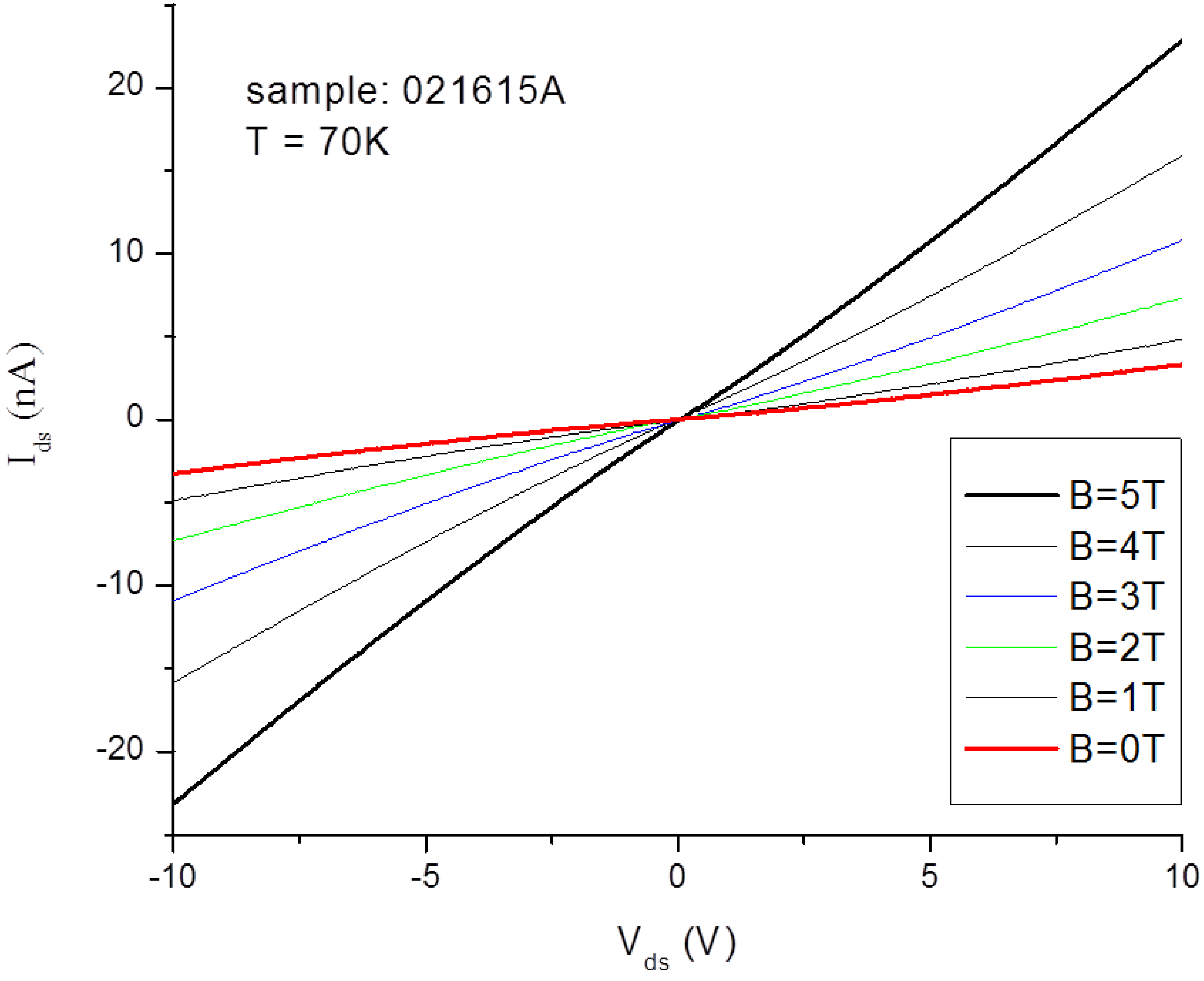
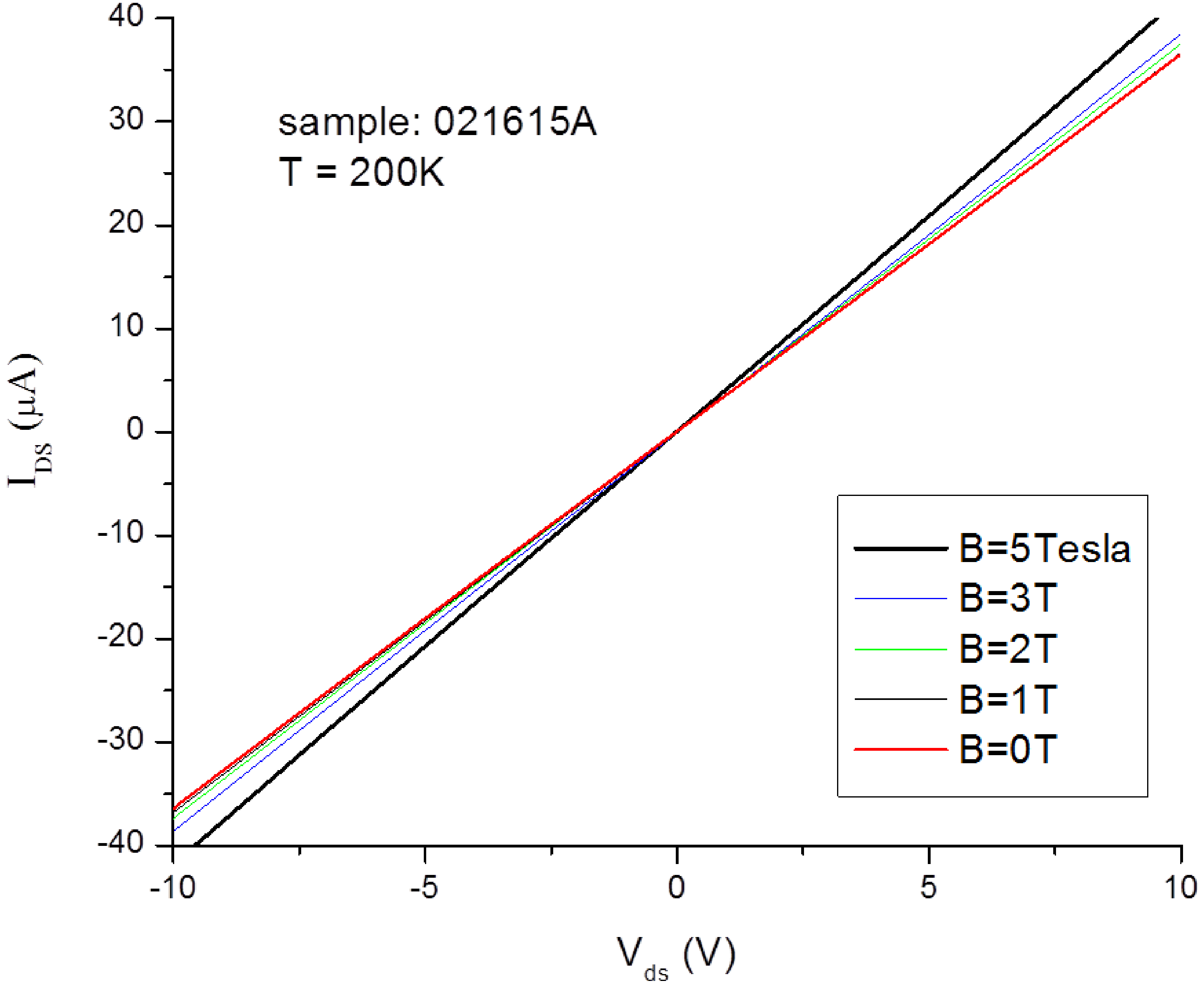
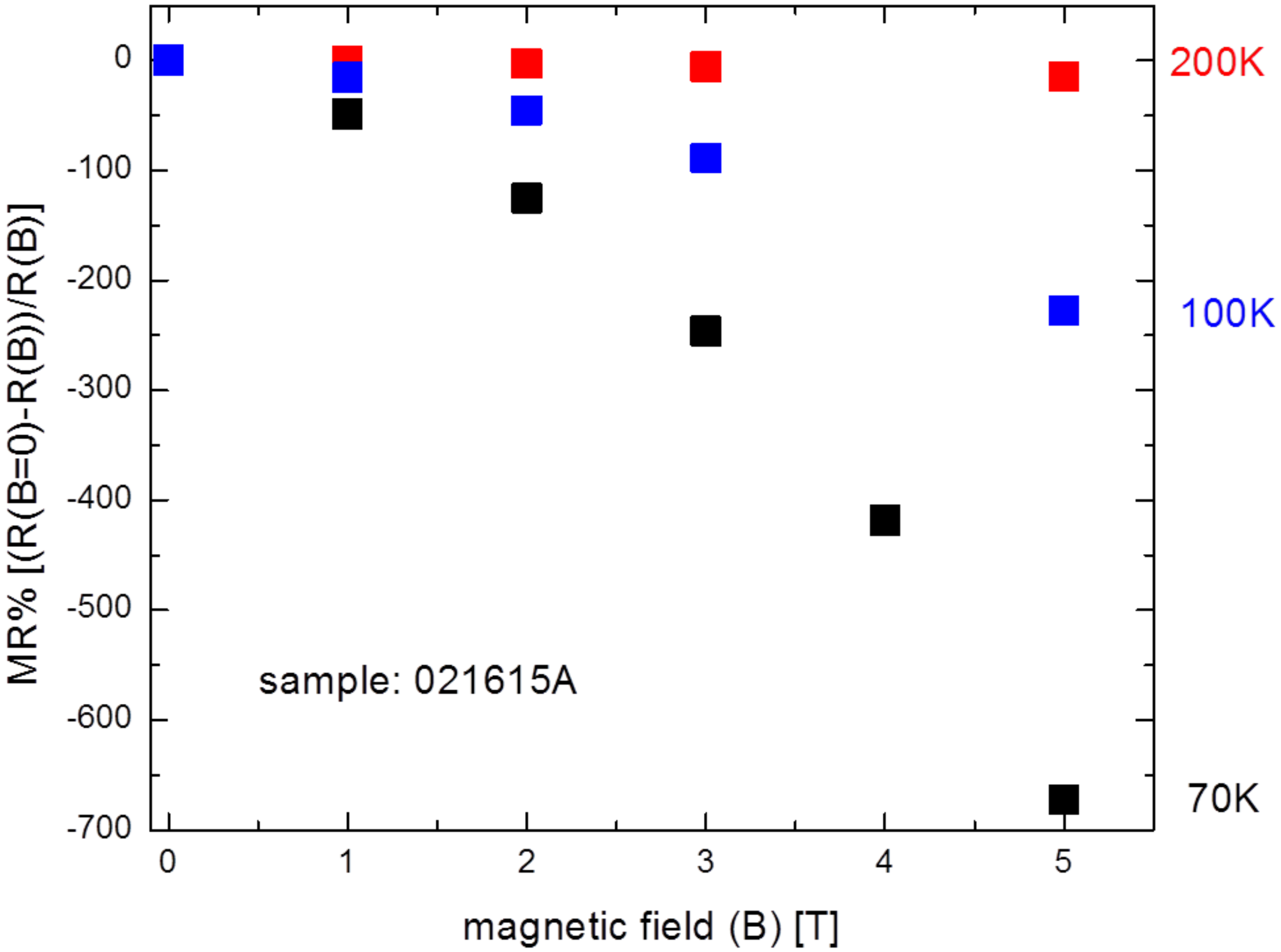

4
3
1
2
LSMO
ZnO
LAO


I
V_{xx}

Giant magneto-resistance (GMR)



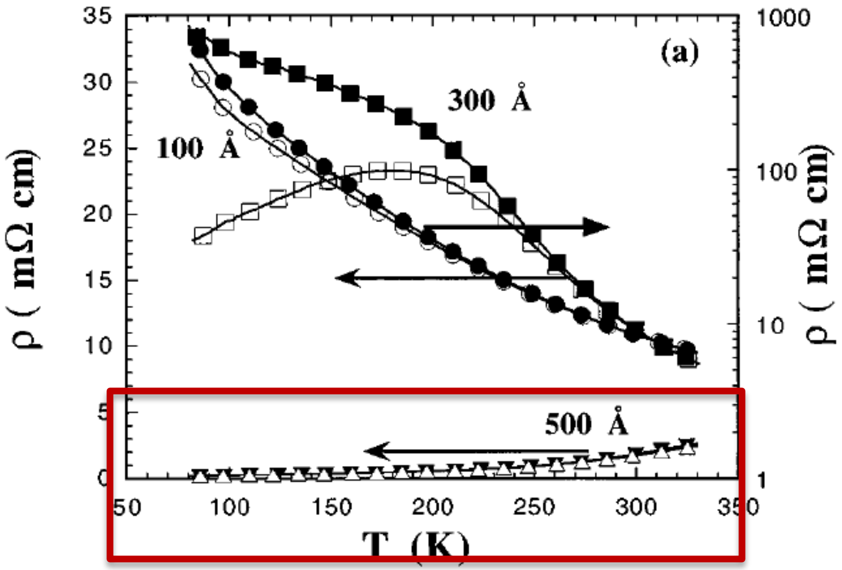

sample: 021615A
T = 200K
I_{DS} (μA)
V_{ds} (V)
40
30
20
10
0
-10
-20
-30
-40
-10
-5
0
5
10
B=5Tesla
B=3T
B=2T
B=1T
B=0T



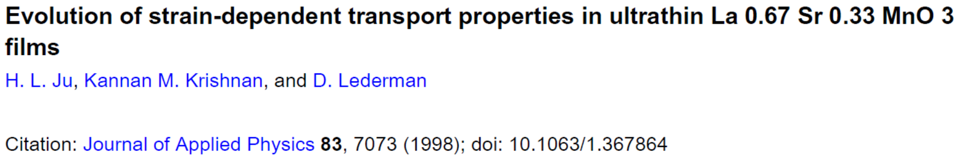
This sample shows a strong negative magneto-resistance at low temperatures, reaching ~ 700% at B = 5T at T = 70K.

Origin of GMR?

ZnO nanopillars must play an import role!



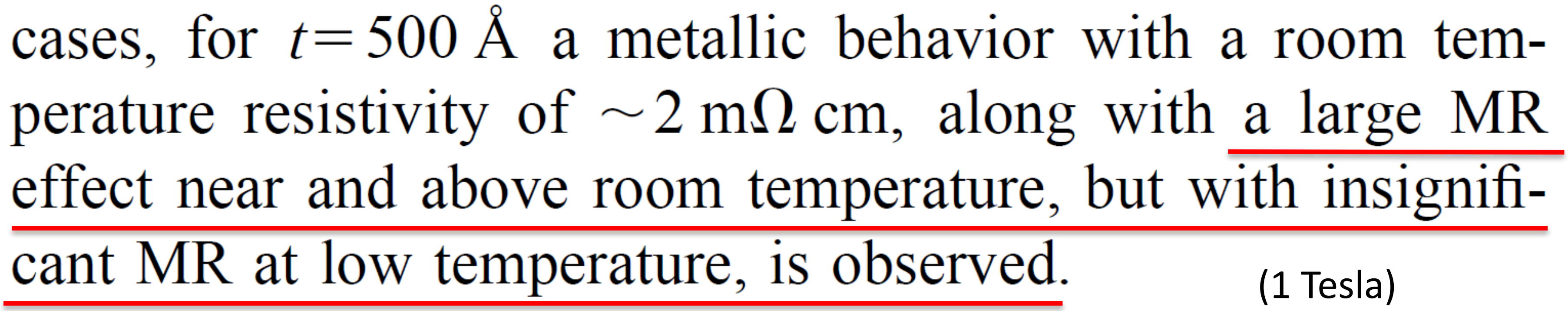
$La_{0.67}Sr_{0.33}MnO_3$ single-phase film on LAO



Evolution of strain-dependent transport properties in ultrathin La 0.67 Sr 0.33 MnO 3 films

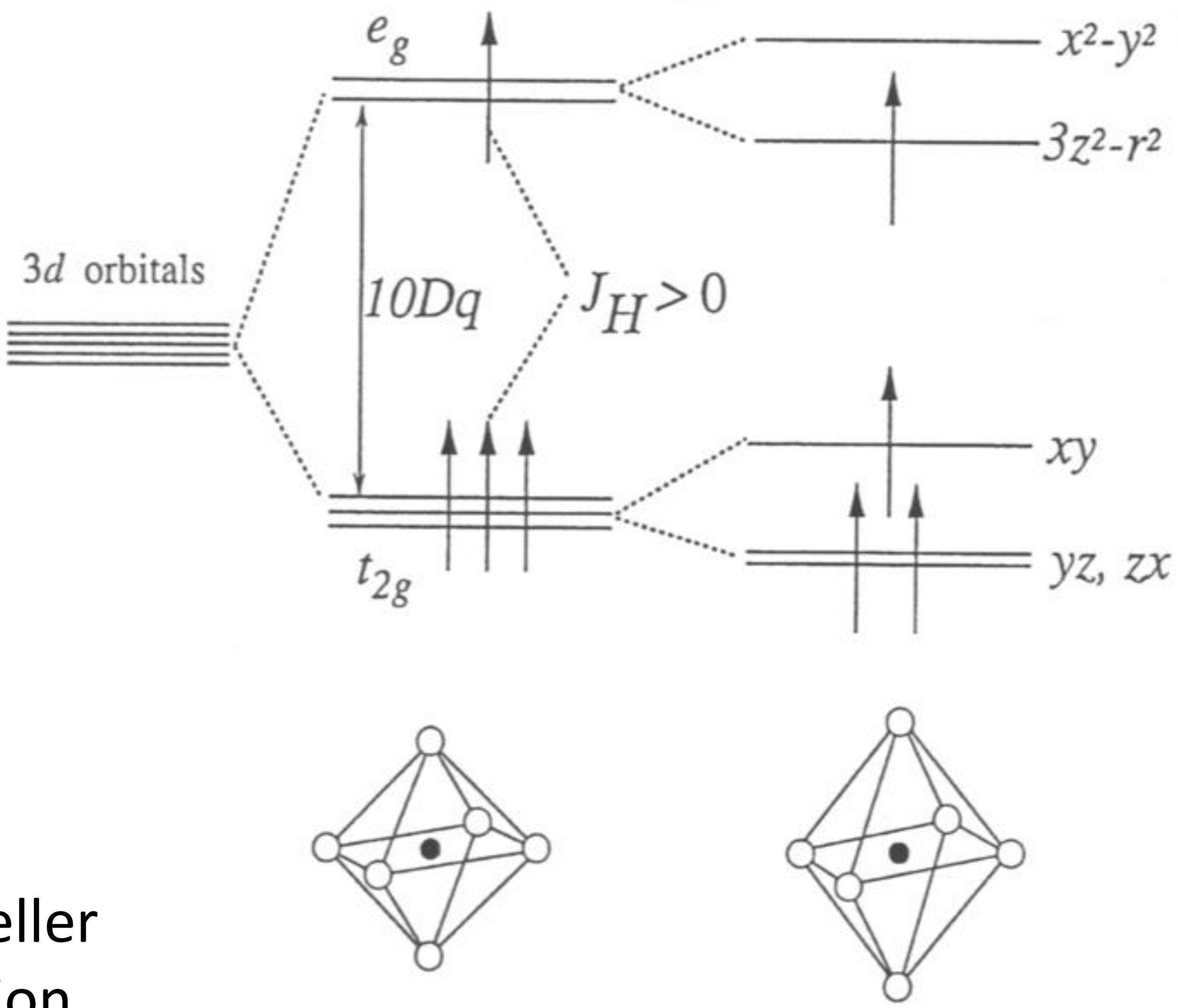
H. L. Ju, Kannan M. Krishnan, and D. Lederman

Citation: Journal of Applied Physics **83**, 7073 (1998); doi: 10.1063/1.367864

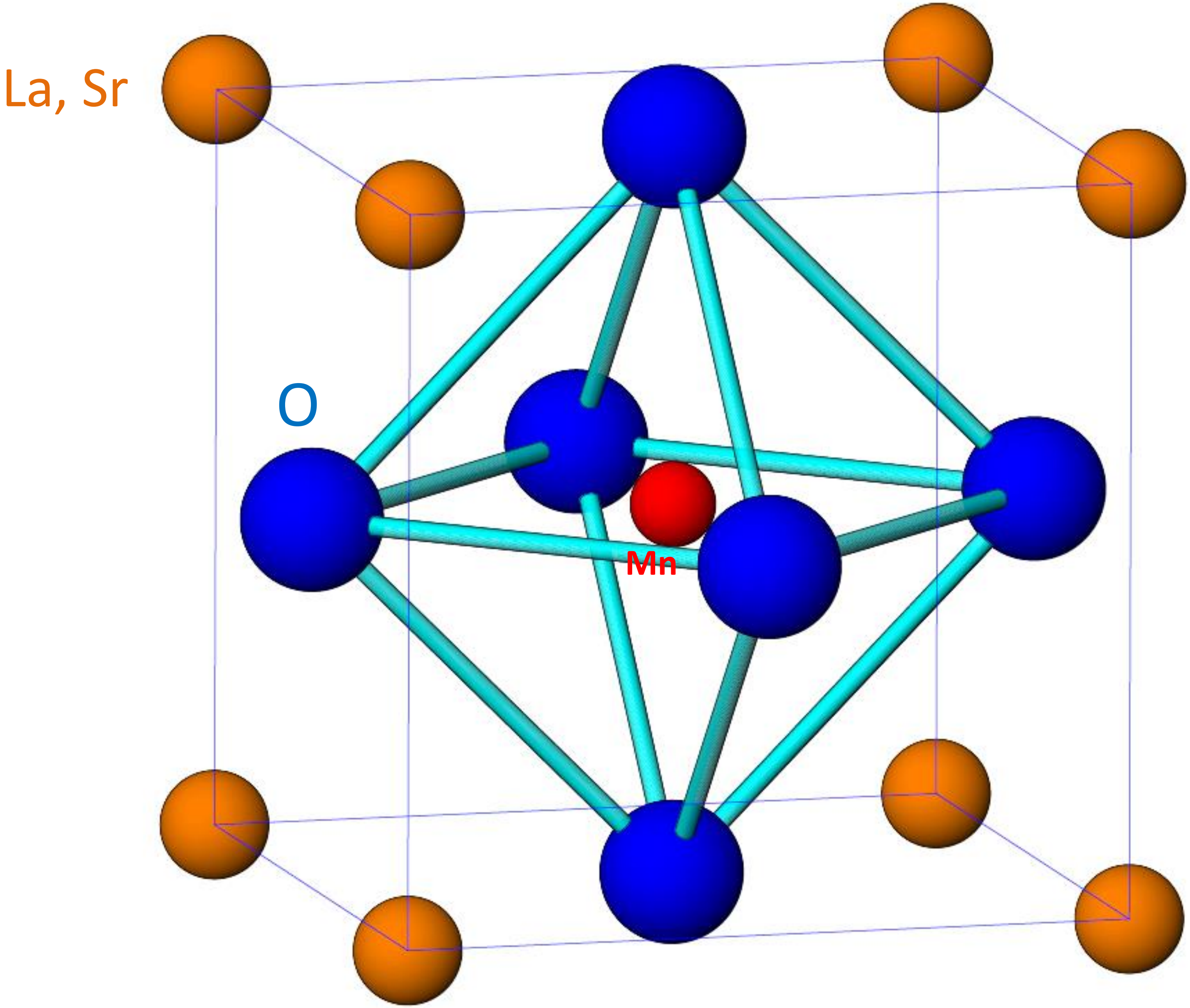


cases, for *t*=500 Å a metallic behavior with a room temperature resistivity of ~2 mΩ cm, along with a large MR effect near and above room temperature, but with insignificant MR at low temperature, is observed.

(1 Tesla)



Jahn-Teller distortion


La, Sr
O
Mn