Vertical nano-composite heteroepitaxial thin films with manganites and ferroelectrics

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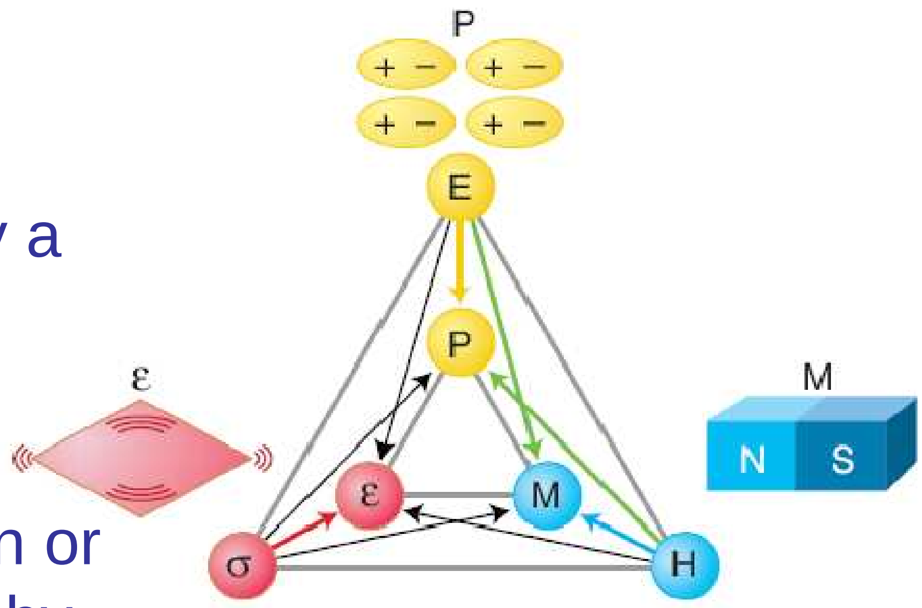
Outline

- Introduction to MultiFerroics
- $La_{1-x}Sr_xMnO_3$
- Experiment
- Summary and Future work

MultiFerroics

- Multiferroics (MF) are materials that exhibit two of the three "main" ferroic properties in the same phase
  - FerroMagnetism (FM) (anti and ferri)
  - FerroElectricity (FE)
  - FerroElasticity

- Multiferroic materials will play a significant role in developing systems with large magneto-electric coupling where the manipulation of magnetization or polarization can be achieved by applying an electric or magnetic field respectively.



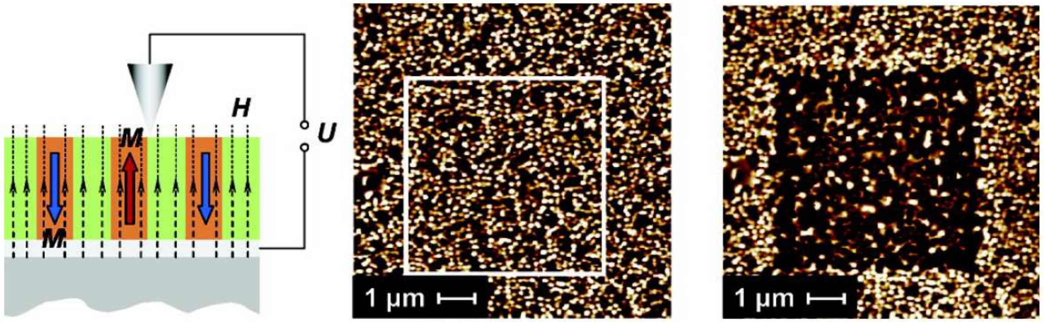
Composite MultiFerroics

- Combining magnetically and electrically ordered materials to produce coupled systems
  - Ex. Ferromagnetic-Ferroelectric
- Coupling formed by interaction of elastic components of each state
  - Electric field induces strain → strain induces rotation of magnetization
- Key to this coupling is:
  - Interfaces
  - Material Choice
  - Ratio
  - Microstructure

  between the constituent materials

Composite MultiFerroics

Electrically Assisted Magnetic Recording (EAMR)

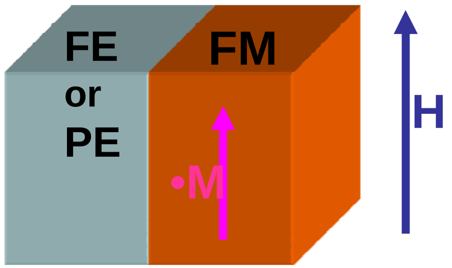


MFM after down magnetization at *H* = *20 kOe*

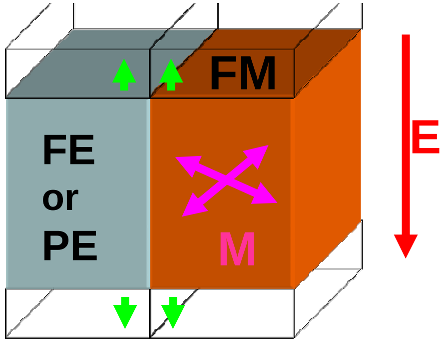
MFM after poling at *U* = *-16* V_{tip} / H_{up} = *700 Oe*

Zavaliche et al. Nano Letters V7 (2007) p1586

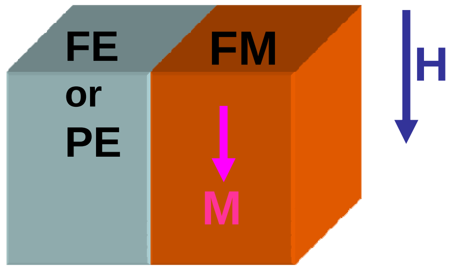
The ferrimagnetic $CoFe_2O_4$ pillars were embedded in a matrix of ferroelectric $BaTiO_3$ or $BiFeO_3$.
180 º rotation of the magnetization of $CoFe_2O_4$ pillars by applying an electric field across the film with the assistance of a very weak external magnetic field at room temperature[5]



A magnetic phase and a piezoelectric phase coexist (MF) out of plane magnetic anisotropy



Electric Field
⇩
Piezoelectric Strain
⇩
Magnetostriction
⇩
Magnetic Anistropy Changes to In-Plane



Electric Field Removed
⇩
Anisotropy Changes back to Out-of-Plane
⇩
H_c reduced

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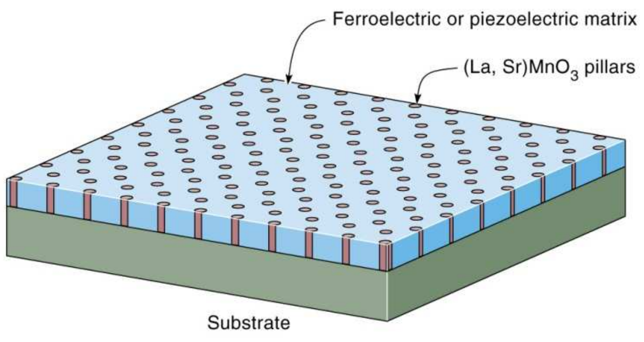
- Summery and Future work

Motivation

$La_{1-x}Sr_xMnO_3$ (LSMO) has

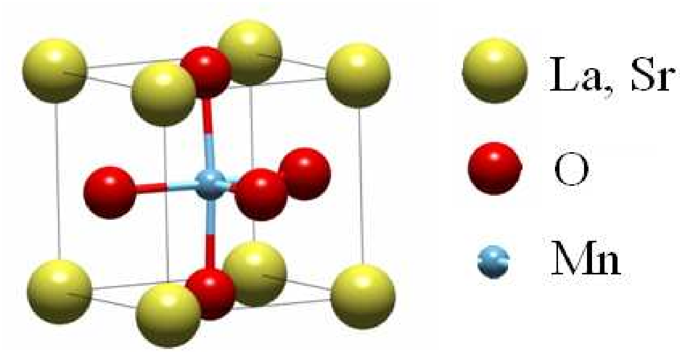
- Room temperature ferromagnetism
- High conductivity
- High spin polarized electrons
- Multiple phase transitions

These magnetic and transport properties may be useful in applications, such as spin logic or spin memory, and it is a potential material for electrically-control magnetism.



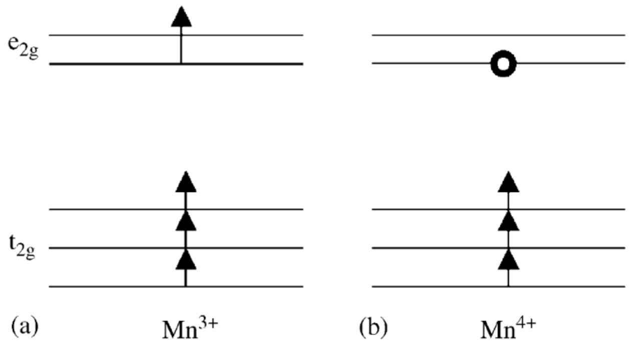
Manganite

perovskite unit cell



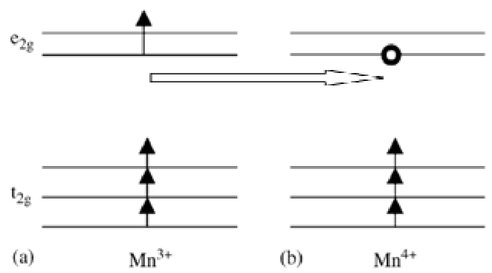
The parent compound is $LaMnO_3$, which belong to manganite family.
$La_{1-x}Sr_xMnO$ is provided by doping, La^{3+} -> Sr^{2+}

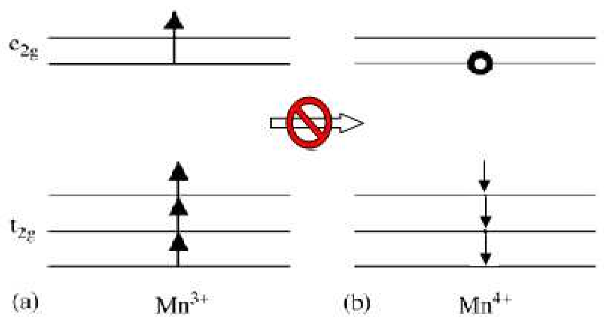
- In $LaMnO_3$, the electrons of Mn^{3+} ion = (…)$3d^4$
  - t_{2g} (t-core) and e_{2g}
- The Hund's rule demands "t-core" have the same spin-orientation
- The substitution $La^{3+} \rightarrow Sr^{2+}$ leads to $Mn^{3+} \rightarrow Mn^{4+}$.
  ->Mn ion loses e_{2g} election->creat hole
  ->conductivity

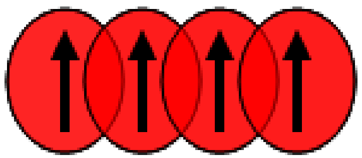


Double exchange

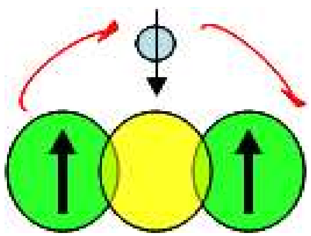
- Hole from the Mn^{4+} ion to opposite spin direction Mn^{3+} is forbidden
- Double exchange: An impurity band forms in the gap and ferromagnetism is mediated by double exchange.
- Half-metal: Charge transfer in the conducting ferromagnetic manganites is provided by spin polarized electrons.







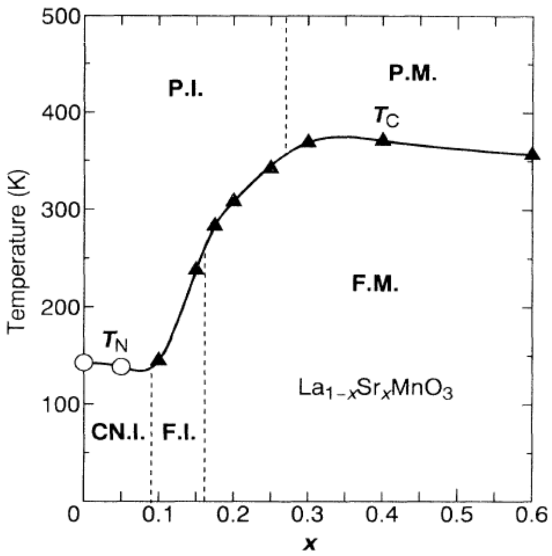
Direct exchange

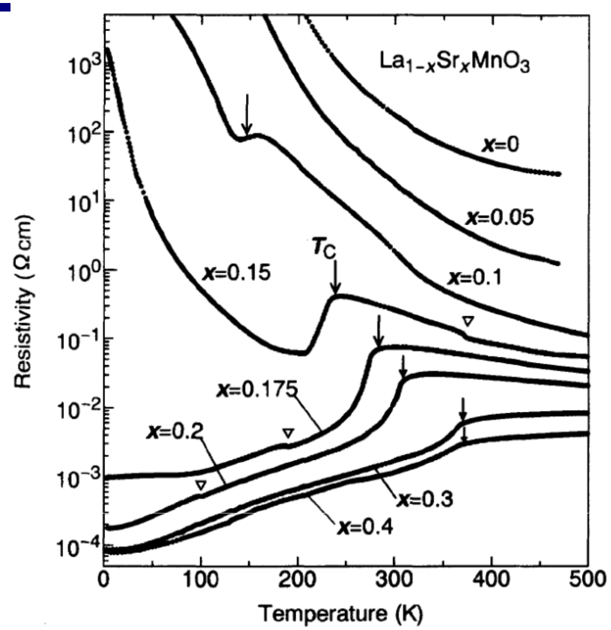


Double exchange

Phase diagram

The conductivity of manganites strongly depends on such parameters as carrier concentration (doping level) and temperature.





Urushibara etc, Phys. Rev. B 51 14103 (1995)

TN: Neel temperature TC: Curie temperature,
PI: paramagnetic insulator CN.I: spin canted insulator,
F.I: ferromagnetic insulator F.M.: ferromagnetic metal,
P.M.: paramagnetic metal.

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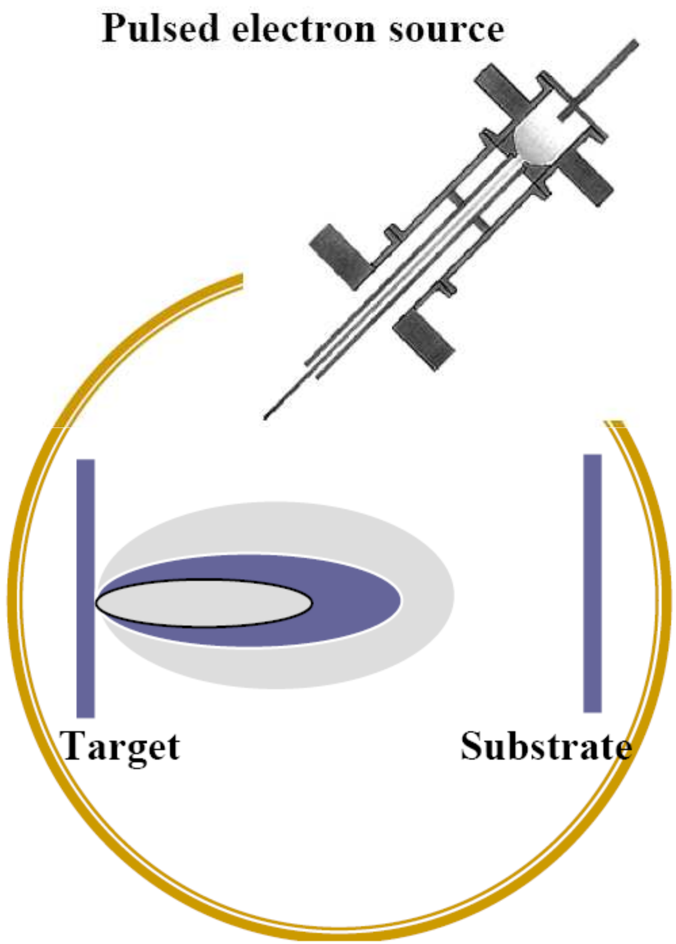
Pulsed Electron Deposition (PED)



NeoCera Inc.

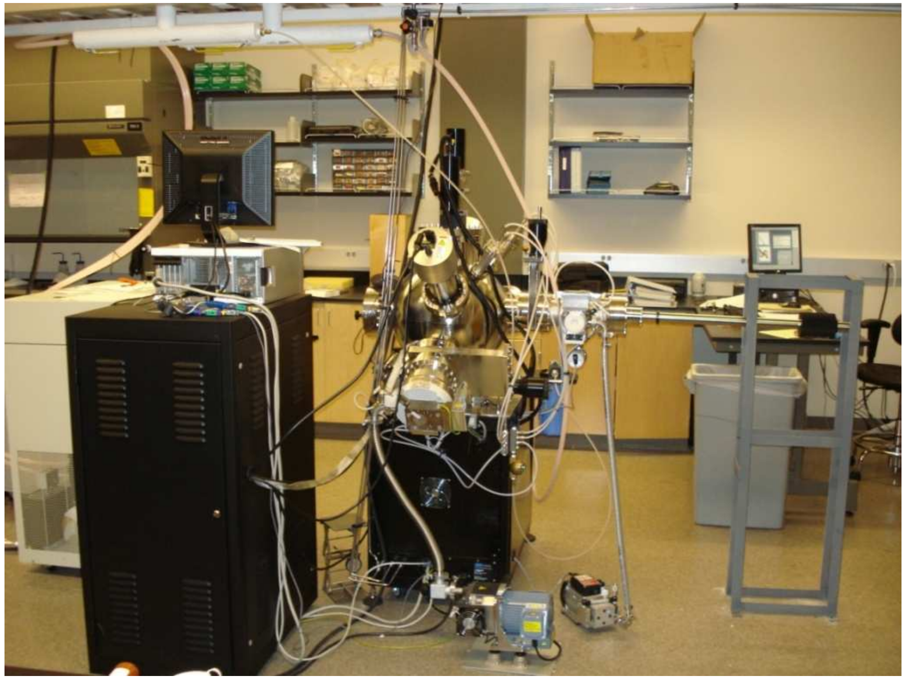
Pulsed Electron Deposition (PED):

- Pulsed (~100 ns) high power electron beam (~10 J/cm^2) penetrates approximately 1µm target, which results in a rapid evaporation of target materials.
- Suitable for a wide range of materials, including multi-component metal-oxides, complex alloys, and novel polymers
- Non-equilibrium extraction of target material (ablation) facilitates stoichiometricdeposition
- Advantage: generate a high power density, regardless to thermodynamic properties, such as the melting point and specific heat

PED system

Film growth controlled by:

- Electron energy/Pulse Frequency
- Dielectric channel/target separation
- Chamber pressure and gas ratio
- Target substrate distance
- Substrate Temperature

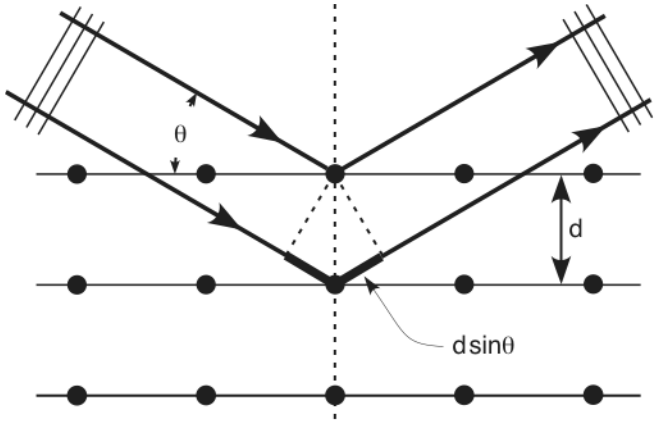


Experiment

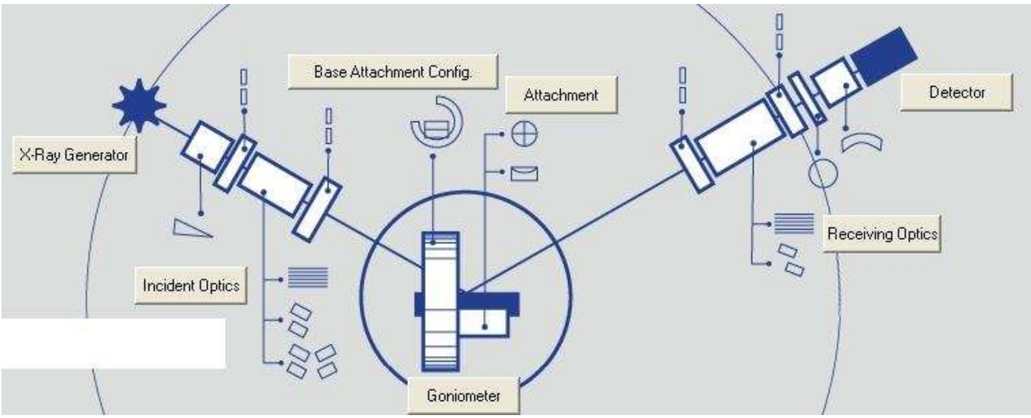
- Growth conditions
  - Target: 1” $La_{0.7}Sr_{0.3}MnO_3$
  - Substrate temperature: 600 °C
  - Pressure: ~10 mTorr
  - E-beam Power: ~ 10 keV
  - Substrate: Pt coated Si wafers, STO (100)
  - Gas composition: $Ar:O_2$ 80:20 ,60:40, 40:60, 20:80
- Characterizations:

  AFM, XRD, VSM

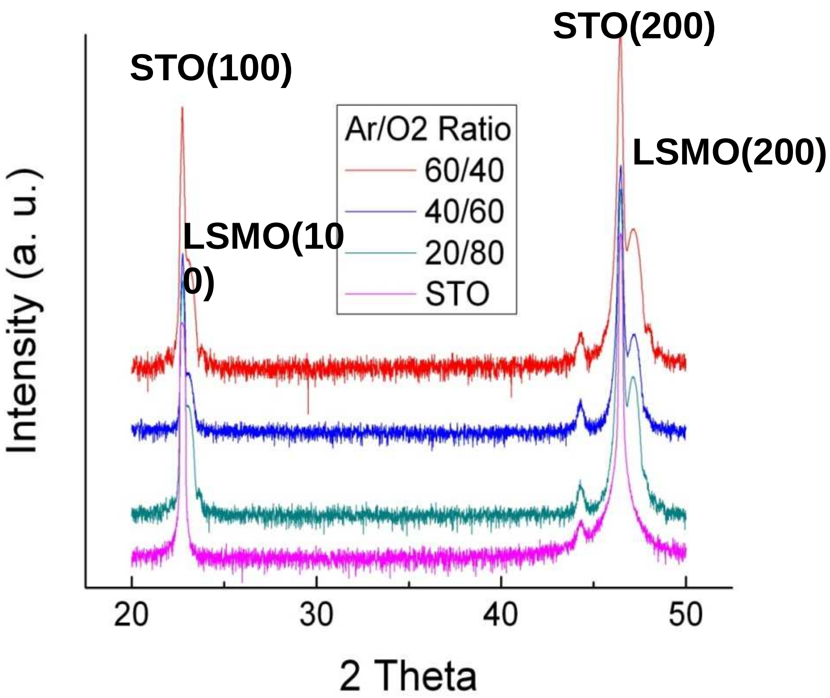
X-Ray diffraction

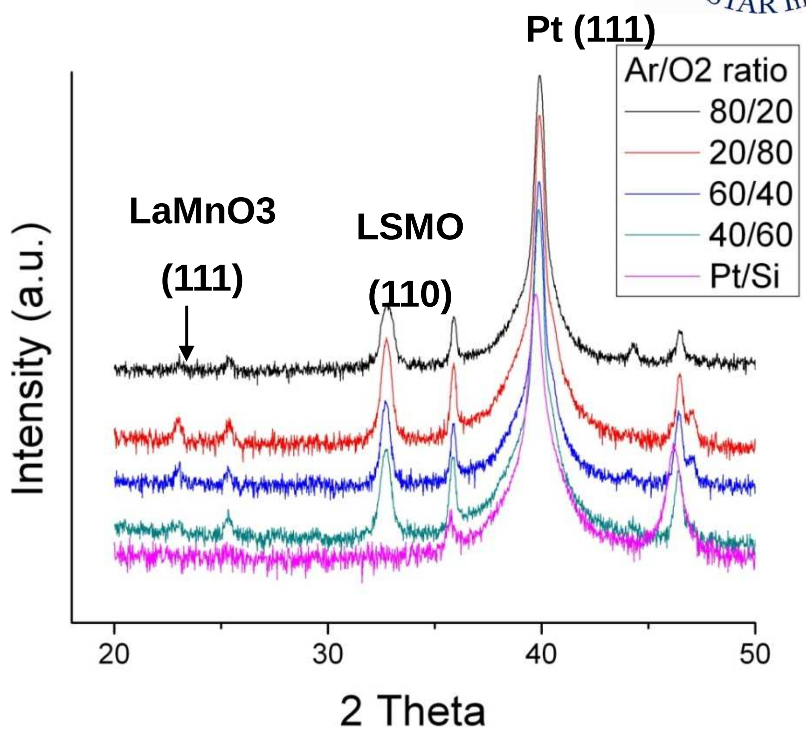


λ=2dsinθ



Phase composition

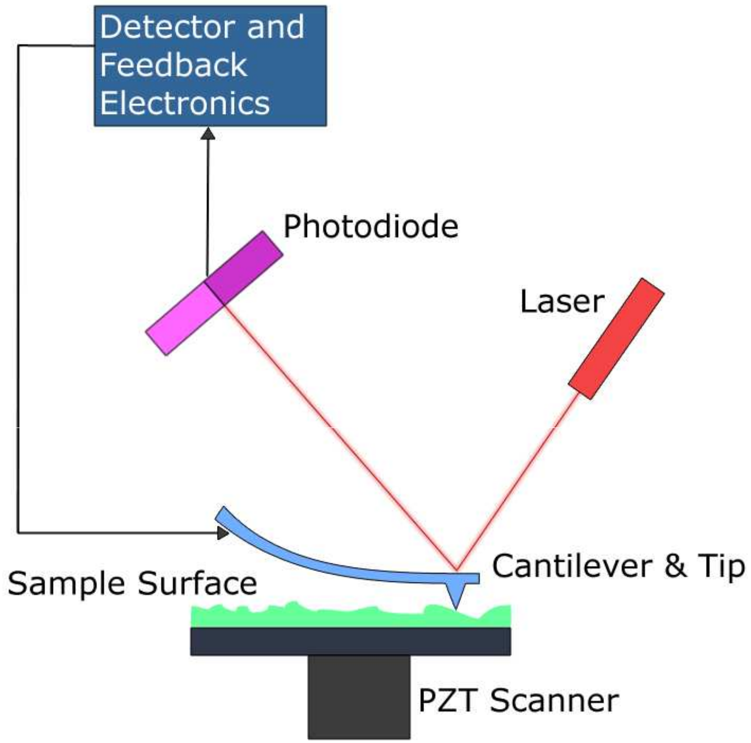




- Epitaxial LSMO is obtained grown on STO (100)
- No impurity phase observed

- LSMO is strongly textured, LSMO 110// Pt 111
- $LaMnO_3$ (111) was observed in XRD

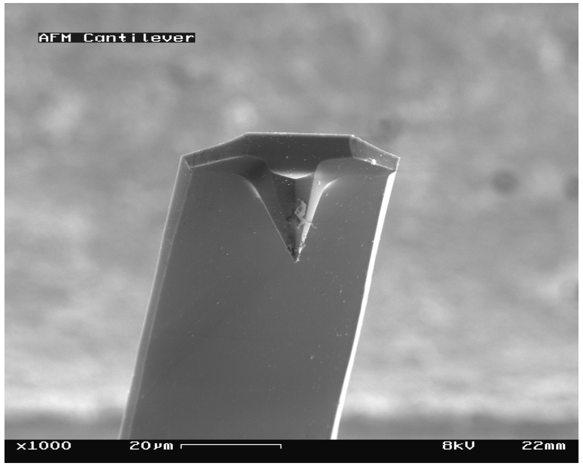
Atomic force microscope



AFM Diagram

Atomic Force Microscopy (AFM) is called Scanning Force Microscopy (SFM)

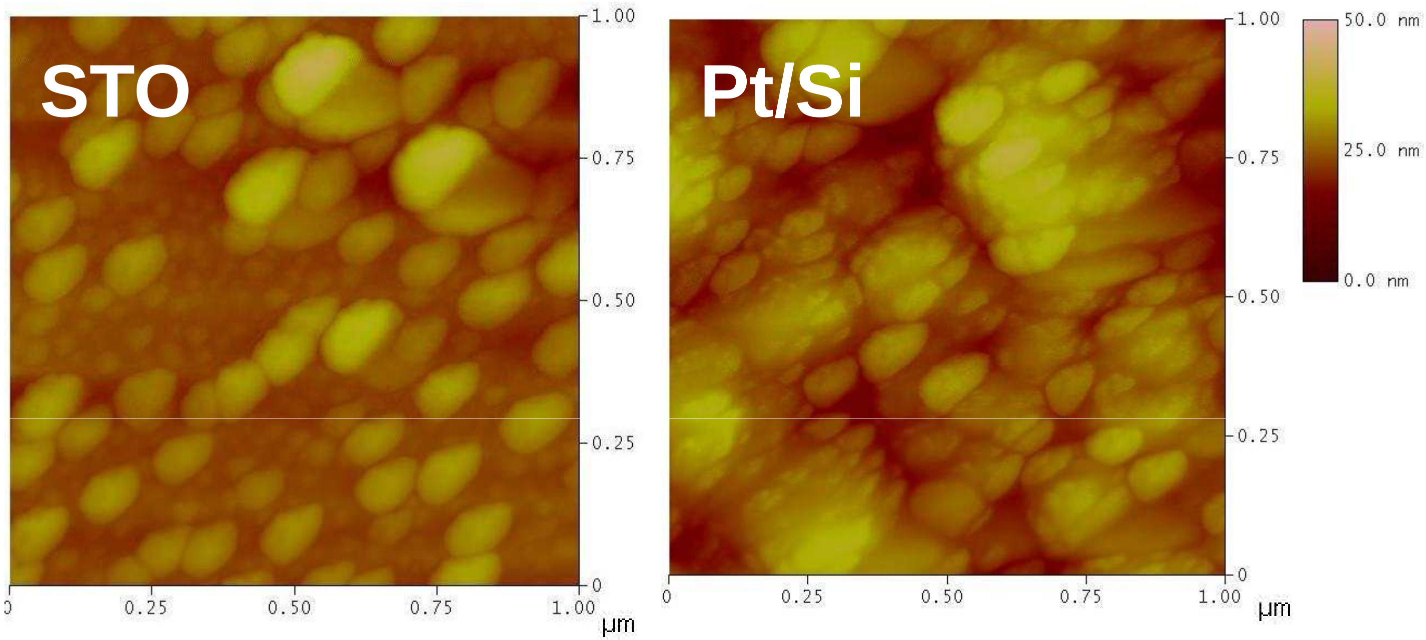
- Contact Mode AFM
- Non-contact Mode AFM
- Tapping Mode AFM



AFM cantilever in the Scanning Electron Microscope

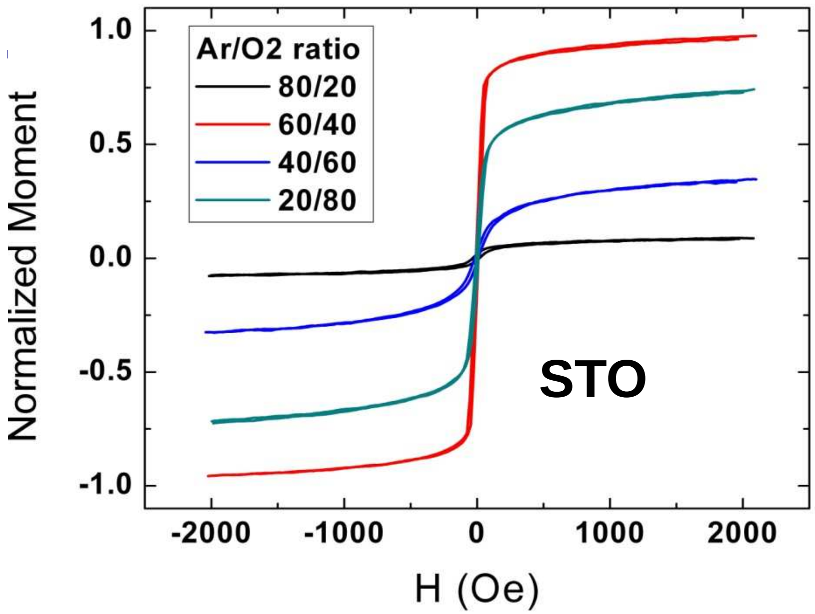
Surface Morphology

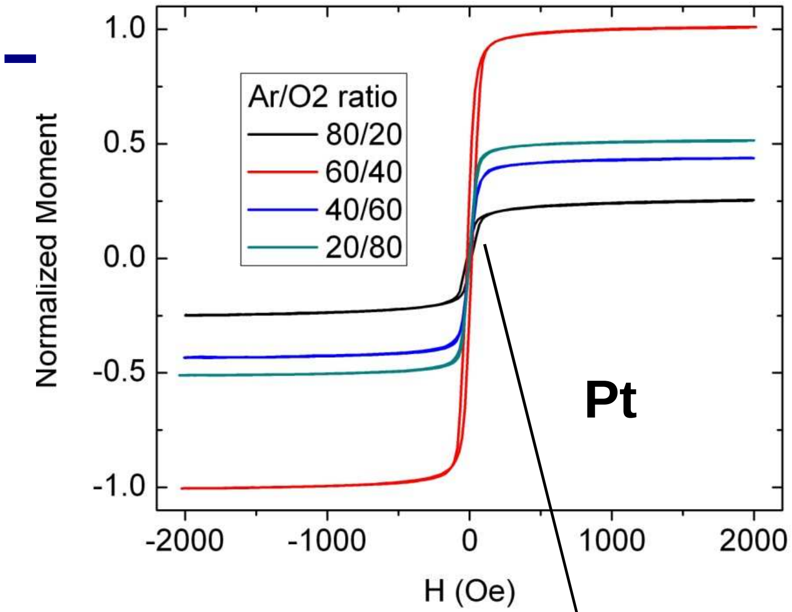
Ar/O2 ratio 60/40

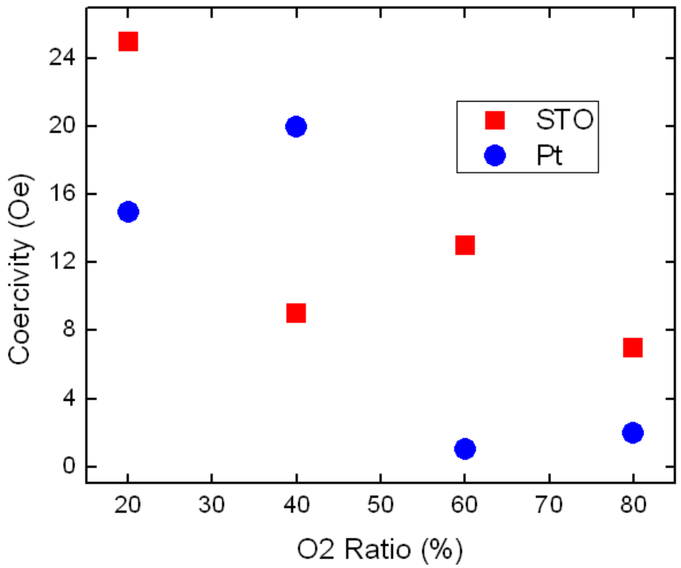


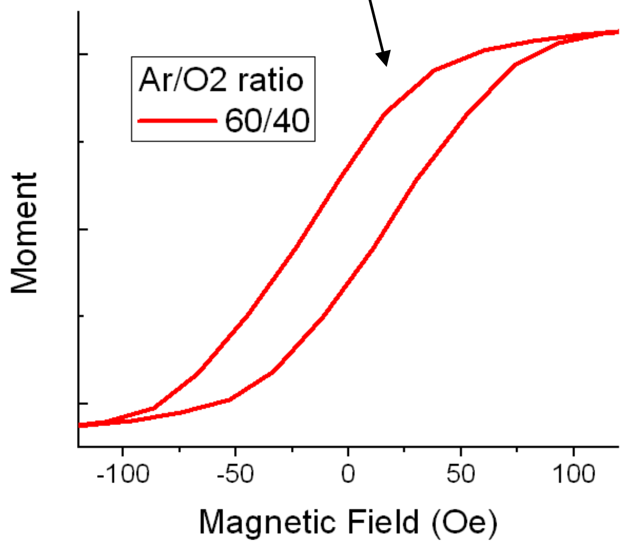
	on STO	on Pt/Si
R_{rms} (nm)	3.344	4.571
Φ (nm)	20-60	~40

Magnetization at 300K

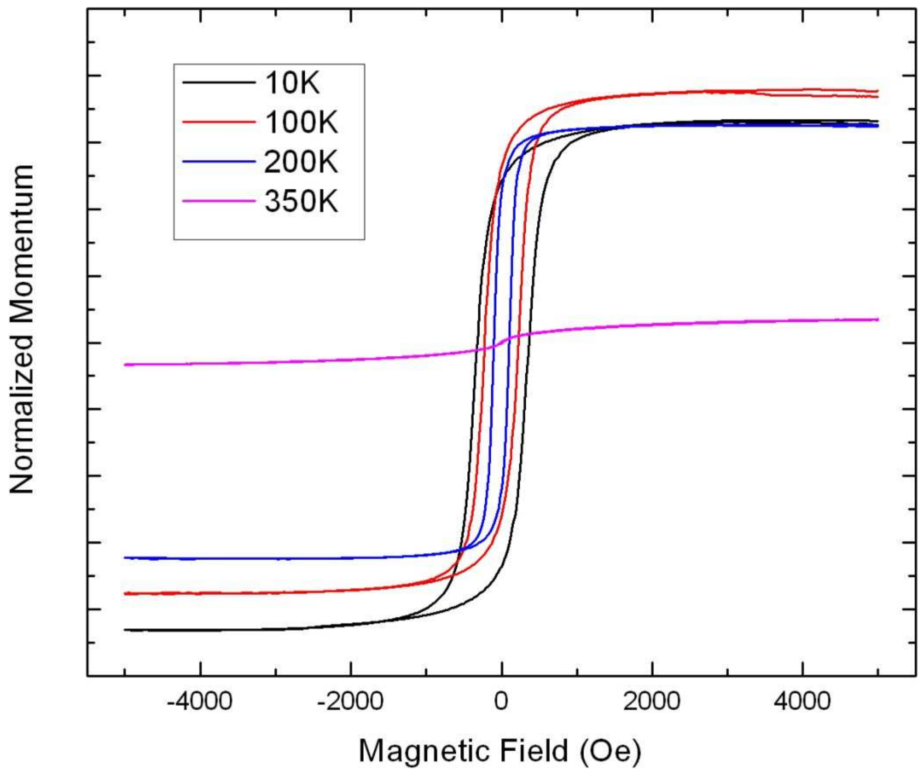




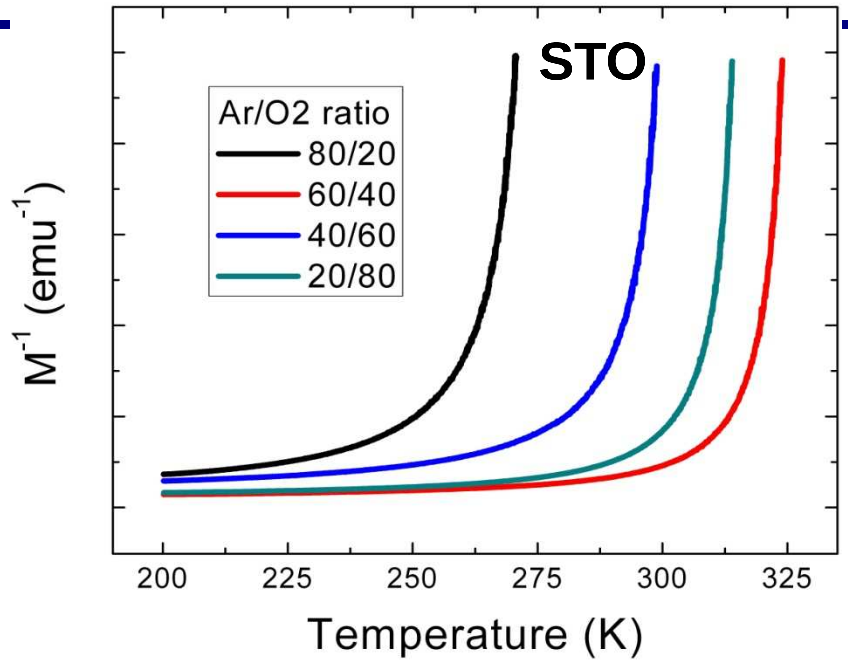


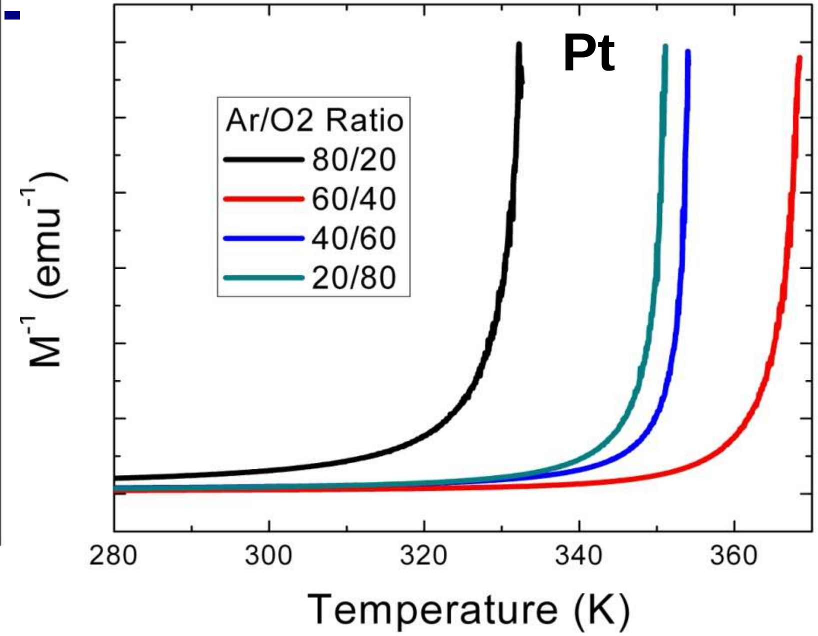


LSMO on Pt with Ar:O_2 at 64/40

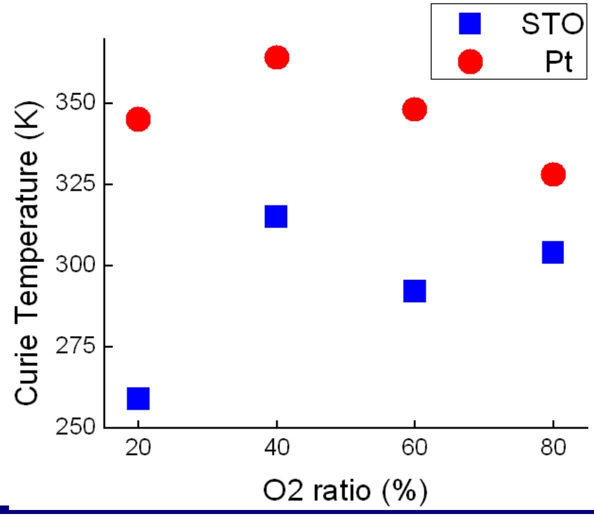


Curie Temperature





- **Determined by extrapolation at $1/\chi=0$ of the Curie-Weiss law.**
- **On both substrate, the films deposited with 40% O_2 have the highest T_c.**



Summary

- LSMO thin films are highly textured with LSMO 110// Pt 111. LSMO is epitaxial when deposited on STO 100 single crystal substrate. Phase pure LSMO films were obtained deposited on STO (100)
- LSMO thin films deposited on Pt/Si exhibited better magnetic properties with higher T_c. T_c of ~365 K was measured on LSMO deposited on Pt/Si with Ar/O2 ratio of 60/40.
- Further optimization by changing growth parameters is necessary to obtain phase-pure LSMO thin films. It is also important to characterize the transport properties of LSMO films.

Future Work

- Further optimization by changing growth parameters, such as temperature, gas ratio and the voltage, is necessary to obtain phase-pure LSMO thin films.
- Deposit $La_{1-x}Sr_xMnO_3$ with x ≈0.3, where LSMO is P.I. or P.M above T_c.
- Deposit some multilayer, such as $SrTiO_3$ and $BiFeO_3$ on LSMO, to study the strain and stress effect on LSMO and make multiferroic structure

Thank you

Questions?