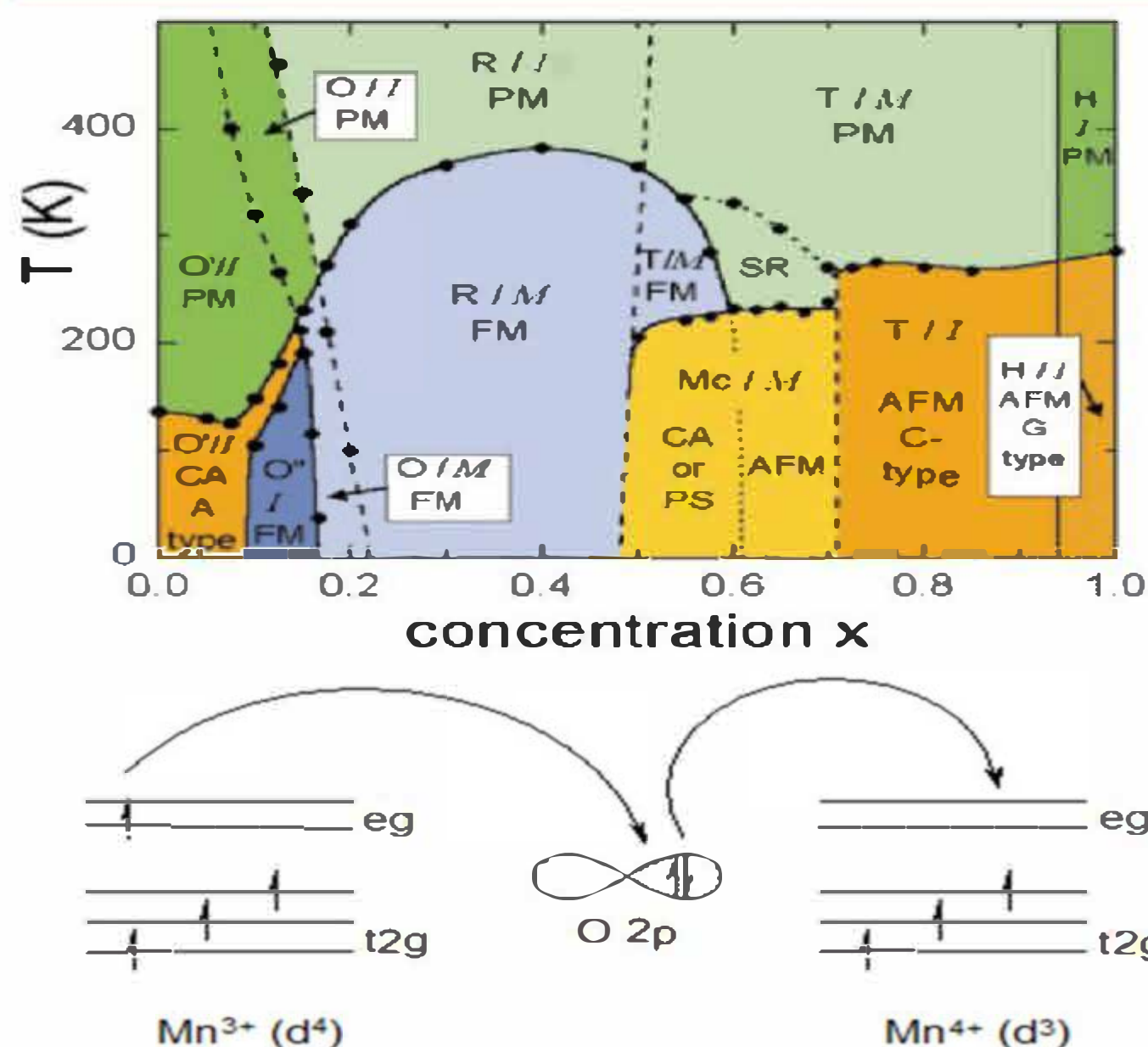


## Abstract

This project investigates the magnetic properties of a  $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$  ( $x = 0.40$ ) sample of high quality. This sample was grown one atomic layer at a time by Prof. Warusawithana using UNF's Molecular Beam Epitaxy (MBE) machine. These magnetic properties are investigated over a range of temperatures from 5 to 400 K in fields up to 7 T. We make use of the techniques to analyze the sample to determine to a high degree of precision the critical temperature of the sample, we determined it to be 252 K.

We further identified the saturated magnetization, remnant magnetization, and coercive field at 5 K to be 0.00733 emu/g, 0.00563 emu/g and 0.0090 T respectively

## $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ Bulk Phase Behavior



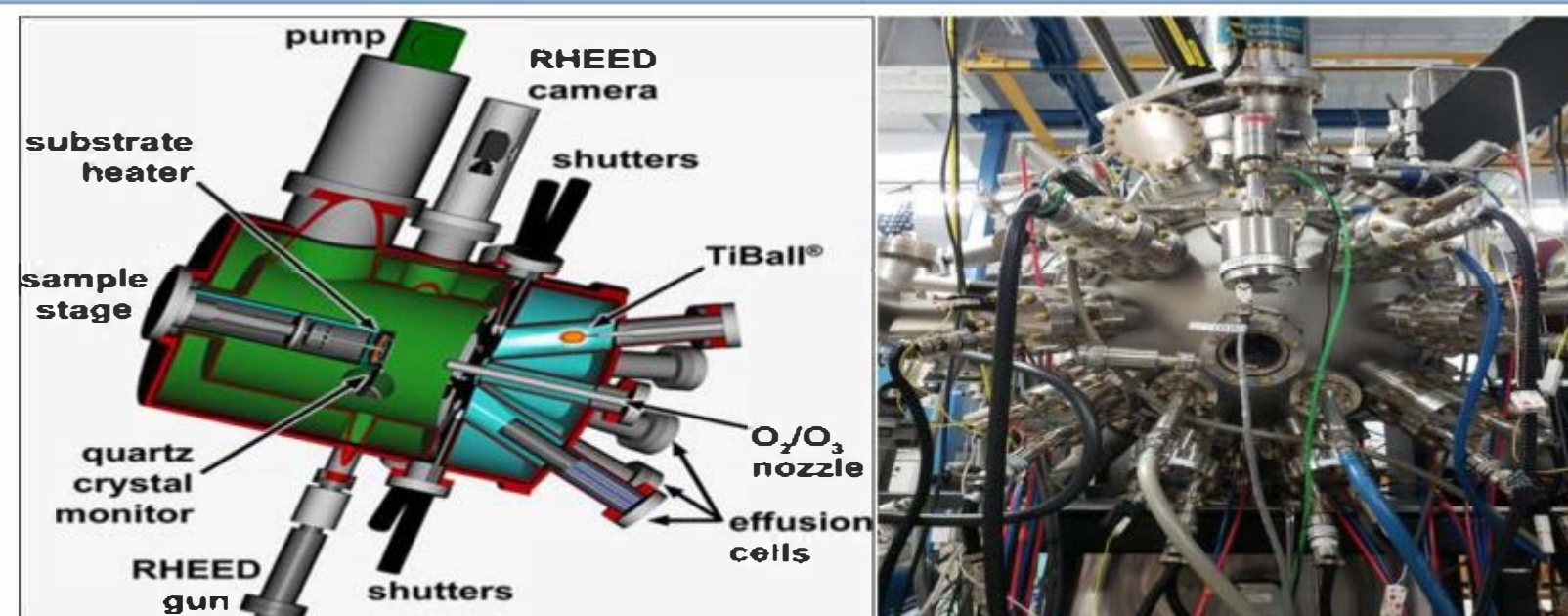
(Top) Bulk  $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$  Phase diagram.

[Hemberger *et al*, PRB 66, 094410 (2002).]

(Bottom) Mechanism for double exchange interaction.

- $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$  has been extensively studied in bulk crystals with respect to temperature and strontium concentration.
- Undoped  $\text{LaMnO}_3$  is a Mott insulator that is paramagnetic at high temperature and antiferromagnetic at low temperature.
- Around  $x = 0.4$ ,  $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$  behaves as a ferromagnetic conductor at low temperatures, however at high temperatures it transitions to a paramagnetic insulator.
- The conducting ferromagnetic state is favored at  $x = 0.4$  at lower temperatures due to a double exchange interaction which reduces free energy by allowing for the delocalization of electrons across the spin-aligned Mn atoms

## Molecular Beam Epitaxy

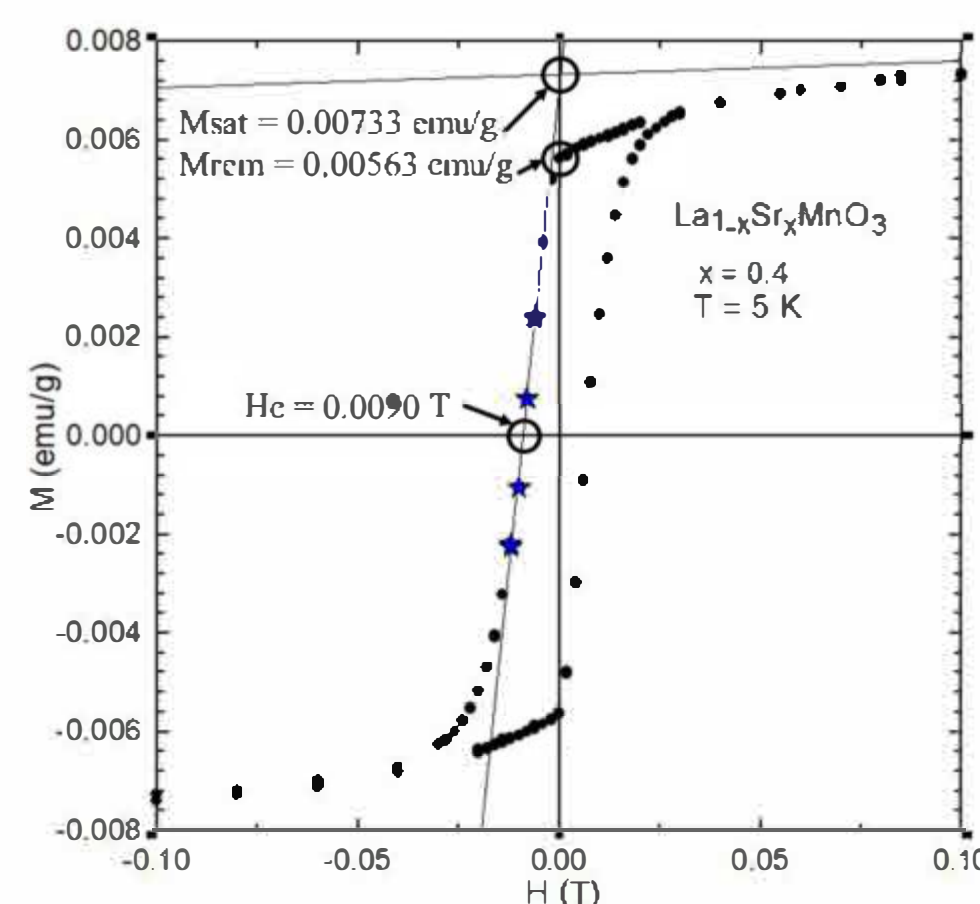


Side view diagram of an MBE chamber.

Front view picture of the chamber used in our growths.

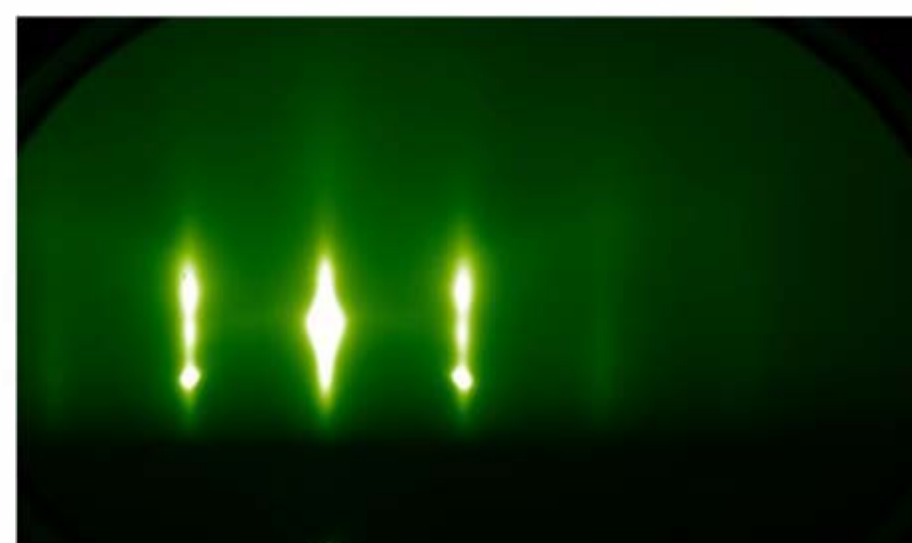
- Samples grown using Molecular Beam Epitaxy (MBE).
- Carefully calibrated molecular beams of constituent elements produce thin films one atomic layer at a time.
- Constituent elements sources are heated in effusion cells to evaporate material into the chamber, forming collimated molecular beams.
- Ozone was introduced into the chamber to form oxides, allowing us to keep the chamber pressure low ( $5 \times 10^{-7}$  Torr) due to ozone's high oxidizing potential.

## Ferromagnetic Hysteresis Loop at 5 K



Analysis of the data at low temperatures shows complete hysteresis for the concentration  $x = 0.4$  confirming the expected ferromagnetic behavior predicted by the bulk sample. The figure reveals the remnant magnetization ( $M_{\text{rem}}$ ) to be 0.00563 (emu/g) and the saturated magnetization ( $M_{\text{sat}}$ ) to be 0.00733 (emu/g). Finally the coercive field ( $H_c$ ) is found to be 0.0090 T.

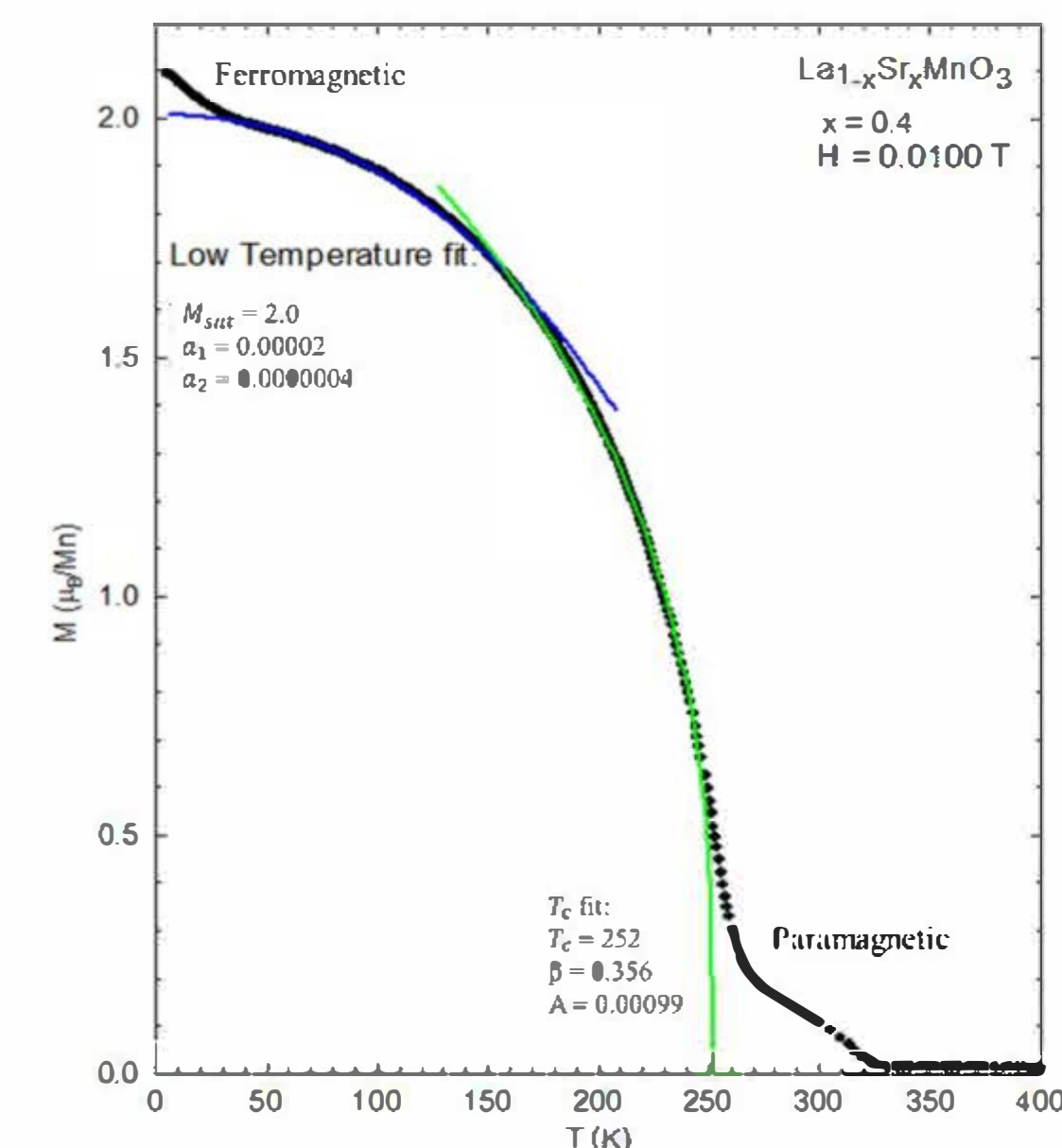
## RHEED



LSMO  $x=0.4$

Reflection High Energy Electron Diffraction (RHEED) patterns taken nearing the end of growth reveal a well-strained 2-D system. Images taken *in situ* during the growth of the films indicate epitaxial layer-by-layer growth. Transport data of the sample as well as expectations of the bulk sample indicate that at this concentration the material is a paramagnetic insulator at high temperature.

## Ferromagnetic Transition Temperature



Magnetization versus temperature for the  $\text{La}_{0.6}\text{Sr}_{0.4}\text{MnO}_3$  random alloy sample is shown. The key feature is a ferromagnetic transition near 252 K.

The fit at low temperature

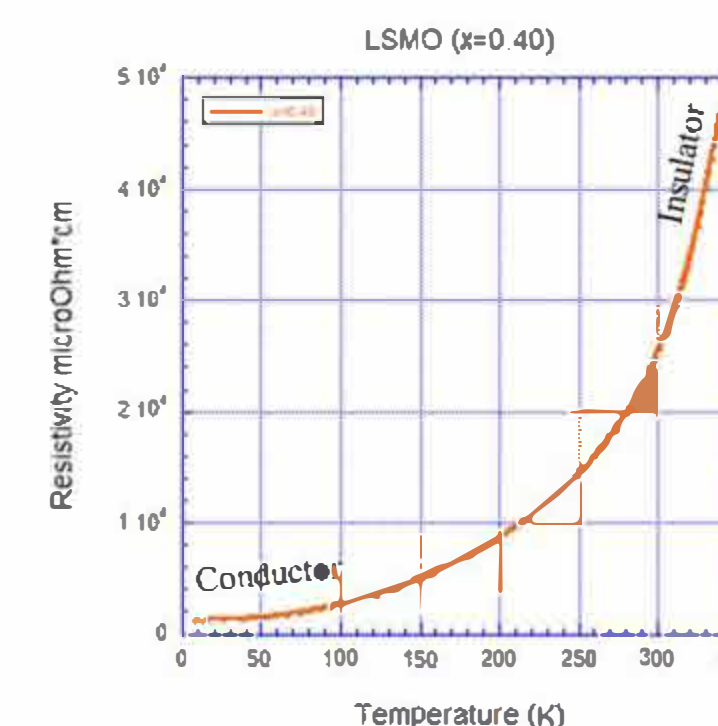
$$[M = M_{\text{sat}}(1 - a_1 T^2 - a_2 T^5)]$$

is consistent with the decrease due to spin density waves.

The fit near  $T_c$  follows the standard power law behavior

$$[M = A(T - T_c)^\beta].$$

## Resistivity



When grown as a random alloy, where La and Sr atoms randomly occupy the A-site of the perovskite structure,  $\text{La}_{0.6}\text{Sr}_{0.4}\text{MnO}_3$  has a conducting-ferromagnetic ground state. Its resistivity increases rapidly as a function of temperature. This indicating that at high temperatures it becomes a paramagnetic insulator, whereas at low temperatures it behaves as a ferromagnetic conductor.