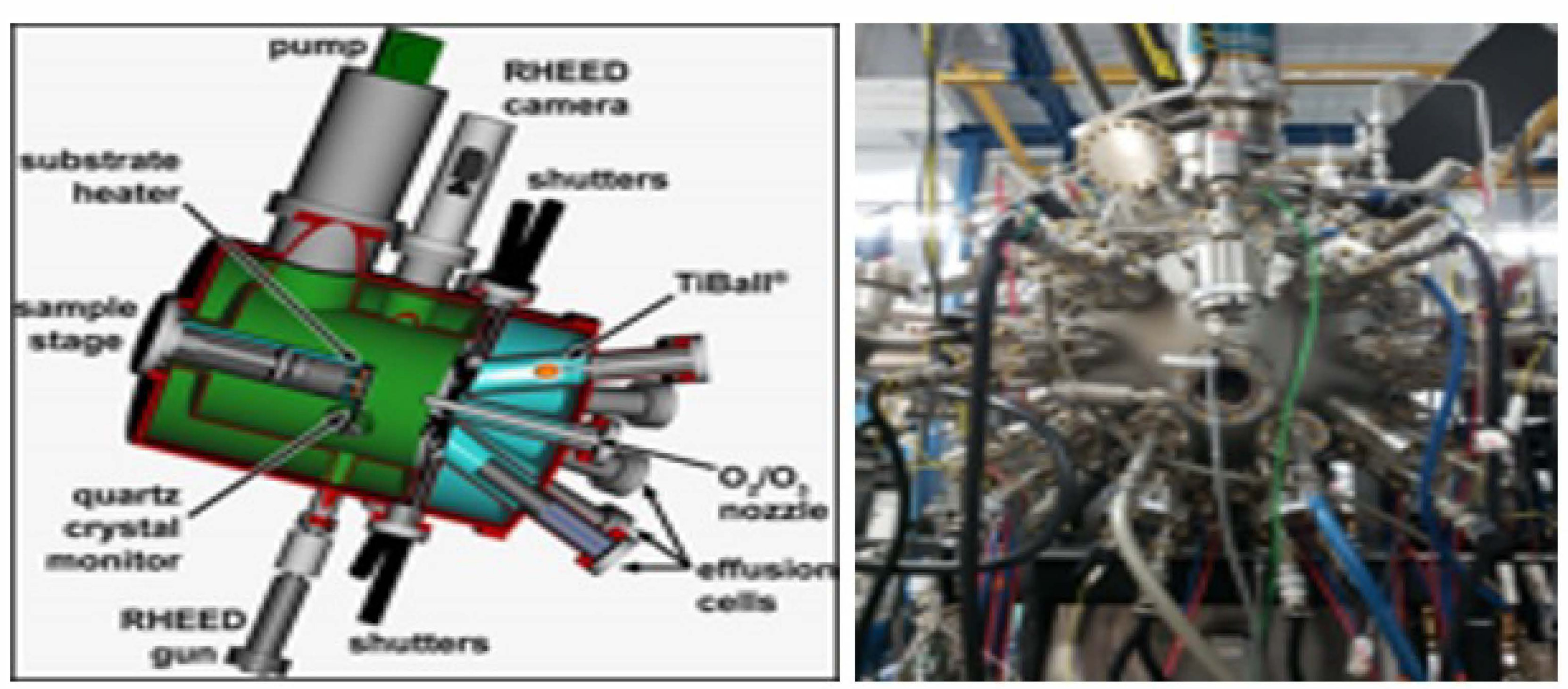
Magnetic Properties of MBE Grown $La_{1-x}Sr_xMnO_3$ Thin Films versus Bulk Crystal Data

Charles Bryant, James Payne, Calleigh Brannan, Rodolfo Marquez Tavera, Maitri P. Warusawithana, Tom M. Pekarek
Department of Physics, University of North Florida, Jacksonville, Florida 32224, USA

Abstract

We have studied how the ferromagnetic transition and other magnetic properties vary with concentration. Data collected has been analyzed, using SigmaPlot software, to better evaluate reduced dimensionality effects on the magnetic behavior of lanthanum strontium manganite ($La_{1-x}Sr_xMnO_3$ or LSMO). Measurements using reflection high-energy electron diffraction (RHEED) were incorporated to verify that the crystals are high quality. We then measured the magnetic properties using our Superconducting Quantum Interference Device (SQUID) magnetometer. These magnetic properties have been analyzed to determine the characteristics of the superlattice. The primary goal has involved the magnetic data collection and analysis. Our analysis has investigated the major ferromagnetic properties and other qualities of the samples. Critical temperature, saturated magnetic moment, remnant moment, and Bohr magneton versus temperature as well as the ferromagnetic to paramagnetic transition temperature have been studied in detail over a sample range of Sr concentration values from $x = 0.04$ to 0.20. This has provided a better insight into the interesting behavior exhibited at concentration $x = 0.04$, where the canted anti-ferromagnetic properties begin to become apparent in this doping range but aren't apparent at higher doping (higher concentrations). Thanks to the research grant provided by The Office of Undergraduate Research we have the helium gas that is essential for producing the liquid helium needed for more measurements that will be required to fine tune and verify our data for scientific publication.

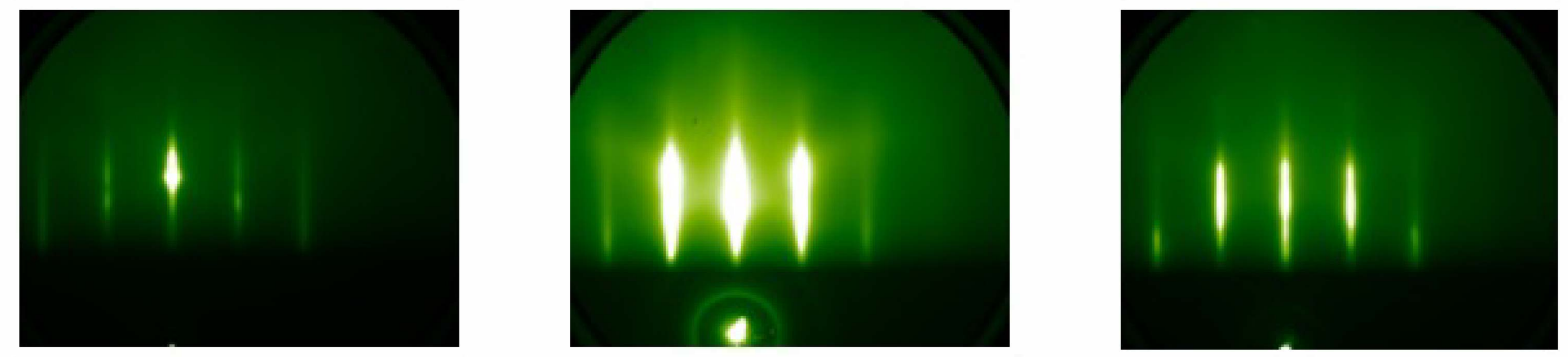
Molecular Beam Epitaxy



MBE chamber used to create samples and actual photo of MBE chamber

- 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 (5×10^{-7} Torr) due to ozone's high oxidizing potential.

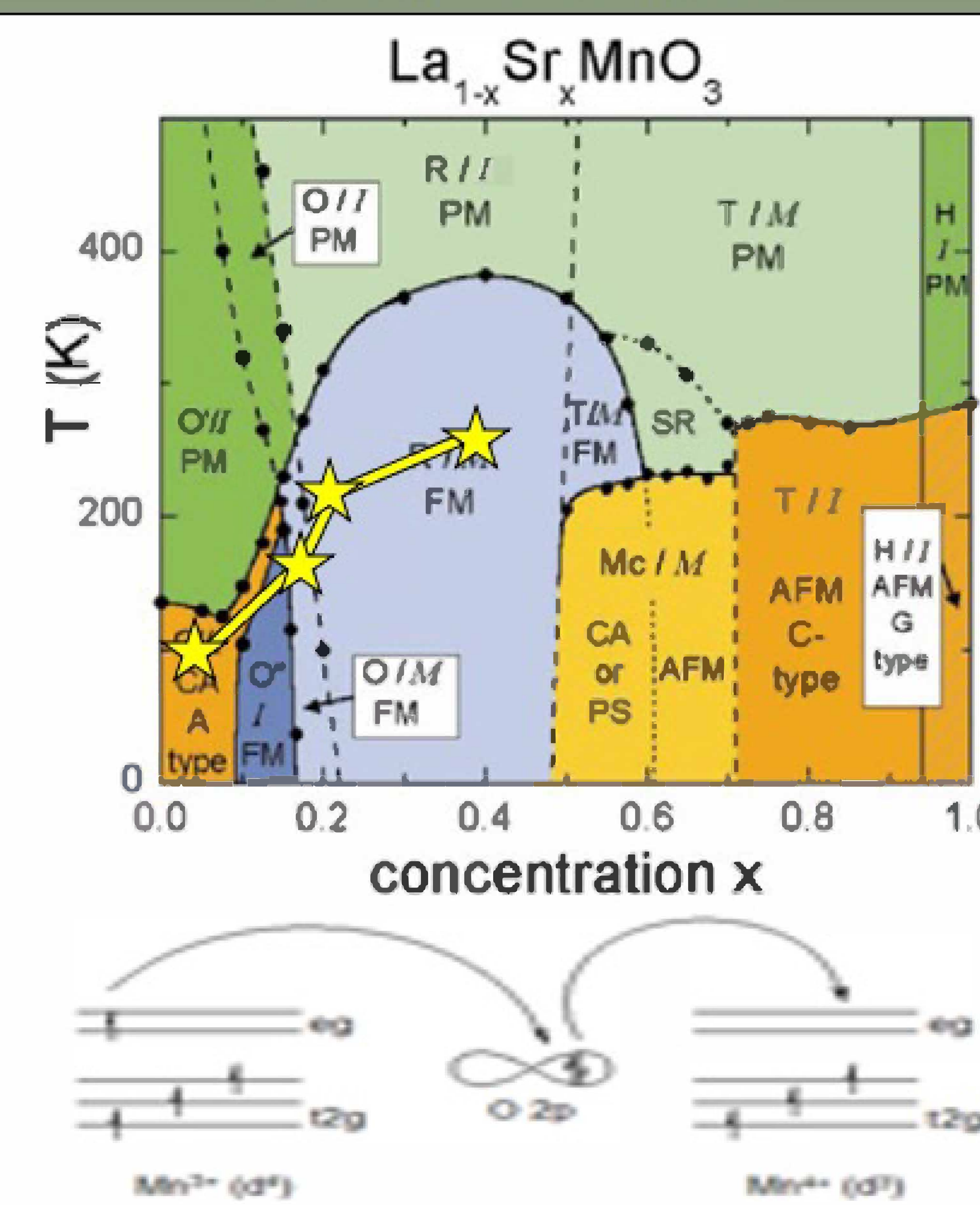
RHEED



LSMO $x = 0.04$ LSMO $x = 0.17$ LSMO $x = 0.20$

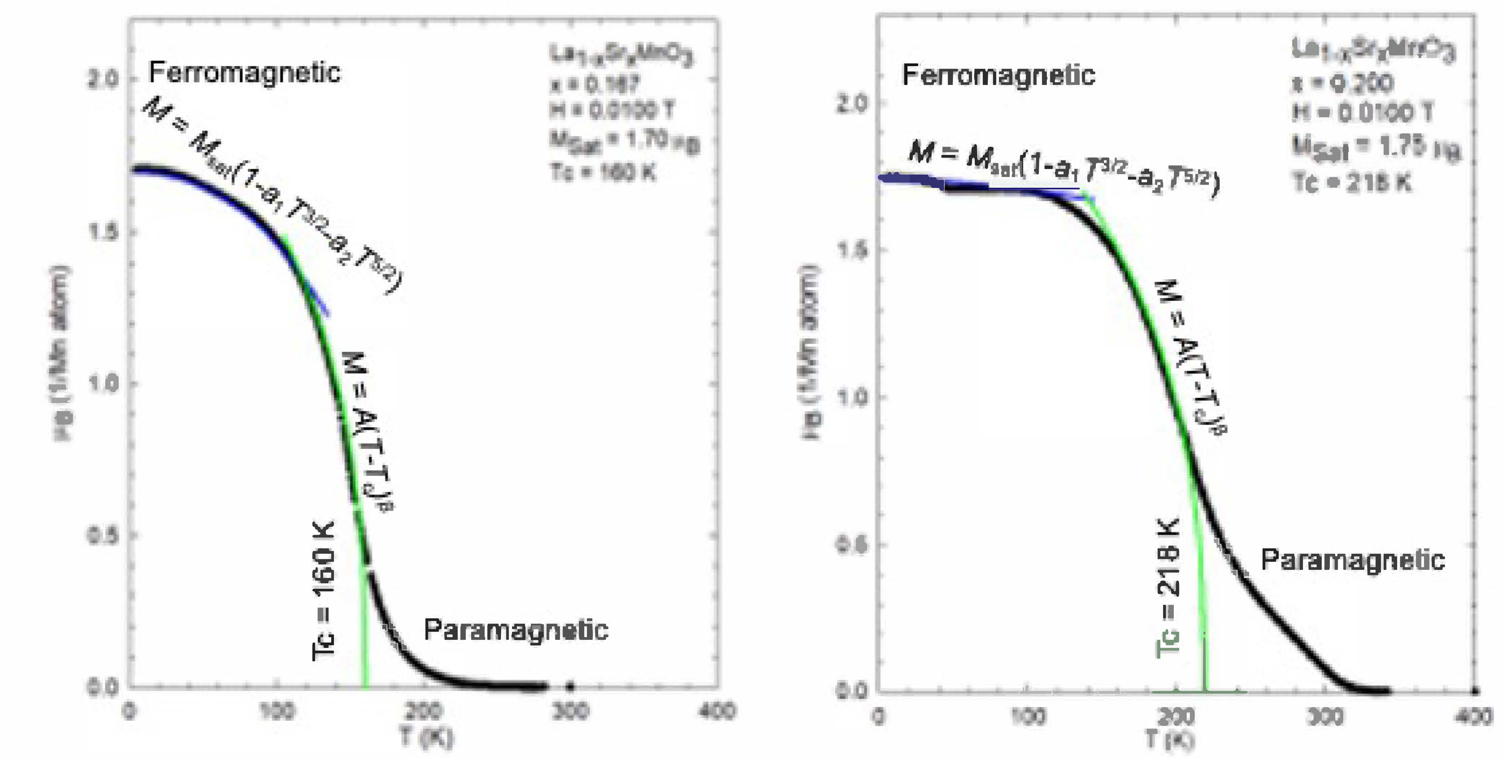
Reflection High Energy Electron Diffraction (RHEED) images taken *in situ* during the growth of the films indicate epitaxial layer-by-layer growth. RHEED images during the growth of a supercell: (left) concentration $x = 0.04$, (center) concentration $x = 0.17$, and (right) concentration $x = 0.20$. Surface reconstructions observed in RHEED patterns indicates well-strained growth and the appropriate degree of octahedral distortions in the strained superlattice. It also shows a two-dimensional surface morphology.

Bulk Phase Behavior



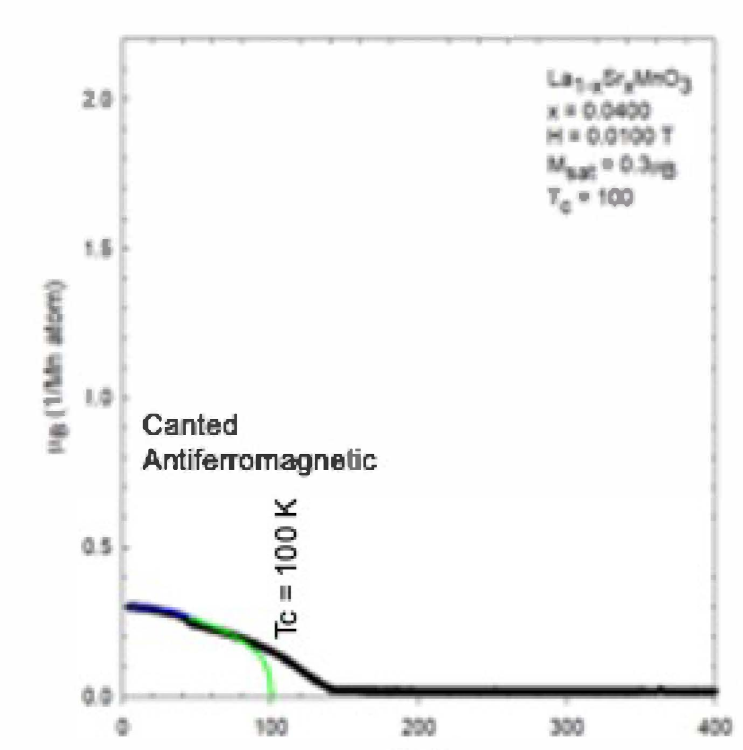
The behavior of $La_{1-x}Sr_xMnO_3$ has been extensively documented in bulk crystals with respect to temperature and strontium concentration. Undoped $LaMnO_3$ is known to be a Mott insulator that at higher temperatures has paramagnetic behavior and becomes antiferromagnetic at lower temperatures. In the range around $x = 0.4$ $La_{1-x}Sr_xMnO_3$ is a paramagnetic insulator at higher temperatures but at lower temperatures it transitions to a ferromagnetic conductor. This ferromagnetic-conducting state is kinetically favorable around $x = 0.4$ at lower temperatures because the double exchange interaction allows for the delocalization of electrons across spin aligned manganese atoms, reducing free energy.

Ferromagnetic Transition at High x



The above graphs show Bohr magneton versus temperature. There is a ferromagnetic transition at around 218 K for the $x = 0.200$ concentration and one at 160 K for the $x = 0.167$ concentration. The sample has paramagnetic behavior above critical temperature. The samples at $x = 0.200$, and $x = 0.167$ are ferromagnetic at lower temperatures. Then they transition to paramagnetic at their critical temperature, indicated by T_c, and remain that way above T_c. This can be seen in the graph where μ_B drops off to zero.

Canted Antiferromagnetic Transition at Low x



This graph represents the Bohr magnetons per Mn atom versus temperature. These plots will mirror M (emu/g) versus temperature graphs, but with these parameters, also give a glimpse into whether-or-not the sample is in a canted antiferromagnetic state. This is all part of our magnetic data analysis and there is evidence of the canted antiferromagnetic behavior seen in the graph of $x = 0.040$. The lower value of the magnetization in Bohr magnetons for the canted antiferromagnetic phase is consistent with the partial canceling of the magnetic moments.

Acknowledgements

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