Fabrication of Single Crystal Thin Films of $La_{1-x}Sr_xCoO_3$ on $SrTiO_3$ (001) substrates

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Motivation

Complex oxides with perovskite structures offer an interesting and intriguing field of research for material scientists and physicists due to their wide range of electronic and magnetic properties like high Tc superconductivity, colossal magnetoresistance (CMR), ferroelectricity, spin state transitions etc.

Examples include $PbTiO_3$ (ferroelectric), $YBa_2Cu_3O_{7-\delta}$ (high temperature superconductor), $SrTiO_3$ (high K insulator), $LaAlO_3$, $LaMnO_3$, and, of course, $La_{1-x}Sr_xCoO_3$.

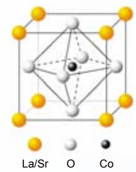
Although bulk $La_{1-x}Sr_xCoO_3$ has received considerable attention due to the existence of spin-state transitions, magnetoelectronic phase separation, and giant anomalous Hall Effect, a thorough and comprehensive study in thin films is still missing.

The potential applications for thin films of $La_{1-x}Sr_xCoO_3$ include ferroelectric random access memories, magnetic tunnel junctions, and solid oxide fuel cells.

$La_{1-x}Sr_xCoO_3$

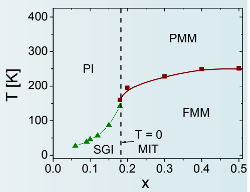
$La_{1-x}Sr_xCoO_3$ (LSCO) assumes a simple cubic structure in which all of the sides of the lattice are of equal length.

The structure itself is composed of eight lanthanum and strontium atoms (exact ratio is dependent on the doping constant, *x*) forming the cubic shape of the lattice. At the center of each face lies an oxygen atom (six total), and in the center resides the cobalt atom.

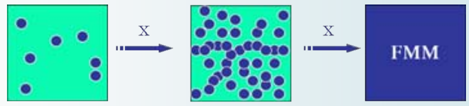


Unlike LSCO in bulk form, thin films of the compound are made up of tons of the tiny structures repeating without any grain boundaries throughout the whole sample. As a result, the sample is referred to as being a single crystal thin film.

Bulk $La_{1-x}Sr_xCoO_3$ Phase Diagram



The phase diagram for bulk LSCO pictured right shows how magnetic phase varies with changing temperature and doping constant. The red plotted points show the boundary between ferromagnetic metal (FMM) and paramagnetic metal (PMM). The green plotted points show the boundary between spin glass state (SG) and paramagnetic insulator (PI). The dotted line shows the doping constant where the metal insulator transition (MIT) occurs. Below is an illustration of how the ferromagnetic clusters (blue) can combine after a certain concentration to produce the FMM and PMM phases.

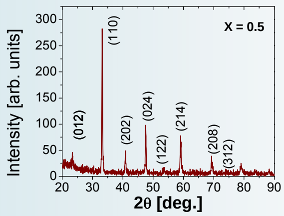


Synthesis of $La_{1-x}Sr_xCoO_3$ Powder

LSCO is made by periodically grinding together correct amounts of La_2O_3, Co_3O_4, and $SrCO_3$, heating them to 1000° C for seven days, and pressing them into flat disks called targets. Before they are pressed, however, a powder sample of the mixture is analyzed by X-ray diffraction to ensure a complete reaction. The complete reaction is below.

$$\frac{1-x}{2}La_2O_3 + xSrCO_3 + \frac{1}{3}Co_3O_4 + \left(\frac{x}{2}+\frac{1}{6}\right)O_2 \rightarrow La_{1-x}Sr_xCoO_3 + xCO_2$$

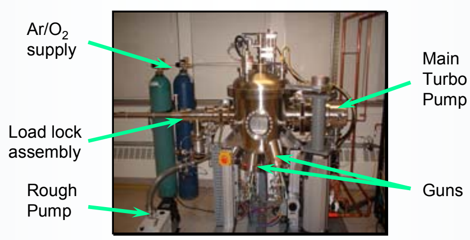
The X-ray diffraction of the powder sample utilizes Bragg's Law to identify the sample from the different interplanar distances. An example X-ray diffraction scan is shown below along with the planes that correspond to each peak.



Fabrication of Thin Films

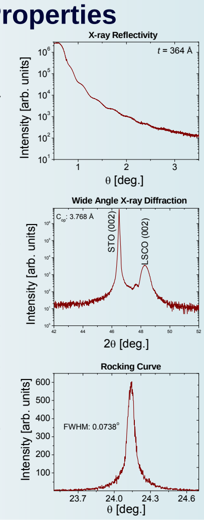
The single crystal thin films are grown via DC magnetron sputtering in the vacuum chamber shown below.

The "target" containing the pressed polycrystalline LSCO powder is loaded into the chamber along with the $SrTiO_3$ (001) substrate the film is to be grown on. After the pressure is reduced and the temperature adjusted to 700°C, positively charged argon atoms are accelerated by an electric potential difference toward the target and knock off atoms through momentum transfer. The individual LSCO atoms are then deposited on a rotating substrate to produce a single crystal thin film of LSCO.



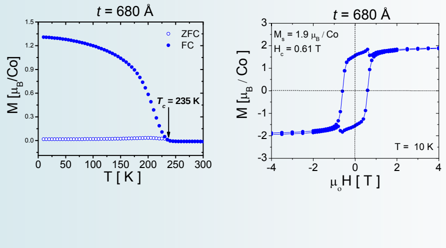
Structural Properties

The structural properties of thin films of LSCO are measured using X-ray diffraction and, for surface analysis, atomic force microscopy. There were three types of scans I conducted using X-ray diffraction. One type of scan is referred to as a reflectivity curve and is used to measure the thickness of the film. Another scan conducted was the coupled scan which is used to again test the purity and crystallinity of the sample. The last scan, called the rocking curve scan, tells how well the crystal planes for the substrate and film are aligned. Examples of the three scans are shown to the right in that order.



Magnetic Properties

The magnetic properties of single crystal thin films of LSCO are measured using a superconducting quantum interference device (SQUID). After being placed in the SQUID, the sample is exposed to varying magnetic fields. The magnetic moment of the sample is concurrently measured by pickup coils to produce a graph of the sample's magnetic moment as a function of the surrounding magnetic field.



Conclusion

I had successfully fabricated epitaxial single crystal thin films of $La_{0.5}Sr_{0.5}CoO_3$ on $SrTiO_3$(001) substrates. Through the analysis of their properties, I found the films to be ferromagnetic (FM) and metallic.

I have learned a lot from this research opportunity. Prior to this experience I hadn't realized the amount of information that could be gathered from epitaxial single crystal thin films using the various techniques mentioned previously. Also, the science behind the growth, structure, and magnetic properties of the thin films was something that I had modest understanding of. After taking part in the research of the films and studying the science behind it, I can say I've gained a lot from this experience.

Future research on this subject could involve an analysis of the properties of epitaxial single crystal thin films of $La_{1-x}Sr_xCoO_3$ deposited on different substrates including $SrTiO_3$(110), $SrTiO_3$(111), and $LaAlO_3$.

References

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