Characterization of MBE grown $SrMoO_3$ thin films as a transparent conductor

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Abstract

$SrMoO_3$ is the most conducting perovskite oxide and has high optical transparency, categorizing it as a Transparent Conducting Oxide (TCO). TCOs are most appealing for transparent electrode and display technologies. Currently, the TCO Indium Tin Oxide (ITO) is widely used; however, ITO has a low electrical conductivity compared to correlated metal oxides. Therefore, we aim to show the correlated metal $SrMoO_3$ as a promising TCO candidate. Previously, $SrMoO_3$ thin films have been grown by pulsed laser deposition and conventional molecular-beam epitaxy. We report the growth of phase-pure $SrMoO_3$ thin films grown by Molecular-Beam Epitaxy at 1250°C on $DyScO_3$ substrates in an adsorption control regime. We characterize the optical and conducting properties of these films using UV-Vis Spectroscopy and a 4-point probe measurement, respectively. Using the Haacke Figure of Merit, we compare our thin films with Indium Tin Oxide and other correlated metal oxides. Our films show room temperature resistivities of 30 μΩ-cm and residual resistivity ratio of 9.4, with a resulting Haacke figure of merit of 1.15×10^{-2}. We show that our $SrMoO_3$ thin films are a promising candidate for TCOs.

I. Introduction

Transparent Conducting Oxides are materials that are both conducting and optically transparent. They are promising materials for application in transparent electrodes and display technologies. Indium Tin Oxide (ITO) is widely used; however, it is expensive and a poor conductor [1]. Correlated metals such as $SrMoO_3$ are more conducting and optically transparent, making them a promising TCO candidate.

II. Methodology

Our $SrMoO_3$ thin films were grown by Molecular-Beam Epitaxy. This thin film deposition method deposits molecular beams from heated sources in ultra-high vacuum. The $SrMoO_3$ films were grown at a growth temperature of 1250°C with Sr and MoO_3 sources in UHV. The films were grown on $DyScO_3$ (110) substrates, which has 0.3% compressive strain with $SrMoO_3$.

A challenge of using the MoO_3 is that it tends to reduce to MoO_2 in ultra-high vacuum. To keep the MoO_3 oxidized, oxygen is supplied directly to the source through a leak valve at the bottom of the differentially pumped effusion cell. Through the leak valve, we supply an oxygen pressure of $2 \times 10^{-8}\ torr$ above the background pressure.

Although we did not experience any source reduction, we did experience clogging. We first used an alumina crucible to hold the MoO_3 powder, which has a 25 °C gradient between the base and tip. After some time, the MoO_3 flux decreased due to the MoO_3 powder clogging the opening of the crucible. Hypothesizing that the crucible was the issue, a pBN crucible was used, with a higher gradient of 100 °C between the base and tip. Unfortunately,

the flux decreased once again, this time clogging the opening of the sleeve. We hypothesize that the MoO_2 starts to form on the sleeve opening, and will explore using a sleeve with a bigger opening for future growths.

III. Results

Before a drift in flux from the MoO_3 source, single-phase $SrMoO_3$ thin films of varying thicknesses were grown. X-ray diffraction scans were taken of $SrMoO_3$ films from 5 to 13nm (Figure 1). The presence of Pendellösung fringes, most prominent around the 001 and 002 peaks, indicates a sharp interface between film and substrate as well as good crystalline quality. The 10.4 nm sample in our series shows a peak around 40°, suggesting the presence of molybdenum metal, possibly due to the drifting MoO_3 source.

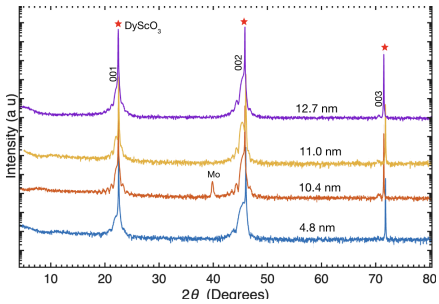

Figure 1. 2Θ-ω scan of $SrMoO_3$ thin films at different thicknesses.

The 4.8 nm and 11.0 nm samples were the focus for optical and transport characterizations. Transport characterization was done with the *dipper*, a 4-point probe resistance vs. temperature measurement taken by dipping the sample into helium as it cools. From this measurement, resistance vs. temperature data is obtained (Figure 2). The 11.0 nm film has a room temperature resistivity of 30 μΩ-cm, comparable with $SrMoO_3$ films reported in literature.

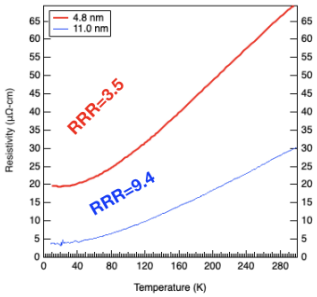

Figure 2. Resistivity vs. Temperature measurement of two $SrMoO_3$ thin films

From the transport measurements, we can obtain information about the purity of the sample using the Residual Resistivity Ratio (RRR) $RRR = \frac{\rho(RT)}{\rho(4K)}$. Because scattering at low temperatures is dominated by defects in the sample, a higher RRR sample indicates fewer defects present in the sample. Although these films show a higher RRR compared to the current literature on $SrMoO_3$, they are not the record value for our $SrMoO_3$ thin films.

UV-Vis Spectroscopy was used to characterize the optical properties of our films, measuring the transmission as a function of wavelength (Figure 3).

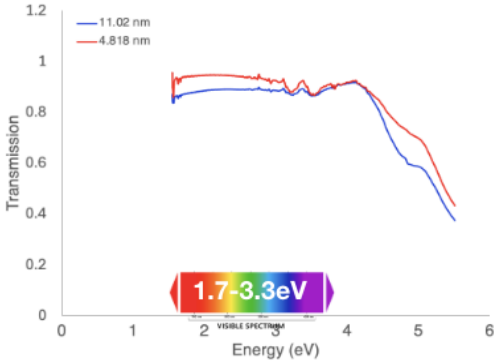

Figure 3. UV-Vis Spectroscopy measurement of $SrMoO_3$

Both films exhibit a transmission between 0.8 - 1 within the visible regime (1.7 - 3.3eV), confirming our films are optically transparent within the visible regime.

After measuring the transport and optical properties of our $SrMoO_3$ films, we calculated the Haack Figure of Merit (FOM) to compare with other TCOs. The Haacke FOM is

calculated as $\Phi_{TC} = \frac{T^{10}}{R_s}$, where T is the transmission at 550 nm divided by the sheet resistance, R_s.

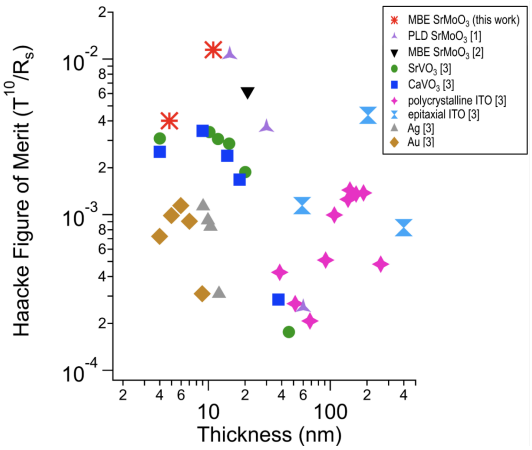

Figure 4. Haacke Figure of Merit vs. Temperature graph

The higher the Haacke FOM, the better the performance of the material as a TCO. The Haacke figure of merit is calculated for different conducting and transparent materials (Figure 4). Metals like silver and gold are good conductors, but opaque in the visible regime, resulting in a lower FOM [1]. The archetypal TCO, Indium Tin Oxide, is a degenerately doped semiconductor and also has a lower FOM because of its poor conductivity [1]. Correlated metals, such as the vanadates and molybdates, have an improved Haacke FOM [1]. Previously grown $SrMoO_3$ grown by PLD [2] and MBE [3] shows a better FOM than the vanadates and ITO. Our films have a comparable and even improved FOM to other $SrMoO_3$ films, making it a favorable candidate for TCOs.

IV. Conclusion and Future Work

In conclusion, we successfully grew $SrMoO_3$ thin films by Molecular-Beam Epitaxy, with our best film having a RRR of 9.4 and a room temperature resistivity of 30 μΩ-cm.

In the future, we aim to improve upon our films with MoO_3 source stability and lower background pressure, and continue growing $SrMoO_3$ thin films of varying thickness to extract their Haacke FOM.

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VI. References

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