Electrical Transport Studies of Epitaxial Sr$_2$RuO$_4$ Films

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The electrical transport properties of epitaxial films of Sr$_2$RuO$_4$ grown by pulsed laser deposition (PLD) have been studied. Sr$_2$RuO$_4$ is the only known layered superconducting perovskite which is free of copper. In single crystal form, Sr$_2$RuO$_4$ becomes superconducting at $T = 0.93$K. Although good metallic conductivity has been found for these epitaxial films, no superconductivity has been detected so far. Results on temperature dependent in- and out-of-plane resistivities of these films are presented and their implications are discussed.

1. INTRODUCTION

There has been a surge of scientific interest in layered perovskites in the past few years due to the discovery of high transition temperature ($T_c$) superconductivity in these materials. Layered perovskite Sr$_2$RuO$_4$ has received special attention due to some of its distinctive properties. First of all, it has a very low electrical resistivity and an excellent lattice match with a widely used high $T_c$ superconductor, YBa$_2$Cu$_3$O$_7$-$\delta$. This makes it a promising normal metal barrier material for fabricating high $T_c$ superconductor devices. In fact, Lichtenberg et al. have used this material as a substrate for growing epitaxial YBa$_2$Cu$_3$O$_7$-$\delta$ films [1].

However, and perhaps more importantly, Sr$_2$RuO$_4$ may play a unique role in revealing the mechanism of high $T_c$ superconductivity. So far, superconductivity above 40K has only been found in layered perovskite materials containing characteristic CuO$_2$ planes. Sr$_2$RuO$_4$ is the only known superconducting layered perovskite which is free of copper [2]. In single crystal form, Sr$_2$RuO$_4$ becomes superconducting at a rather low $T_c$ (0.93K) despite many common features with high $T_c$ cuprates. For example, it is isostructural with high $T_c$ (La$_{1-x}$Ba$_x$)$_2$CuO$_4$. On the other hand, there are also important differences between Sr$_2$RuO$_4$ and high $T_c$ cuprates [3]. Instead of a spin 1/2 state for Cu$^{2+}$ (3$d^9$), Ru$^{4+}$ (4$d^4$) appears to have a spin 1 state. Sr$_2$RuO$_4$ is a paramagnetic metal and becomes superconducting without any intentional doping while the undoped high $T_c$ cuprates are antiferromagnetic and become superconducting only after being doped. The study of Sr$_2$RuO$_4$ may provide insight into the high $T_c$ problem.

It is well known that the normal state in-plane resistivity of high $T_c$ cuprates with optimal doping has a universal linear temperature dependence [4], which is believed to be a manifestation of an unconventional electronic state underlying high $T_c$ superconductivity. However, somewhat ironically, this unconventional state cannot be probed directly by (d.c.) transport measurements at low temperatures because of the onset of superconductivity at a rather high $T_c$. In this regard, Sr$_2$RuO$_4$ has advantages over high $T_c$ cuprates in that electrical transport studies may be carried out down to very low temperatures in pure samples. Key questions to be addressed include whether Sr$_2$RuO$_4$ is a non-Fermi-liquid metal [3] and whether it has an unconventional superconducting state [5].

2. EXPERIMENTAL RESULTS

Epitaxial films of Sr$_2$RuO$_4$ were grown by pulsed laser deposition (PLD). X-ray diffraction results show that these films are single domain and grown c-axis oriented on (100) LaAIO$_3$ and a-axis oriented on (100) LaSrGaO$_4$ substrates. Details of the film growth have been published previously [6]. Electrical resistivity was measured in a $^3$He refrigerator using a four-wire method.

In Fig. 1, in-plane resistivity $\rho_{ab}$ for several c-axis oriented Sr$_2$RuO$_4$ films are plotted against the temperature. The temperature dependence of the resistivity, which can be fitted to the form $\rho_{ab}(T) = \rho_0 + aT + bT^2$, where $\rho_0$, $a$, $b$ are constants, shows that these films are metallic. The quadratic term, which has been seen in less-than-optimally-doped high $T_c$ cuprates, is small but non-negligible, which may suggest that Sr$_2$RuO$_4$ is not as strongly correlated as high $T_c$ cuprates [3].
In Fig. 2, the in-plane and the out-of-plane resistivity for two a-axis oriented films are plotted against the temperature. The in-plane resistivity is again metallic. However, the out-of-plane resistivity shows an insulating behavior. Such behavior suggests a two-dimensional electrical conduction along the ab-planes in these films at low temperatures.

Both c- and a-axis oriented films have been measured down to 0.3K. No superconductivity has been detected so far. Nevertheless, results on low temperature resistivity and magnetoresistance show interesting behaviors even in these non-superconducting films. These results will be discussed in more details in future publications [7].

3. DISCUSSION

So far a detailed chemical composition analysis has not been carried out for either single crystal or thin film Sr2RuO4. Although chemical composition analysis on non-epitaxial Sr2RuO4 films on MgO (grown under the same conditions as those for the epitaxial films) using Rutherford backscattering spectrometry (RBS) indicates that those films are stoichiometric, the same analysis on the epitaxial films on either LaAlO3 or LaSrGaO4 is inconclusive because of the overlap of the Sr and Ru peaks with the heavy elements in the substrates. So far films with low low-temperature resistivities and high room- to low-temperature resistivity ratios have been those which were cooled down slowly in vacuum rather than rapidly in N2 after the deposition, which may suggest that excess oxygen was present in these films. More studies are currently underway to resolve these issues.

4. CONCLUSIONS

In conclusion, the in- and the out-of-plane electrical resistivities of a- and c-axis oriented epitaxial Sr2RuO4 films have been measured. Good metallic conductivity has been found. However, no superconductivity has been detected down to 0.3K. Continuing efforts are underway to fabricate films which are superconducting and to study these films at low temperatures.

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REFERENCES
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