LT 21

Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S2 - Superconductivity 1: HTS - Electromagnetic response, etc.

Electrical Transport Studies of Epitaxial Sr_2RuO_4 Films

Ying Liu[a], J. A. Mitchell[a], S. Madhavan[b], D. G. Schlom[b], A. Dabkowski[c], and H. A. Dabkowska[c]

[a] Department of Physics, Penn State University, University Park, PA 16802, USA

[b] Department of Materials Science and Engineering, Penn State University, University Park, PA 16802, USA

[c] Institute of Materials Research, McMaster University, Hamilton, Ontario, Canada L8S 4M1

The electrical transport properties of epitaxial films of Sr_2RuO_4 grown by pulsed laser deposition (PLD) have been studied. Sr_2RuO_4 is the *only* known layered superconducting perovskite which is free of copper. In single crystal form, Sr_2RuO_4 becomes superconducting at T = 0.93K. 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_2RuO_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, $YBa_2Cu_3O_{7-\delta}$. 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 $YBa_2Cu_3O_{7-\delta}$ films [1].

However, and perhaps more importantly, Sr_2RuO_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_2RuO_4 is the only known superconducting layered perovskite which is free of copper [2]. In single crystal form, Sr_2RuO_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 $(La_{1-x}Ba_x)_2CuO_4$. On the other hand, there are also important differences between Sr_2RuO_4 and high T_c cuprates [3]. Instead of a spin 1/2 state for Cu^{2+} ($3d^9$), Ru^{4+} ($4d^4$) appears to have a spin 1 state. Sr_2RuO_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_2RuO_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 doing 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_2RuO_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_2RuO_4 is a non-Fermi-liquid metal [3] and whether it has an unconventional superconducting state [5].

2. EXPERIMENTAL RESULTS

Epitaxial films of Sr_2RuO_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) $LaAlO_3$ 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 ^3He refrigerator using a four-wire method.

In Fig. 1, in-plane resistivity ρ_{ab} for several *c*-axis oriented Sr_2RuO_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 ρ_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_2RuO_4 is not as strongly correlated as high T_c cuprates [3].

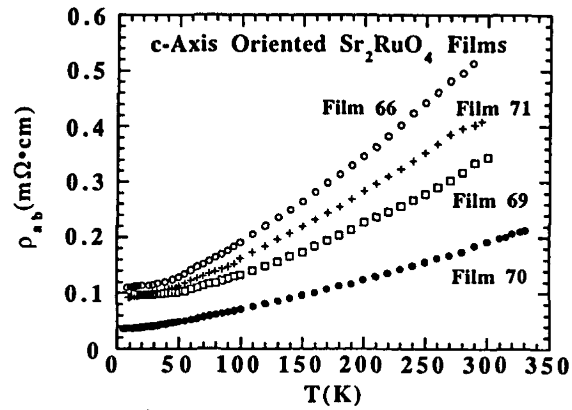

Figure 1. In-plane resistivity ρ_{ab} vs. T for several *c*-axis oriented epitaxial Sr_2RuO_4 films on (100) $LaAlO_3$ prepared under various conditions. Film 66 is 3500Å thick and all others are 700Å thick. Film 69 was doped ($Sr_{1.6}Ba_{0.4}RuO_4$) but others were undoped. Films 66 and 69 were cooled rapidly in N_2 after deposition, while films 70 and 71 were cooled slowly in vacuum.

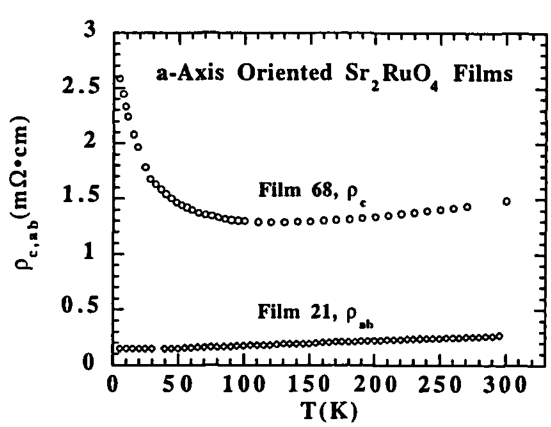

Figure 2. In- and out-of-plane resistivity ρ_{ab} and ρ_c vs. temperature T for two *a*-axis oriented films on (100) $LaSrGaO_4$. The thicknesses for Films 68 and 21 are 700Å and 2200Å respectively. Both films were rapidly cooled in N_2 after deposition.

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 Sr_2RuO_4. Although chemical composition analysis on *non-epitaxial* Sr_2RuO_4 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 $LaAlO_3$ or $LaSrGaO_4$ 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 N_2 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 Sr_2RuO_4 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.

The film growth part of this study is supported in part by ONR through Contract No. N00014-94-1-0815. YL acknowledges helpful conversations with Mac Beasley and Yuyao Zha. He also thanks Ben Blizard for technical assistance.

REFERENCES

[1] F. Lichtenberg *et al.*, Appl. Phys. Lett. **60**, 1138 (1992).
[2] Y. Maeno *et al.*, Nature **372**, 532 (1994).
[3] D. J. Singh, Phys. Rev. B **52**, 1385 (1995).
[4]H. Takagi *et al.*, Phys. Rev. Lett. **69**, 2975 (1992) and references cited therein.
[5] T. M. Rice and M. Sigrist, J. Phys.: Cond. Matt. **7**, L643 (1995).
[6] S. Madhavan *et al.*, Appl. Phys. Lett. **68**, 559 (1996).
[7] Ying Liu *et al.*, to be published.