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Measurements of magnetoresistivity and magnetization of Sr_2RuO_4 single crystals

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We report measurements of magnetoresistivity, dc magnetization, and ac magnetic susceptibility on several single crystal samples of Sr_2RuO_4 (T_c = ~1 K). Magnetoresistivity was measured in the temperature range 0.1 ~ 4K, and in applied magnetic fields up 6 tesla. The magnetic field and current were applied both parallel and perpendicular to the c-axis of the crystal. From the measurements, we determined the superconducting upper critical field, $H_{c2}(T)$. We observed that in magnetic fields above H_{c2}, and for transport currents both in the ab-plane and along the c-axis, Sr_2RuO_4 exhibits a metallic resistivity down to 0.1 K. We have also studied the magnetic phase diagram by measuring dc magnetization M(H) in the temperature range 0.4 ~ 2 K and in applied fields up to 60 mT along the c-axis of the crystal using a Faraday magnetometer. We discuss the resistively and magnetically determined superconducting phase diagrams along with ac susceptibility data.

1. Introduction

The discovery of superconductivity in the layered perovskite Sr_2RuO_4 (SRO) [1] has attracted much attention due to the fact that it might be a p-wave superconductor [2]. Recent NMR [3] and μSR [4] experiments give strong evidence of p-wave superconductivity.

In this paper, we report the magnetic phase diagrams of SRO, which were derived from measurements of magnetoresistivity from 0.1 ~ 4 K and dc magnetization from 0.37 ~ 1 K.

2. Experiments

We measured the magnetoresistivity of SRO in a ^3He-^4He dilution refrigerator in the temperature range 0.1 ~ 4 K, in applied magnetic field up to 6 tesla, using a standard 4 probe method. Contact resistance ~ 0.5 Ω was obtained by attaching gold leads with silver epoxy (Epotek) cured at 500°C for 3min.

The magnetic field was applied both parallel and perpendicular to the c-axis of the crystal. The results are shown in Figs. 1 and 2. The superconducting transition temperature (T_c) was defined as the mid-point of the transition. As the magnetic field is increased up to 6 tesla (> 100·$H_{c2}(0)$), the resistivity along the c-axis and the ab plane exhibits metallic behavior down to 0.1K (≈ 0.1·T_c), which is an unusual feature compared to that among high T_c superconductors [5, 6].

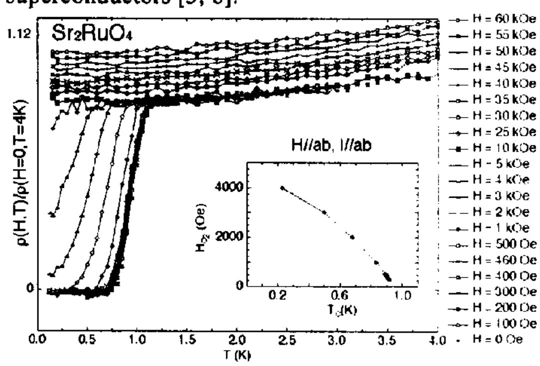

Fig.1. Normalized resistivity vs. temperature with magnetic field parallel to the ab plane of the crystal (T_c = 0.95 K). The direction of I is perpendicular to that of H. Inset: H_{c2}-T phase diagram. T_c was defined as the mid-point of the superconducting transition.

Through measurements of magnetoresistivity, we obtained the magnetic phase diagram, $H_{c2}(T)$, which is shown in insets of Figs. 1 and 2.

$H_{c2}(T)$ for magnetic field parallel to the ab plane is approximately one order of magnitude larger than that for the magnetic field along the c-axis. The $H_{c2}(T)$ curves for both magnetic field directions exhibit negative curvature, in contrast to the positive curvature seen in hole [7] and electron [8] doped cuprates.

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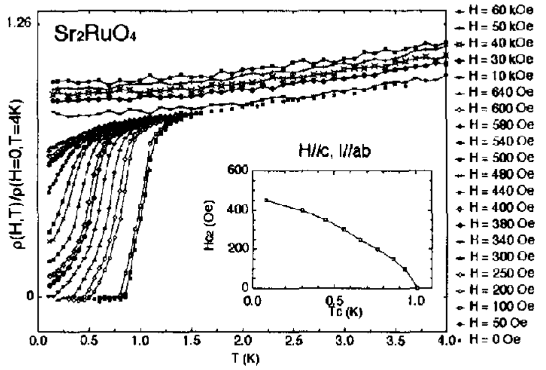

Fig.2. Normalized resistivity vs. temperature with magnetic field parallel to the c axis for a crystal with T_c = 1 K. Inset: H_{c2}-T phase diagram. T_c was defined as the mid-point of the superconducting transition.

We also measured the dc magnetization of SRO (T_c = 1.09 K) with the magnetic field applied parallel to c-axis of a SRO crystal using a Faraday magnetometer. Based on magnetization curves, we obtained the magnetic phase diagram shown in Fig. 3. The insets of Fig. 3 show the transition curve in zero field and a magnetization curve measured at 0.37 K. The smooth transition of the ac susceptibility curve implies that this sample is relatively homogeneous and clean. These H_{c2}(T) values are similar to those obtained by ac suceptibility measurements [9].

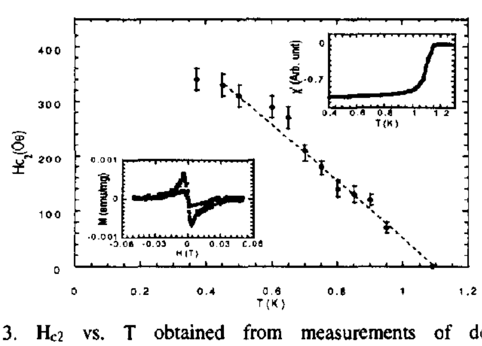

Fig. 3. H_{c2} vs. T obtained from measurements of dc magnetization using a Faraday magnetometer. Insets: dc magnetization curve at 0.37 K and ac susceptibility measurement (T_c = 1.09 K). The dashed line is a linear fit near T_c.

3. Summary

We measured the magnetoresistivity of SRO single crystals whose T_c's were 1 K and 0.95 K. From these measurements, we obtained the magnetic phase diagrams (H_{c2}(T)) for the magnetic field both parallel to the c-axis and the ab plane. The curvatures of resistive H_{c2}(T)'s are negative for both magnetic field directions. We also observed that SRO exhibits metallic resistivity behavior down to the 0.1 K ($T/T_c \approx 0.1$), when the magnetic field was increased to 6 T (> 100·H_{c2}(0)). Using a Faraday magnetometor, we measured the dc magnetization of SRO (T_c = 1.09 K) with magnetic field parallel to the c-axis of the crystal, which gave an H_{c2}(T) curve simillar to that reported by other groups.

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