Study of $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ under pressures and magnetic fields

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Abstract

We measured the resistivity and magnetization of $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ polycrystals under hydrostatic pressures and magnetic fields. With increasing pressures and fields, overall resistivity values drop sharply and, at the same time, the metal-insulator transition temperature increases monotonically. However, the resistivity data show an anomaly developing at lower temperature than T_C with increasing fields and pressures. Based upon the susceptibility measurements, we suggest that this new anomaly is not due to a thermodynamic transition but that it should be related to a percolation phenomena of the metallic phase coexisting with the insulating phase.

Key words: hydrostatic pressure, magnetic field, $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$

1. Introduction

Recently doped manganites, (R,A)MnO_3 (R=rare earth and A=alkaline earth ions), have attracted considerable interest since they show various interesting physical phenomena: for example, colossal magnetoresistance(CMR), metal - insulator transition, charge and orbital ordering. Hwang *etal*. [1] measured the resistivity and magnetization of $La_{0.7-x}Pr_xCa_{0.3}MnO_3$ to find that the Curie temperature of $La_{0.7}Ca_{0.3}MnO_3$ (T_C=245K) decreased with Pr doping. For x larger than 0.6, the low-temperature ground state transformed from a ferromagnetic metal to an antiferromagnetic insulator. This phenomena may be understood qualitatively in terms of a decrease in the hopping parameter (t) with Pr doping. However, it is to be noted that the variation of t under the tight-binding approximation is estimated to be less than 2% for full Pr doping in $La_{0.7}Ca_{0.3}MnO_3$, which is far too small to account for over 50% decrease in T_C due to Pr doping [2]. Therefore, it is naturally assumed that there might be another important physical parameter responsible for such a big change in T_C.

In order to understand better the Pr doping effects in $(La,Pr)_{0.7}Ca_{0.3}MnO_3$, we have measured several $La_{0.7-x}Pr_xCa_{0.3}MnO_3$ with $x = 0$, 0.13, 0.4, and 0.5. In this study, we report mainly the pressure and field dependence of the resistivity and magnetization of $La_{0.5}Pr_{0.2}Ca_{0.3}MnO_3$, which is located close to the antiferromagnetic insulating phase.

2. Experimental Details

All our samples were prepared by using a standard solid-state reaction method and details of the sample preparation are given elsewhere[2]. We measured the resistivity and magnetization of polycrystalline $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ under magnetic fields by using a commercial cryostat (PPMS9, Quantum Design) equipped with a 9-Tesla superconducting magnet. Pressure-dependent resistivity measurements were made with a piston-cylinder type Cu-Be pressure cell up to 12kbar using a cryostat equipped with a 7-Tesla superconducting magnet.

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3. Data and Analysis

Metal-insulator(MI) transition temperature of $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$, defined by the temperature of the resistivity maxima, are 121 K at ambient pressure and without magnetic fields (see Figure 1). This transition temperature is the same as that obtained from the susceptibility measurements and in good agreement with the previously reported results [1]. Figure 1(a)-(c) shows the temperature-dependent resistivity of $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ under magnetic fields, up to 9 Tesla. A shoulder-like structure appears at higher temperature with increasing fields. On the other hand, the peak in the resistivity remains almost at the same temperature. Our AC and DC mageneti-zation measurements show that the upper transition is the ferromagnetic transition while no anomalous behavior is seen in the magnetization data around the temperature of the resistivity peak. The arrows in Figure 1 indicate the magnetic transition temperatures, T_C, obtained from the AC and DC magnetization experiments. Similar behavior is also observed in the pressure-dependent resistivity measurements shown in Figure 1(d) and (e). Together with our magnetization measurements taken at the same condition, we found that with increasing pressures the ferromagnetic transition temperature moves towards higher temperatures as marked by the arrows while there is another anomaly in the resistivity at lower temperatures. What is noticeable with the pressure-dependent resistivity data is that the resistivity show a stronger feature at T_C than at the lower-temperature anomaly unlike the field-dependent resistivity data taken at ambient pressure. However, we note that the relative strength of the two features in the resistivity shown in Figure 1 can vary depending on applied fields and pressures. In some fields, we find that the overall resistivity curve taken at 12 kbar looks very similar to that of Fig. 1(c). What is clear from our magnetization data is that this new feature seen in the resistivity data is not due to a thermodynamic transition.

As regards the origin of the lower-temperature anomaly in the resistivity, we note that a recent microscopic study of $La_{0.7-x}Pr_xCa_{0.3}MnO_3$ shows that the ferromagnetic metallic phase coexists with the antiferromagnetic insulating phase in some of the ferromagnetic samples[3]. Since $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ is much closer to the antiferromagnetic $Pr_{0.7}Ca_{0.3}MnO_3$, we can expect that this kind of phase separation phenomenon would be stronger than in Pr dilute samples. In such a case, we can anticipate that there would be some sort of pecolation behavior induced by the temperature dependence of the volume fraction of the metallic phase [4]. In fact, it is what we found in our analysis of the magnetization and noise measurements.

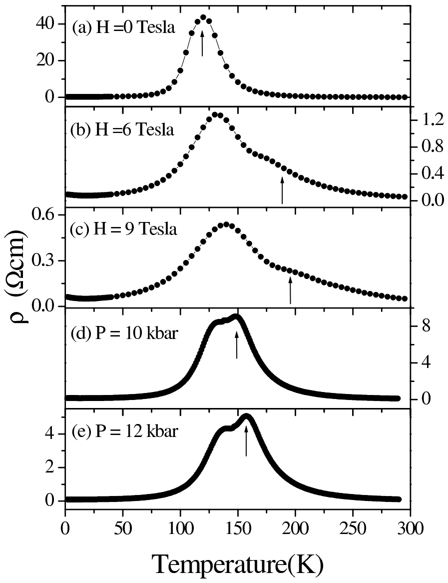

Fig. 1. Resistivity of $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ measured under magnetic fields and pressures: (a)-(c) were taken at ambient pressure while (d) and (e) with zero field. Arrows indicate T_C that is obtained from the magnetization measurements taken at the same conditions.

If we take the magnetization as the volume fraction of the ferromagnetic metallic phase, this volume fraction at the lower-temperature anomaly is over 15$\sim$ 20%, which is a percolation thershold in three-dimensional percolated systems. Our subsequent noise measurements also confirmed that there is a broad peak in the 1/f noise data near the lower-temperature anomaly, which supports that the lower-temperature anomaly is closely related to the percolation behavior of the metallic phase.

To summarize, we measure the resistivity of polycrystalline sample $La_{0.2}Pr_{0.5}Ca_{0.3}MnO_3$ under magnetic fields and pressures. With increasing magnetic fields and pressures, we found that our resistivity shows new anomaly at lower temperaure than T_C, which we attribute to some sort of percolation phenomenon.

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