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Magnetic inhomogeneity effects in DC transport properties and microwave absorption of $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ film

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Abstract

Transport properties in a PLD $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ film are studied by DC and microwave (41 GHz) technique. It is found that the microwave conductivity increases by the order of the magnitude at the transition to the ferromagnetic state. This is accompanied by only 10% increase in the DC conductivity. This effect and the DC magnetoresistance data obtained are discussed considering the extrinsic and intrinsic sources of magnetic inhomogeneity in doped cobaltates, including the phase separation.

Keywords: Doped cobaltates; Microwave absorption; Phase separation; Colossal magnetoresistance

Hole-doped lanthanum cobaltates of the type $La_{1-x}Sr_xCoO_3$ have attracted much attention in recent years due to their unique magnetic and transport properties [1,2]. Study of this system is also important for understanding the nature of colossal magnetoresistance in the related oxides, doped manganites [3]. In the intermediate range of Sr doping ($0.3 < x < 0.5$) the system is a metal, which shows ferromagnetism (FM) below Curie temperature $T_c = 240 \pm 10$ K [1,2]. The doped cobaltates (as well as the manganites) are always inhomogeneous to some extent due to extrinsic (technological factors in the sample preparation) or intrinsic (the phase separation) reasons [1–3]. Actually, they often present a random mixture of hole-rich FM metal and hole-poor insulator. This is reflected in their magnetic and transport properties.

Transport properties of FM oxides are usually studied by direct current (DC) measurements. For manganites, the microwave studies are known [4]. These have revealed that microwave conductivity is more sensitive than DC conductivity to the changes in magnetic state of manganites at the transition to FM state. In this way the magnetic inhomogeneity in manganites can be disclosed. It can be expected that it will also be for doped cobaltates. This motivate us to study transport properties in $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ film with both, the DC and microwave absorption, methods.

The film (about 220 nm thick) was grown by pulsed-laser deposition (PLD) on a (0 0 1) oriented $LaAlO_3$ substrate. A PLD system with an Nd-YAG laser operating at 1.06 μm was used. The film resistance, as a function of temperature and magnetic field H (up to 20 kOe), was measured using a standard four-point technique. The microwave conductivity of the film placed in a waveguide was determined at frequency $\nu = 41$ GHz from measurements of the reflection coefficient. The technique employed is similar to that used in IR experiments [5]. It is possible to calculate the microwave resistivity, ρ_{mw}, from the data obtained. In doing so the permeability μ was taken to be equal to unity.

The temperature dependence of the DC resistivity, $\rho(T)$, is non-monotonic (Fig. 1a) with a maximum at $T \approx 250$ K and a minimum at $T \approx 107$ K. $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ samples with fairly perfect crystalline structure and δ close to zero are known to be metallic ($d\rho/dT > 0$) in the whole range below and above T_c [2]. The $\rho(T)$ behaviour in Fig. 1a

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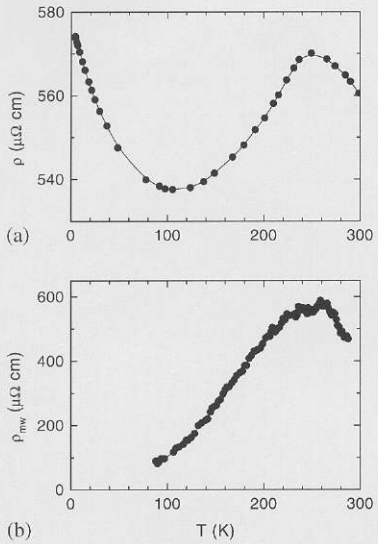

Fig. 1. Temperature dependencies of the DC resistivity, ρ, (a) and the microwave resistivity, ρ_{mw}, and (b) for the PLD $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ film.

reflects inhomogeneous structure of the film and some oxygen deficiency. Due to the last factor, the hole concentration is less then a nominal one (at $\delta = 0$). This is responsible for the resistance peak at $T = 250$ K which is common for low-doped samples with $0.2 \geqslant x \geqslant 0.3$ [2]. The low temperature resistance minimum is typical for systems of FM regions (grains or clusters) with rather weak interconnections. The inhomogeneous structure can be determined by technological factors (causing the polycrystalline structure with rather high tunneling barriers between the grains) or by the phase separation. The MR of the film is negative, its temperature dependence has a peak close to T_c (as expected). But for temperatures $T \ll T_c$, an increase in MR with decreasing temperature is found which is one more indication of poor enough connectivity between the FM grains (or clusters) in the film.

The microwave data are presented in Fig. 1b. The maximum values of ρ_{mw} for $T > T_c$ are found to be quite close to the DC resistivity. The $\rho_{mw}(T)$ dependence has a peak at nearly the same temperature, as the $\rho(T)$ curve. The sharpest distinction between the $\rho(T)$ and $\rho_{mw}(T)$ curves is the following: for temperature decreasing below T_c, the ρ_{mw}-magnitude decreases by a factor of about 10. This change is huge in comparison with the 10% decrease in the film DC resistivity in the same temperature range.

The effect found appears, at first sight, inconsistent from the standpoint of the Drude theory of optical properties of metals. According to that, for electromagnetic waves with low enough frequency ($\omega \ll 1/\tau$, where τ is the electron relaxation time in a conductor) the optical conductivity should not depend on the frequency and ought to be equal to the DC conductivity. It is true, however, only for homogeneous systems. The point is that the DC and optical conductivities are determined by quite different physical processes. The DC conductivity is defined by the ability of the charge carriers to propagate through a conducting system. It is apparent that this ability is affected profoundly by any kind of structural or phase inhomogeneity. Take as an example a granular FM metal with poor intergrain connectivity. At the transition to the FM state the intragrain conductivity of this inhomogeneous system can increase profoundly, but the measured DC conductivity of the whole sample can show only rather weak increase due to the weak intergrain connectivity.

The optical conductivity is determined by the ability of metal to absorb the energy of the electromagnetic field. For low frequency $\omega < kT$ (microwave and IR range) the main contribution to it comes from classical absorption, at which the charge carriers are accelerated by the electric field of electromagnetic wave. The absorption ability is characterized by the processes of transformation of energy flux of electromagnetic field to a thermal flux through the scattering of the charge carriers on phonons, impurities and other lattice defects. In FM metals the electron scattering on the spin disorder can contribute significantly to these processes.

On approaching and crossing T_c for decreasing temperature, the film transforms into a magnetically inhomogeneous phase of weakly connected FM clusters (or grains) together with a pervasive hole-poor insulating matrix. It is clear that the main contribution to the changes in microwave absorption and thus in the microwave conductivity at this transition will be determined by the formation of metallic FM regions even when they are not or are poorly connected to one another. In this way the changes in the microwave absorption (in contrast to the DC resistivity) reflect rather closely the corresponding changes in the intragrain conductivity.

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