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Electronic transport of bilayer manganite $La_{1.2}Sr_{1.8}Mn_2O_7$

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Abstract

We report magnetoresistivity measurements on a $La_{1.2}Sr_{1.8}Mn_2O_7$ single crystal. The charge transport in the ferromagnetic phase is dominated by two-magnon scattering in the high T range and by weak localization effects at lower T, in the non-metallic regime. In the paramagnetic phase, $\rho_{ab}(T)$ obeys the adiabatic small polaron hopping mechanism, while $\rho_c(T)$ follows an Arrhenius behavior with the same activation energy.

Keywords: Colossal magnetoresistance; Electronic transport; Scattering mechanism

There is growing interest in the electrical transport phenomena of perovskite manganites in order to elucidate the microscopic origin of the colossal magnetoresistance (CMR) effect. The bilayer manganite $La_{2-2x}Sr_{1+2x}Mn_2O_7$ has proven to be a fruitful system for understanding the CMR [1]. Its reduced dimensionality gives rise to anisotropic characteristics of charge transport and magnetic properties and also enhances the CMR effect near the magnetic transition temperature. At present, the electronic transport mechanism of manganites remains controversial and is far from being fully understood. In this paper, we address this issue through resistivity measurements on a $La_{1.2}Sr_{1.8}Mn_2O_7$ single crystal.

Fig. 1(a) is a plot of σ_{ab} and σ_c of $La_{1.2}Sr_{1.8}Mn_2O_7$ for temperatures $T \leqslant 50$ K, down to 1.9 K, measured in zero field. Both σ_{ab} and σ_c follow a $T^{1/2}$ dependence below a certain T. It has been suggested [2] that the observed $T^{1/2}$ dependence of σ_{ab} is consistent with weak localization effects in ordered three-dimensional (3D) metals. Since the crystal structure and the conductivity are strongly anisotropic, the bilayer manganites appear to be more 2D like. However, $\sigma_c(T)$ clearly follows the same $T^{1/2}$ dependence at low temperatures, consistent with 3D weak localization effects in disordered metals. This $T^{1/2}$ behavior in *both* $\sigma_{ab}(T)$ and $\sigma_c(T)$ confirms the 3D nature of the metallic state and is in good agreement with the theory of quantum interference in highly anisotropic layer metals [3].

Fig. 1(b) shows the temperature T dependence of the zero-field ρ_{ab} and ρ_c for $50 \leqslant T \leqslant 110$ K. In this T regime, the experimental data follow a $T^{9/2}$ dependence of the form $\rho(T) = \rho_0 + BT^{9/2}$ (see the solid curves in Fig. 1(b)). This clearly reveals the two-magnon scattering nature [4] of the low-temperature resistivity in the ferromagnetic phase. The fitting coefficients B for ρ_{ab} and ρ_c are 4.04×10^{-13} and 2.83×10^{-11} Ω cm/K$^{9/2}$, respectively. In $La_{1.2}Sr_{1.8}Mn_2O_7$, the hole concentration $n \equiv x = 0.40$, the in-plane hopping distance is $R_{ab} = 3.87$ Å [5], the magnitude of the effective spin is $S = 1.8$, the effective stiffness constant $D_{ab}^{\star} = 151$ meV Å^2 based on recent neutron scattering measurements [6], and the effective hopping integral $t^{\star} = 40$ meV as estimated from the measured effective plasma frequency [7]. With these values, we obtained $B_{ab} = 1.01 \times 10^{-13}$ Ω cm/K$^{9/2}$ by using the expression of B in the case of a simple parabolic band [7]. The calculated B_{ab} has the same order of magnitude as the fitting parameter.

Based on the relationship $D = JSR^2$ with J the strength of the magnetic exchange coupling, one obtains the ratio of J_{ab} and J_c as: $J_{ab}/J_c = (B_c R_{ab}/B_{ab} R_c)^{2/9}$ in terms of the analytical expression of B [7]. With the fitted values of B_{ab} and B_c, $R_{ab} = 3.87$ Å, and the out-of-plane hopping distance as the Mn–Mn distance between

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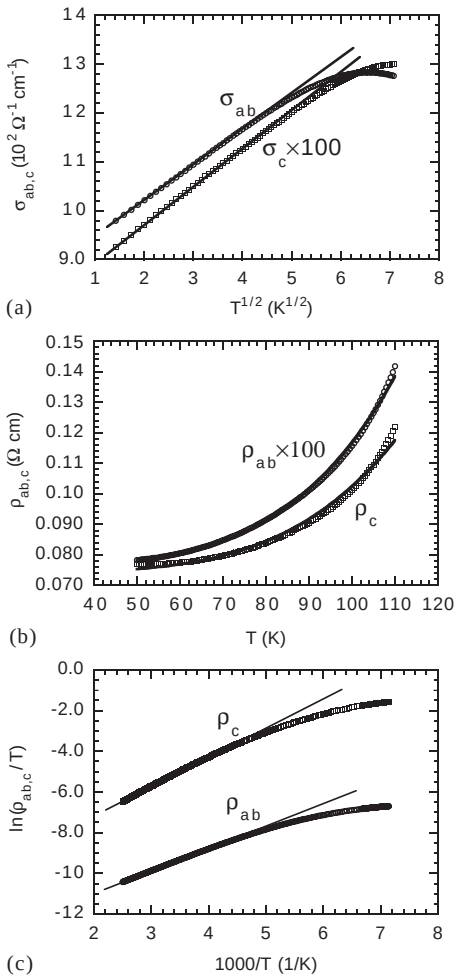

Fig. 1. (a) In-plane conductivity σ_{ab} and out-of-plane conductivity σ_c vs. $T^{1/2}$ measured down to 1.9 K, (b) in-plane resistivity ρ_{ab} and out-of-plane resistivity ρ_c vs. T, (c) plot of $\ln(\rho_{ab,c}/T)$ vs. $1000/T$, for a $La_{1.2}Sr_{1.8}Mn_2O_7$ single crystal measured in zero field.

the MnO_2 layers $R_c = 3.88$ Å [5], this gives $J_{ab}/J_c = 2.6$, which is in excellent agreement with the value of 2.8 determined from inelastic neutron scattering measurements [8]. This result further indicates that the two-magnon scattering plays a dominant role in both $\rho_{ab}(T)$ and $\rho_c(T)$ for $50 \leqslant T \leqslant 110$ K.

We observed that there is the following relationship between resistivities: $\rho_c/\rho_{ab} = -14.8 + 2.63 \times 10^4/T$ for $150 \leqslant T \leqslant 400$ K in zero field. It has been generally accepted that the resistivity in high-T paramagnetic phase follows the adiabatic small polaron transport mechanism with the form $\rho = CT\exp(E_A/k_BT)$ [9]. To examine the polaronic nature of the high-T resistivity of $La_{1.2}Sr_{1.8}Mn_2O_7$, we plot in Fig. 1(c), $\ln(\rho_{ab,c}/T)$ vs. $1000/T$ for $T \geqslant 140$ K and in zero field. The adiabatic polaron model describes well the in-plane resistivity data for $T \geqslant 218$ K, with a zero-field activation energy $E_A = 93.8$ meV and a prefactor $C = 2.0 \times 10^{-6}$ Ω cm/K. In fact the out-of-plane resistivity can also be fitted using the adiabatic small polaron model. Considering the resistive anisotropy ρ_c/ρ_{ab}, we can also describe ρ_c in an Arrhenius-type form with the same activation energy E_A as ρ_{ab}, if the preexponential factor is taken into account.

In the adiabatic limit, the electron motion is assumed to be much faster than the ionic motion of the lattice. In the approximation that all correlations except on-site Coulomb repulsion are ignored, one can express the prefactor C as [10]: $C = k_B\Omega/(x(1-x)e^2R^2v)$, where Ω is the unit-cell volume, x is the fraction concentration of occupied sites, and v is the frequency of the longitudinal optical phonons. Using the lattice parameters $a = 3.87 \times 10^{-8}$ cm and $c = 2.0 \times 10^{-7}$ cm [5], the doping level $x = 0.4$, and the characteristic frequency $v = 2.42 \times 10^{14}$ Hz, taken from optical conductivity spectra [11], we obtained the adiabatic prefactor $C = 1.85 \times 10^{-6}$ Ω cm/K for $La_{1.2}Sr_{1.8}Mn_2O_7$. The good agreement between the calculated value of C and the above fitting parameter of ρ_{ab} provides strong evidence in favor of small polaronic transport in the *ab* plane in the high-T paramagnetic state of bilayer manganites.

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