Approximation of Electrical and Magneto Transport Properties of LSMO Thin Films

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We have used a three term polynomial expression to approximate electrical and magneto transport properties of epitaxial La0.67Sr0.33MnO3 (LSMO) thin films in wide temperature range (2-350 K) and in magnetic field up to 9 T. The first term is determined by a low temperature (T < 20 K) residual resistivity \( \rho_0 \) and this term is magnetic field independent. The second term describes the electron-electron scattering in LSMO, it shows \( \sim T^2 \) dependence of resistivity up to temperature about 160 K and depends only weakly on magnetic field. The third term, proportional to \( \sim T^{4.5} \) dependence, describes a significant increase of resistivity in temperature range 100-350 K and due to its sensitivity to applied magnetic field it is possible to approximate temperature dependence of magnetoconductivity below 350 K.

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1. Introduction

The effort to interpret electrical and magneto transport properties of perovskite manganites in a ferromagnetic-metallic (FMM) state (0 < T < Tc, TMI, where Tc is Curie temperature and TMI is a temperature of metal-insulator transition) has been registered for many years. Snyder et al [1] suggested for the resistance in FMM state relation \( R(T) = R_0 + R_2 T^2 + R_N T^N \), where \( R_0, R_2, R_N \) are fitting parameters and \( N = 4.5 \), due to an electron-magnon scattering predicted by double exchange theory [2]. The experimental data were approximated by a polynomial fit expression for temperatures below 250 K. Boscher and al [3] presented the polynomial fit expression in the form \( \rho(T) = \rho_0 + a_2 T^2 + a_N T^N \), where the term \( \sim T^6 \) describes the electron-ion scattering and the polynomial fit expression approximated the resistivity data up to the temperature of 300 K. Recently, we have introduced the polynomial fit expression in the form \( \rho(T) = \rho_0 + a_2 T^2 + a_N (T - T_0)^{4.5} \), where \( \rho_0, a_2, a_N, T_0 \) are fitting parameters [4]. We found out that this expression approximates well the FMM electrical transport in zero magnetic field up to a temperature of 350 K. The first term \( \rho_0 \) represents the low temperature residual resistivity, the second term \( \sim T^2 \) describes the electron-electron scattering and the third term with \( N = 4.5 \) describes the electron-magnon scattering [2]. The additional parameter \( T_0 \) indicates a temperature above which the ferromagnetic term \( \sim T^{4.5} \) contributes to the total resistivity, whereas the low temperature \( T < T_0 \) resistivity is described only by the first two terms of polynomial fit expression.

In this paper we show that the magneto transport properties of La0.67Sr0.33MnO3 (LSMO) thin films can be well described by the polynomial fit expression in a wide temperature range 2-350 K and in magnetic field at least up to 9 T.

2. Experimental

The LSMO films were deposited using an on-axis dc magnetron sputtering from a stoichiometric ceramic target onto a one-side polished MgO (001) substrate [5]. The deposition was performed in an Ar(80%) + O2(20%) atmosphere at a total pressure of 65 Pa. The substrate was heated to 800°C during the deposition. The growth rate of the LSMO films was 1.2 nm/min and the films were 100 nm thick. The LSMO films were subsequently in-situ annealed in O2 (10⁴ Pa) at 800°C for 1 hour.

The magnetotransport properties were measured in magnetic field 0, 4.5, and 9 T oriented parallel to the film surface, in a temperature range 2-400 K using a four-probe method with physical properties measurement system (PPMS). The patterning of the basic structure \((10 \times 10 \mu m^2)\) was carried out by a photolithography process and argon ion beam etching with cooling of the substrate.

3. Results and discussion

The magnetic properties (Curie temperature > 400 K) and structural characterization of the epitaxial LSMO films with enhanced temperature of metal-insulator transition \( T_{MI} = 406 \text{ K} \) were described elsewhere [5]. The experimental resistivity vs. temperature \((\rho - T)\) dependencies in magnetic field of 0, 4.5 and 9 T are shown in Fig. 1 (points). These dependencies were approximated by the polynomial fit expression \( \rho(T) = \rho_0 + a_2 T^2 + a_N (T - T_0)^{4.5} \) (Fig. 1, full lines). The average squared errors of fitting curves are 2.43 \times 10^{-3}, 6.34 \times 10^{-4} and 2.41 \times 10^{-4} for curves at 0, 4.5 and 9 T, respectively. Very good agreement was achieved in temperature range 2-350 K for \( B = 0 \text{ T} \), at magnetic field of 9 T even up to 380 K. In case of increasing magnetic field the experimental curves move more and more approach the magnetic
field independent behaviour of the first two terms $\rho_0$ and $a_2 T^2$ (dashed line in Fig. 1).

The magnetic field dependence of the fitting parameters is shown in Fig. 2. Whereas the parameter $\rho_0$ is magnetic field independent, the second term depends on the magnetic field only weakly ($<10\%$). The magnetic field has a significant influence on fit parameters of the third term $T_0$ and $a_N$. $T_0$ parameter decreases by 20\% at $B = 9$ T, $a_N$ parameter decreases by as much as 80\% (5 times smaller than at $B = 0$ T). It means that the magneto transport properties of LSMO are primarily concentrated in the third (ferromagnetic) term.

Two temperature dependences of the magnetoresistivity for two values of magnetic field 4.5 and 9 T are shown in the Fig. 3. The magnetoresistivity is defined as $MR = [\rho(B) - \rho(B = 0)]/\rho(B = 0)$. The experimental magnetoresistivity (points) are well approximated by the one computed from the fitting curves (full lines).

Our results (Figs. 1 and 3) show that the upper temperature limit of the three term polynomial approximation is about 350 K for the LSMO thin films with enhanced $T_{MI}$ values.

4. Conclusions

The three term polynomial expression $\rho(T) = \rho_0 + a_2 T^2 + a_N(T - T_0)^{4.5}$ was used to describe the properties of the epitaxial LSMO thin films under magnetic field. The first term (residual resistivity $\rho_0$) is temperature and magnetic field independent. The second term characterizes the electron-electron scattering and it depends on magnetic field only weakly. The third term plays a crucial role to interpret the magnetoresistivity properties of manganites. Its temperature dependence $\sim T^{4.5}$ is in agreement with the double exchange theory and its sensitivity to applied magnetic field was used to approximate the magnetoresistivity dependence on the temperature. The polynomial fit expression well describes the electrical and magneto transport properties of the LSMO in a wide temperature range (2-350 K) and in magnetic field at least up to 9 T.

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References