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Magneto-transport properties of nano-crystalline and poly-crystalline $La_{0.6}Pb_{0.4}MnO_3$ thin films

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Abstract

We have investigated the magneto-transport properties of nano-crystalline (NC) and polycrystalline (PC) $La_{0.6}Pb_{0.4}MnO_3$ (LPMO) thin films, which have different grain-boundary properties. Above metal–insulator transition temperature (T_{IM}), the magnetic coupling between the grains governs the transport. In the low-temperature ($T < T_{IM}$) metallic state, $T^{4.5}$ dependences of normalized resistance for both types of films suggest the importance of scattering of spin polarized electron by the electron–magnon interaction. In contrast to the field dependence of magneto-resistance (MR) for PC LPMO films, NC films show the absence of low-field MR, which is a characteristic feature of granular CMR samples. Using current–voltage characteristic we demonstrate that the spin flip scattering (inelastic process) of carriers in NC films contributes to enhancement of MR, but does not contribute to the low-field MR.

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Keywords: CMR film; Colossal magnetoresistance; Grain boundary; Low-field magnetoresistance

1. Introduction

In the last few years, attention has been focused on thin films of colossal magnetoresistance (CMR) materials $R_{1-x}A_xMnO_{3-y}$ (R = trivalent rare-earth ion e.g. La, Nd, etc., and A = divalent ion e.g. Ba, Sr, Ca, Pb, etc.), for their striking properties such as CMR. Besides their practical utility, the unresolved transport and magnetic properties of these materials makes them attractive for the scientific community [1–3].

The first attempt was made by Zener to explain CMR by invoking double-exchange mechanism [4]. An important drawback of bare double-exchange model is that it does not consider spin–lattice or charge–lattice interaction, i.e. John–Teller distortion and polarons, which significantly contributes to the resistivity in the insulating phase. The high-temperature electronic transport properties among these materials may be divided into two distinct phenomena based on two different models, each predicting a different temperature dependence of the resistivity. For example to explain conduction just above T_{IM}, the variable range hopping (VRH) model has been suggested, while the small polaron hopping model is considered at temperatures beyond $\theta_D/2$ (where θ_D is the Debye temperature). It has been reported that θ_D shifts towards T_{IM} as the intergranular connectivity between grains increases and, as a result, transport above T_{IM} can be fitted only by the small polaron hopping model [5,6].

A great effort has been made to understand the transport properties of CMR manganites; a complete comprehension of low-temperature resistivity ρ in the ferromagnetic metallic phase remains elusive. Usually, the temperature dependence of low-temperature resistivity (ρ) is normally described by $\rho(T) = \rho_0 + \rho_\alpha T^\alpha$, where ρ_0 is the residual resistivity and measure of effective disorder, and $\rho_\alpha T^\alpha$ a

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generic T-power law which can simulate different scattering processes. $\rho_2 T^2$ term indicates the resistivity due to electron–electron scattering process, and the term $\rho_{2.5} T^{2.5}$ that due to electron–magnon scattering. Kubo and Ohata pointed out that perfect spin polarization of conduction electrons makes a qualitative change in the scattering process of charge carriers by magnon–electron interaction, leading to $T^{4.5}$ dependence in a double-exchange system, which is in disagreement with most of the reported experimental data [7]. The value of exponent α also depends on the disorder in the material [8].

In addition to the interesting transport, these materials show a huge change in resistivity on the application of magnetic fields called magneto-resistance (MR). Intrinsic MR—as observed in single-crystal samples-has linear dependence on field and is very small at low temperatures. Intrinsic MR can be explained by double exchange mechanism, according to which the ferromagnetism favors the metallicity [4]. On the other hand, polycrystalline (PC) samples show an extrinsic MR that yields a sharp drop in resistance at low field called as low-field MR (LFMR). Hwang et al. proposed that LFMR arises due to spin polarized tunneling of charge carriers through the insulating grain boundaries [9,10]. Clearly, the grain boundaries play an important role in describing magneto-transport behavior of PC samples. As the LFMR property of PC manganites can be used for future device applications, it is therefore important to study the magneto-transport properties of PC CMR manganite samples in the form of thin films.

In this work we study the magneto-transport studies of $La_{0.6}Pb_{0.4}MnO_3$ nano-crystalline (NC) (average grain size ~17 nm) and PC (average grain size ~55 nm) thin films. It has been shown that transport above metal–insulator transition temperature (T_{IM}) depends on the magnetic coupling between grains. $T^{4.5}$ dependence of resistivity in metallic state ($T < T_{IM}$) shows that transport is governed by scattering of spin polarized electron by the electron–magnon interaction. LFMR, a characteristic feature of PC samples, is absent for NC films. By comparing the current–voltage characteristic (I–V) for the NC films with the PC LPMO films (which shows LFMR), we demonstrate that spin flip scattering (inelastic process) of carriers in NC films contributes to enhancement of MR, but does not contribute to the LFMR.

2. Experimental details

The $La_{0.6}Pb_{0.4}MnO_3$ (LPMO) thin films having thickness of 50 nm were grown on (1 0 0) oriented single-crystal $SrTiO_3$ substrates by pulsed-laser deposition technique, as described in our earlier papers [11,12]. Briefly, a laser beam from a KrF excimer laser of wavelength 248 nm, pulse width 20 ns and repetition rate of 5 Hz was focused onto a rotating target of nominal composition $La_{0.6}Pb_{0.4}MnO_3$. Deposition temperatures of 550 and 500 °C, under an oxygen partial pressure of 0.2 Torr, reproducibly yielded NC and PC films, respectively.

The surface morphology of the films was examined using atomic force microscopy (AFM) (Model-SPM Solver P47) in contact mode. Rectangular cantilever of Si_3N_4 (length 200 μm and width 40 μm) having force constant of 3 N/m was employed for the measurement. The chemical composition of the target and films of LPMO was determined by energy-dispersive analysis of X-rays (EDX) (OXFORD). X-ray diffraction was carried out to confirm the phase purity and orientation of the film.

The electrical resistance of the film was measured using a standard four-probe method in the temperature range between 50 and 300 K using a closed-cycle helium cryostat (APD make). The MR of the film was measured by applying a field of 1 T parallel to the plane of film. I–V curves at different temperatures and magnetic fields were recorded using Lab-view software.

3. Results and discussion

3.1. Film characteristics

Typical AFM images (200 nm × 200 nm scan) of NC and (200 nm × 200 nm) PC LPMO films are shown in Fig. 1. XRD measurements revealed that both the films have (0 0 l) orientation. The c-lattice parameter (computed from the d-value of (0 0 2) reflection) of NC and PC films were

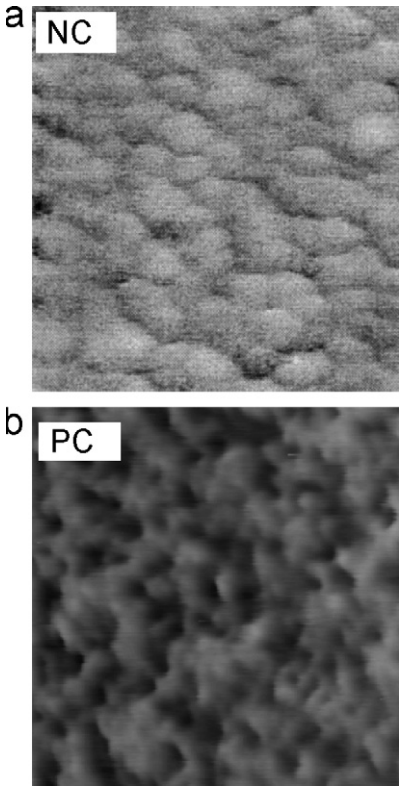

Fig. 1. AFM images for (a) nano-crystalline (NC) (200 nm × 200 nm scan) (b) poly-crystalline (PC) (200 nm × 200 nm scan) LPMO thin film.