Investigation of Electrical Conduction Mechanism of Double Layered Colossal Magnetoresistive $Sm_{1.2}Sr_{1.8}Mn_2O_7$

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Abstract

Samarium based double layered (DL) manganite $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was synthesized by sol-gel method and its lattice structure determination was done using powder X-ray diffraction. The sample shows single phase body-centered tetragonal structure. The electrical resistivity measurements, both in absence and presence of applied magnetic field, were undertaken in the temperature range 70 K - 300 K. The sample is found to exhibit very high electrical resistivity with no insulator-to-metal transition temperature (T_{IM}) in the region of investigation. The analysis of temperature dependent resistivity data reveals that the conduction in the entire temperature range is well-described by Efros-Shkloskii (ES) type of variable range hopping (VRH) model which indicates the dominance of electron-electron interactions in the conduction process. The sample shows magnetoresistance of 24% at 74 K with an applied magnetic field of 3 T.

Keywords: Manganites, Magnetoresistance, Conduction Mechanism, Hopping,

1. INTRODUCTION

The double layered (DL) perovskite manganites with general compositional formula $R_{2-2x}A_{1+2x}Mn_2O_7$ (R=rare earth ion and A=alkaline earth ion) attract considerable attention because of their unique properties, such as colossal magnetoresistance (CMR), Jahn-Teller effect and metal-insulator (M-I) transition [1]. These materials belong to the n=2 member of Ruddlesden-Popper (RP) series. The DL manganites consist of two perovskite blocks of MnO_6 octahedra, separated by a rock-salt (R, A)O layer. The anisotropic two dimensional Mn-O-Mn network gives rise to remarkable changes in electrical properties of the DL manganites.

Recent studies on $R_{2-2x}A_{1+2x}Mn_2O_7$ show that the properties of the layered perovskites are very sensitive to the size and concentration of R and A site ions. In particular, $La_{2-2x}Sr_{1+2x}Mn_2O_7$ compounds are widely studied because of their simple synthesis process and significant CMR effect [2,3]. However, there are few reports about the electrical and magnetic properties of DL manganites with other rare earth ions (Pr, Nd, Sm, etc.) [4,5]. In this paper, we report the results obtained with $Sm_{1.2}Sr_{1.8}Mn_2O_7$ with a main focus on its electrical transport and CMR effect in the temperature range 70 K - 300 K.

2. EXPERIMENT

The polycrystalline DL manganite sample $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was synthesized by sol-gel method. The obtained powder was calcined in air at 1100^{o}C for 10 h and then pressed into circular pellets. These pellets were sintered at 1400^{o}C for 6 h in air. The structural characterization was done using powder X-ray diffraction using M/s PANalytical X-ray diffractometer giving Cu-K_α radiation (λ = 1.54056 Å) in 2θ range 20^o – 80^o with step size 0.01^o and a count time of 0.6 s per step. The temperature dependent electrical resistivity measurements from 70 K to 300 K were made using four-probe method in absence and presence of applied magnetic field (H = 1.5 T, 3 T). A superconducting magnet system of OXFORD was used to produce the required magnetic fields.

3. RESULTS AND DISCUSSION

The powder XRD pattern (Fig. 1) of $Sm_{1.2}Sr_{1.8}Mn_2O_7$ suggests that the samples is of single phase with $Sr_3Ti_2O_7$-type body-centered tetragonal perovskite structure with space group *I*4/*mmm* (Z = 2). The values of lattice parameters (*a* and *c*) and cell volume (V) are *a* = 3.8689 Å, *c* = 19.7979 Å and V = 296.35Å^3.

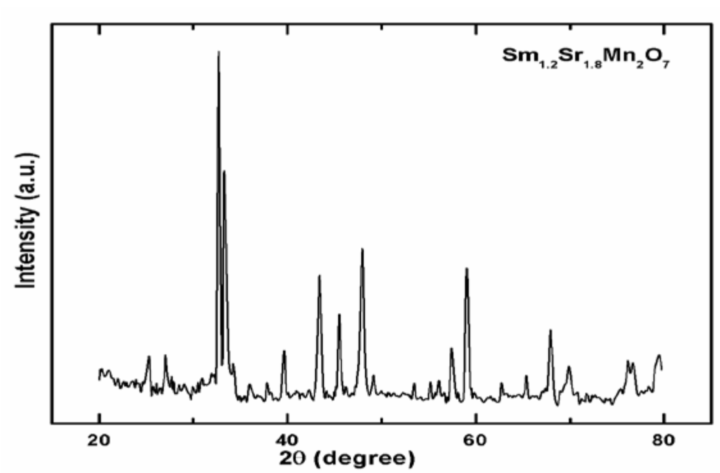

Fig. 1 Powder XRD pattern of $Sm_{1.2}Sr_{1.8}Mn_2O_7$

The temperature dependent electrical resistivity (H = 0 T, 1.5 T, 3 T) plots are shown in Fig. 2. The resistivity of the sample increases largely with decreasing temperature and there is no sign of IMT which is in contrast to the IMT shown by La-based DL manganite sample at 120 K [3]. This can be attributed to the weakening of FM-DE interactions.

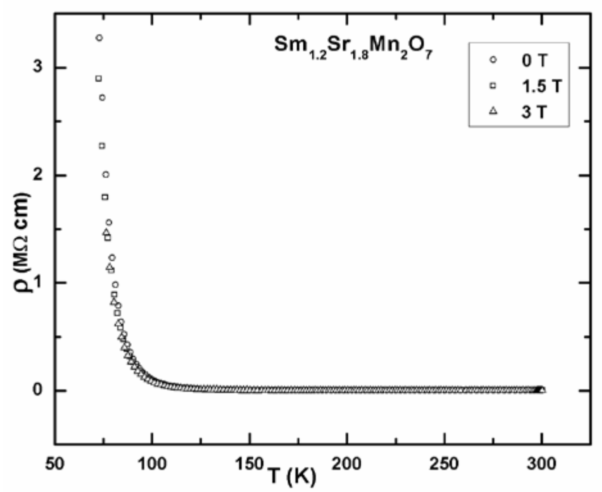

Fig. 2 Temperature dependent electrical resistivity plots of $Sm_{1.2}Sr_{1.8}Mn_2O_7$ (H = 0 T, 1.5 T, 3 T)

The conduction mechanism in semiconducting/insulating region in manganites is usually explained by four models: They are: (i) semiconduction (SC) model described by Arrhenius equation $\rho = \rho_0 \exp(E_a / k_B T)$ [6], (ii) nearest neighbor small polaron hopping (SPH) model described by $\rho = \rho_0 T^n \exp(E_p / k_B T)$, where n = 1 for adiabatic hopping and n = 1.5 for non-adiabatic hopping, [7] (iii) Mott type of variable range hopping (VRH) model described by $\rho = \rho_\infty \exp(T_0 / T)^p$, where p = 1/(d+1), d being the dimensionality of the system [8] and (iv) Efros-Shkloskii (ES) type of VRH model described by $\rho = \rho_\infty \exp(T_0 / T)^{1/2}$ [9]. Here, ρ_0 is a pre-factor in SC and SPH models and ρ_∞ is a pre-factor in VRH models. E_a and E_p are the activation energies in SC model and SPH model, respectively. T_0 is characteristic temperature in VRH models and its value in Mott VRH model is given by $24/\pi L^d k_B N(E_F)$, where L is localization length of trapped charge carriers (here, L = 10^{-10} m), $N(E_F)$ is density of the localized states at Fermi level and d is the dimensionality of the system. The Coulomb interaction in hopping regime which produces a gap in electronic density of states (DOS) is responsible for ES VRH type of conduction mechanism, whereas Mott VRH arises when such gap is filled. Each predicts a different temperature dependence of the resistivity and fits the resistivity data in different temperature ranges. Generally, electron hopping is variable range type at low temperatures, where the thermal energy is not great enough to allow electrons to hop to their nearest neighbors. In that case, electrons choose to hop farther to find a smaller potential difference. At high temperatures, conduction may be by activation by mobility edge or narrow band gap. In the intermediate temperature range, nearest neighbor (small polaron) hopping dominates.

In the present study, the ρ-T data above T_{IM} are analyzed by fitting the data to all the equations of the conduction models mentioned above. Interestingly, the ρ-T data are well fitted the equation of ES VRH model in the entire temperature region, i.e., 70 K – 300 K (Fig. 3). The ES VRH mechanism is a dimensionality independent mechanism which arises due to strong electron-electron Coulomb interactions reducing the density of states near the Fermi level. The observed ES VRH mechanism in this sample may be attributed to its very high resistivity where electron-electron interactions are dominant in the conduction process. The best fit parameters obtained with all VRH models are listed in Table 1.

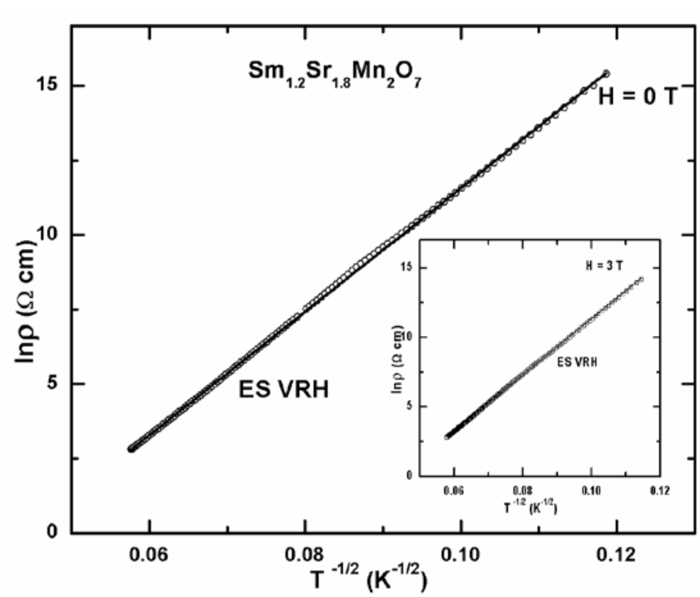

Fig. 3 Plots of lnρ *versus* $T^{-1/2}$ for $Sm_{1.2}Sr_{1.8}Mn_2O_7$. The solid lines give the best fits to the ES VRH model

Table 1. The best-fit parameters obtained from VRH model fittings for $Sm_{1.2}Sr_{1.8}Mn_2O_7$

Model	T_0 (K)	ρ_∞ (Ω cm)	$N(E_F)$ ($eV^{-1}cm^{-3}$)	R^2
Mott 3D VRH	1.99×10^8	5.23×10^{-12}	4.45×10^{20}	0.9983
Mott 2D VRH	2.47×10^6	2.38×10^{-8}	3.58×10^{14}	0.9993
ES VRH	4.28×10^4	1.08×10^{-4}	-	0.9998

Magnetoresistance

MR is defined as $MR\% = 100\times(\rho_0 - \rho_H)/\rho_0$, where ρ_0 and ρ_H represent the resistivity in absence and in presence of applied magnetic field H, respectively. The temperature dependent MR (H = 3 T) plots are shown in Fig. 4. Usually, cubic perovskite manganites show MR peak at T_{IM} in their MR-T plots. But, the present manganite sample does not show MR peak at its T_{IM} although resistivity peak is observed at T_{IM} and this property is similar to many DL manganite systems [10]. The maximum MR% shown by the sample is ≈ 24% at 74 K and nearly MR% ≈ 20-24% is exhibited in the temperature range 75 K - 135 K. This property of exhibiting large MR over a wide temperature range supplies the potential applications for layered perovskite manganites. The variation of MR finds a linear relation with applied magnetic field at 70 K (Inset: Fig. 4)

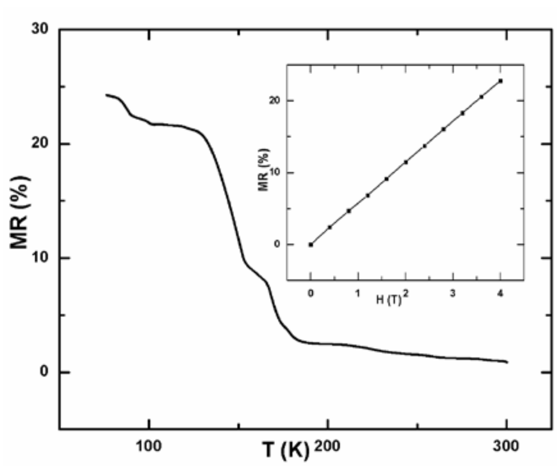

Fig. 4. MR (H = 3 T) *versus* T plot for $Sm_{1.2}Sr_{1.8}Mn_2O_7$. (Inset: MR *vs.* H plot)

4. CONCLUSION

A polycrystalline DL manganites $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was synthesized in single phase by the sol-gel method. The sample shows very high resistivity at low temperature and the insulator-to-metal transition is absent in this sample. The conduction mechanism in the entire temperature range is found to follow Efros-Shkloskii (ES) type of VRH indicating the dominance of electron-electron interactions in the conduction process. The sample shows reasonably good values of MR over a wide temperature range indicating its suitability for MR based device applications.

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