Synthesis, Characterization and Electrical Properties of Double Layered CMR Manganite $Sm_{1.2}Sr_{1.8}Mn_2O_7$

Y.S. Reddy *
Department of Physics, Chaitanya Bharathi Institute of Technology (A), Gandipet, Hyderabad – 500 075 INDIA

M. Venkateshwarlu
Department of Civil Engineering, CMR college of Engineering & Technology (A), Kandlakoya, Medchal District, Telangana State – 501401 INDIA

K. Rajagopal
Department of Biotechnology, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad – 500 075 INDIA

ABSTRACT

Polycrystalline bulk sample of $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was prepared by sol-gel method and was characterized using powder X-ray diffraction and scanning electron microscope. The sample shows single phase body-centered tetragonal structure. The electrical resistivity of the sample was measured, both in absence and in presence of applied magnetic field, in the temperature range 70 K - 300 K. The sample shows highly insulating behaviour in the measured region. The temperature dependent electrical resistivity data was fitted to the equations of various models. The results of the fittings indicate that the electrical conduction of the sample can be due to Efros-Shkloskii (ES) type of variable range hopping (VRH) mechanism in which electron-electron interactions are dominant.

Keywords: Manganites, Conduction, Magnetotransport, Sol-gel, Polaron

1. INTRODUCTION

The manganites with general formula $R_{2-2x}A_{1+2x}Mn_2O_7$ (R = rare earth ion and A=alkaline earth ion) are knows as double layered (DL) perovskite manganites. These materials, because of their reduced dimensionality and structural anisotropy, have been studied to explore the ways to improve their colossal magnetoresistance property with moderate magnetic fields [1]. 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. The two important interactions between Mn ions, namely double exchange (DE)-driven ferromagnetic (FM) interactions and superexchange (SE)-driven antiferromagnetic (AFM) interactions, are responsible for the observed transport and magnetic properties of the manganites.

There are many reports on the magnetotransport properties of lanthanum based DL manganites [2,3]. Nevertheless the DL manganites based on other rare earth manganites (Pr, Nd, Sm) have not been studied much [4,5]. This paper presents the results of the fittings of temperature dependent electrical resistivity data $Sm_{1.2}Sr_{1.8}Mn_2O_7$ to the equations of the different models to understand the electrical conduction mechanism in the sample.

2. EXPERMENTAL

Polycrystalline bulk sample of $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was synthesized by sol-gel method. As compared to solid state reaction method, the sol-gel synthesis method has many advantages like homogenous mixing of the materials, low processing temperatures, uniform size of the particle, etc. Further, the DL manganites require high processing temperaturesn long reaction times and hence the sol-gel method is more appropriate for the synthesis of these DL manganites.

High purity powders of Sm_2O_3, $MnCO_3$ and $Sr(NO_3)_2$ were the starting materials. After the conversion of oxides into nitrates, the pH of these nitrates was adjusted to ~ 6 with the help of ammonia solution. The obtained solution was slowly heated so as to evaporate the water in it. Then, ethylene glycol was added and heated at around 90°C till a gel-type solution was formed. After the gel was dried, it was heated at about 250 °C in air for 2 h to decompose nitrates and all organic materials. The resultant ash was then ground and homogenous powder was obtained. The powder was calcined in air 1100 °C for 10 h and then pressed into circular pellets. The pellets were finally sintered in air at 1400 °C for 6 h.

The structural characterization of the sample 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° – 80°. The electrical resistivity as a function of temperature was measured by standard four-probe method in the temperature range 4.2–300 K using OXFORD superconducting magnet system.

3. RESULTS AND DISCUSSION

The single phase formation of the sample $Sm_{1.2}Sr_{1.8}Mn_2O_7$ is confirmed by the powder XRD pattern shown in Fig. 1. The sample is of $Sr_3Ti_2O_7$-type body-centered tetragonal perovskite structure with space group I4/mmm (Z = 2). The lattice parameters are found to be a = 3.8689 Å, c = 19.7979 Å and the cell volume is V = 296.35Å^3.

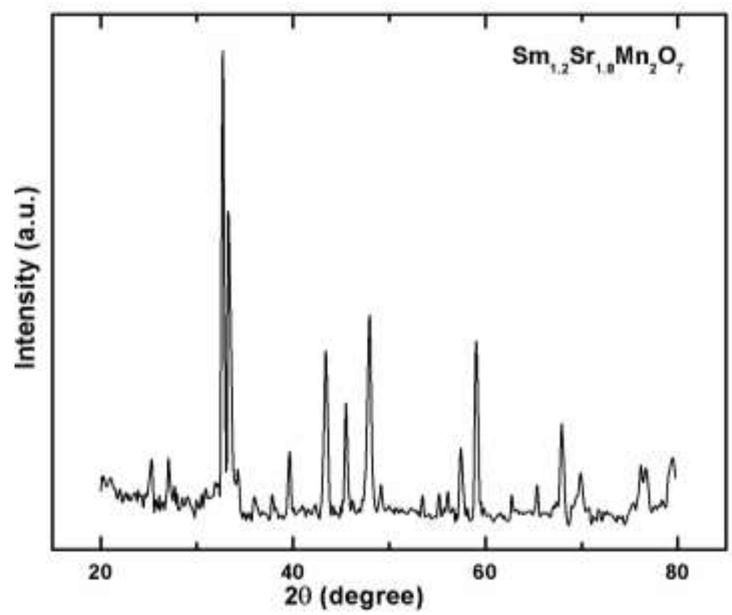

Figure 1. Powder XRD pattern of $Sm_{1.2}Sr_{1.8}Mn_2O_7$

The temperature versus electrical resistivity plots (70 K - 300 K) at applied magnetic field H = 0 T and H = 3 T are shown in Fig. 2. As the temperature is lowered, the resistivity of the sample is found to increase largely and there is no insulator-to-metal transition (IMT) is observed in the measured temperature range. The absence of IMT can be attributed to the weakening of FM-DE interactions.

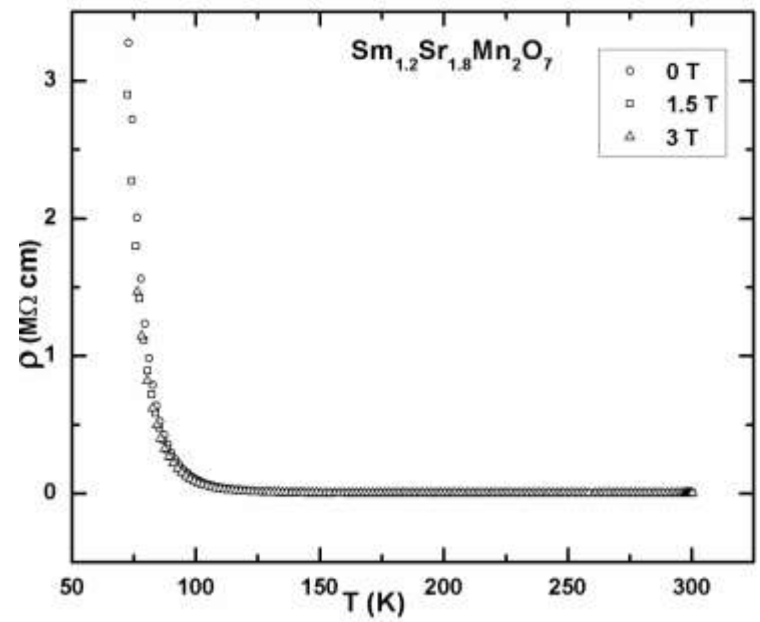

Figure 2. Temperature dependent electrical resistivity plots of $Sm_{1.2}Sr_{1.8}Mn_2O_7$ (H = 0 T, 1.5 T, 3 T)

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 [10]. 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 this study, the ρ-T data in the temperature range 70 K – 300 K are analysed by fitting the data to all the conduction models mentioned above. Interestingly, the ρ-T data are well fitted the equation of ES VRH model in the entire temperature region (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.

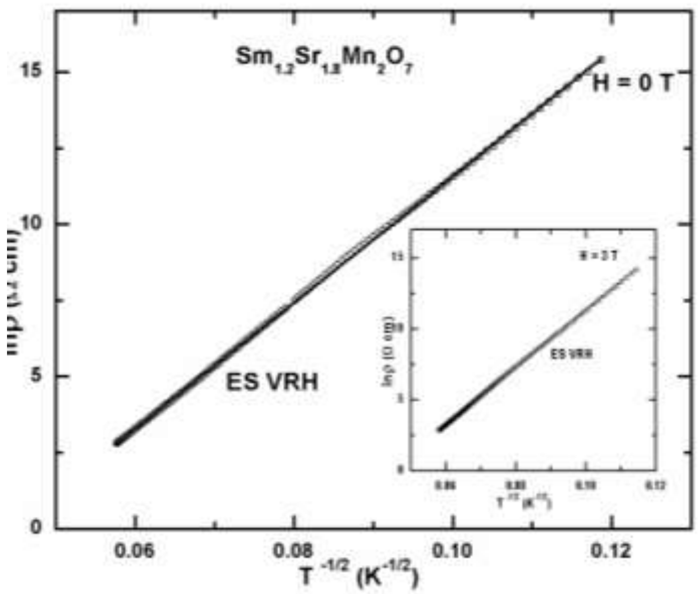

Figure 3. Plots of lnρ *versus* $T^{-1/2}$ for $Sm_{1.2}Sr_{1.8}Mn_2O_7$. The solid lines give the best fits to the ES VRH model

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

4. CONCLUSION

A polycrystalline DL manganite $Sm_{1.2}Sr_{1.8}Mn_2O_7$ was synthesized in single phase by the sol-gel method. The sample shows high resistivity at low temperature and the sample does not exhibit insulator-to-metal transition in the observed temperature range. 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.

References

1. Y. Moritomo, A. Asamitsu, H. Kuwahara, Y. Tokura, Giant magnetoresistance of manganese oxides with a layered perovskite structure, *Nature (London)*, 380, 141-144 (1996).
2. E. O. Chi, Y.-U. Kwon, J.-T. Kim, N. H. Hur, Lattice effects on the magnetic and transport properties in $La_{1.4}Sr_{1.6-x}A_xMn_2O_7$ (A = Ca, Ba), *Solid State Commun.*, 110, 569-574 (1999).
3. C. L. Zhang, X. J. Chen, C. C. Almasan, and J. S. Gardner, J. L. Sarrao, Low-temperature electrical transport in bilayer manganite $La_{1.2}Sr_{1.8}Mn_2O_7$, *Phys. Rev. B,* 65, 134439 (1-6) (2002).
4. M. Triki1, S. Zouari1, A. Cheikhrouhou, P. Strobel, Praseodymium deficiency effects on the physical properties of $Pr_{1.2-x}A_xSr_{1.8}Mn_2O_7$ bilayer manganese oxides, *Phys. Stat. Sol. (c),* 243, 3266-3271 (2006).
5. J.W. Liu, G. Chen, Z.H. Li, Z. Lu and Z.G. Zhang, Synthesis and colossal magnetoresistance effect of layered perovskites $Sm_{2-2x}Sr_{1+2x}Mn_2O_7$ (x = 0.2, 0.4, 0.5), *Mater. Chem. Phys.*, 105 185-188 (2007).
6. H. Zhu, D. Zhu, and Y. Zhang, Effect of lattice expansion on the magnetotransport properties in layered manganites $La_{1.4}Sr_{1.6-y}Ba_yMn_2O_7$, *J. Appl. Phys.*, 92, 7355 – 7361 (2002).

7. S. B. Ogale, V. Talyansky, C. H. Chen, R. Ramesh, R. L. Green, and T. Venkatesan, Unusual electric field effects in $Nd_{0.7}Sr_{0.3}MnO_3$, *Phys. Rev. Lett.*, 77, 1159-1162 (1996).
8. M. Jaime, H.T. Hardner, M.B. Salamon, M. Rubinstein, P. Dorsey, and D. Emin, Hall-effect sign anomaly and small-polaron conduction in $(La_{1-x}Gd_x)_{0.67}Ca_{0.33}MnO_3$, *Phy. Rev. Lett.*, 78, 951-954 (1997).
9. M. Viret, L. Ranno, and J. M. D. Coey, Colossal magnetoresistance of the variable range hopping regime in the manganites, *J. Appl. Phys.*, 81, 4964 – 4966 (1997).
10. Y.S. Reddy, V. Prashanth Kumar, R. Rawat, A. Banerjee, P. Kistaiah and C. Vishnuvardhan Reddy, Effect of Ca substitution on transport and magnetic properties of doublelayered manganite $La_{1.2}Sr_{1.}8Mn_2O_7$, *Phys. Stat. Sol. (b)*, 244, 3719 - 3729 (2007).