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Electrical and Ultrasonic Properties of CMR Manganite $Ce_{0.7}Sr_{0.3}MnO_3$

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ABSTRACT
A polycrystalline colossal magnetoresistive (CMR) manganite $Ce_{0.7}Sr_{0.3}MnO_3$ was prepared by solid state reaction method and characterized using powder X-ray diffraction. The sample shows single phase orthorhombic structure. The electrical resistivity measurements were done employing four-probe method in the temperature range 70 K - 300 K. The sample shows an insulator-to-metal transition temperature (T_{IM}) at 140 K. The temperature dependent resistivity data ($T>T_{IM}$) were fitted to the different equations governing the electrical conduction in manganites. The obtained results indicate that the conduction in insulator region follows Mott type of variable range of hopping mechanism. The ultrasonic investigations were made at room temperature and elastic constants were determined.

Keywords: Manganites, Electrical Conduction, Ultrasonic Velocity, Elastic Properties, Perovskites

I. INTRODUCTION

The discovery of CMR phenomenon in rare earth manganites has been creating a lot of interest among materials scientists [1-5]. The insulator-to-metal transition in electrical behavior, para-to-ferro magnetic transition in magnetic behavior, large values of magnetoresistance at moderate magnetic fields and the presence of different kinds of conduction mechanisms in manganites have been motivating the researchers to unearth the hidden facts in these materials. The general compositional formula of perovskite manganites is $R_{1-x}Sr_xMnO_3$ (R is a rare earth ion and A is an alkaline earth ion). A lot of research has been in progress in the area of rare earth manganites with different rare earth ions and alkaline earth ions with different doing levels. Apart from studying underlying physics of manganites, the main objective of research on manganites is to bring Curie temperature to room temperature and to enhance magnetoresistance at moderate magnetic fields [6-10]. The present study also aims at the same. This research article deals with the electrical behavior of $Ce_{0.7}Sr_{0.3}MnO_3$ in the temperature range 70 – 300 K and determination of elastic constants of the sample at room temperature.

II. EXPERIMENTAL

Polycrystalline perovskite manganite samples of $Ce_{0.67}Sr_{0.33}MnO_3$ were prepared by the solid state reaction method [10]. High purity powders of Ce_2O_3, $MnCO_3$ and $SrCO_3$ weighted in appropriate proportions were used to obtain the nominal composition of $Ce_{0.67}Sr_{0.33}MnO_3$. The starting materials were mixed and ground thoroughly and calcined in air at 1100˚C for 8 h with intermediate grinding. Then, the resultant powders have were pressed into pellets of ~12 mm diameter and ~3 mm thickness and sintered in air at 1200˚C for 6 h. The structural characterization was done by powder X-ray diffraction (XRD) using M/s PANalytical X-ray diffractometer giving Cu K_α radiation (λ = 0.154056 nm) in 2θ range of 20˚–80˚.

The values of bulk density (ρ) of the samples were estimated employing Archimedes principle, with xylene as buoyant. The equation for bulk density is given by $\rho = \frac{W_a}{W_a - W_b} \times d_b$, where W_a is weight of the sample in air, W_b is weight of the sample in buoyant and d_b is density of the buoyant (0.865 g/cc). The values of X-ray densities (ρ_x) were calculated from the lattice parameters using the formula: $\rho_X = \frac{z \times M}{V \times 0.6023}$, where z is number of chemical units in one unit cell of the crystal (in the present case, z = 4), M is molecular weight (for one unit of the chemical formula) of the sample in atomic weight units and V is volume of the crystalline unit cell as determined by the powder XRD (V = a×b×c for orthorhombic unit cell). From the values of bulk and X-ray densities, porosity fraction (C) has been calculated using the formula: C = 1-(ρ/ρ_x).

The ultrasonic measurements were carried out by the UPT technique at room temperature [10]. Longitudinal and shear velocities have been measured using X-cut and Y-cut quartz transducers, respectively, with a fundamental frequency of 1 MHz. The r.f. pulses generated by the pulse oscillator were applied to the transmitting transducer, which converts them into acoustic pulses. These acoustic pulses, after propagating through the test sample, were converted back into electrical signals by the receiving transducers. The amplified output signal was displayed on a 100 MHz digital storage oscilloscope (Tektronix model No. 2221). The difference in time ΔT between two overlapping received pulse trains was noted using a timer. The velocity of sound was measured using the equation V = t/ ΔT, where t is the thickness of the sample. The overall accuracy of these measurements is ±10 ms^{-1}.

The temperature dependent electrical resistivity measurements from 70 K to 300 K were made using four-probe method.

III. RESULTS AND DISCUSSION

The powder X-ray diffraction results indicate the single phase formation of $Ce_{0.7}Sr_{0.3}MnO_3$ with orthorhombic structure [8]. The values of lattice parameters are: a = 5.4116 Å, b = 5.5728 Å, c = 7.6660 Å and cell volume V = 231.19 $Å^3$. The variation of electrical resistivity with temperature is depicted in Fig. 1. It can be seen that the resistivity of the sample increases largely with decreasing temperature and the sample shows insulator-to-metal transition at 140 K (T_{IM}).

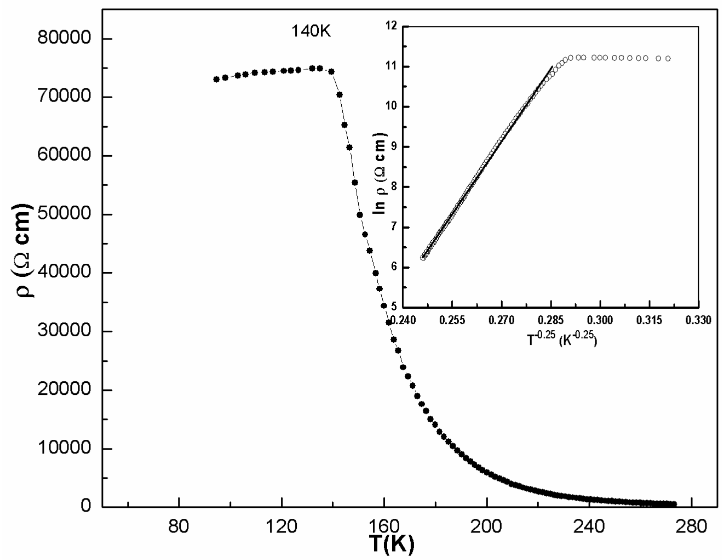

Figure 1.
Variation of electrical resistivity with temperature. Inset shows linear fitting of ρ-T data to Mott VRH equation.

To explore the conduction mechanism in insulating/semiconducting region of the sample, the electrical resistivity (ρ) dada were fitted to the equations of semiconduction (SC) model, adiabatic hopping of small polaron (AHSP) model and Mott type of variable range hopping (VRH) model [6-8]. Each model 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. The equations of SC, AHSP and Mott VRH models are $\rho = \rho_0 \exp(E_a / k_B T)$, $\rho = \rho_0 T \exp(E_p / k_B T)$ and $\rho = \rho_\infty \exp(T_0 / T)^{1/4}$, respectively. Here, ρ_0 is pre-factor in SC and AHSP equations and ρ_∞ is pre-factor in Mott VRH equation. E_a and E_p are activation energies in SC and AHSP equations, respectively. k_B is Boltzmann's constant and T_0 is characteristic temperature whose value is given by $16\alpha^3/k_BN(E_F)$, where the value of α is 2.22 nm^{-1} and $N(E_F)$ is density of the localized states at Fermi level. The linear fittings, thus, obtained clearly indicate that Mott VRH equation fits the data well and the conduction (T > T_{IM}) is mainly contributed by one electron hopping [9, 10]. The best fit parameters from Mott VRH equation are: $T_0 = 2.1\times10^8$ K, $\rho_\infty = 7.1\times10^{-11}$ Ω cm and $N(E_F) = 9.6\times10^{-24}$ $eV^{-1}cm^{-3}$.

As the samples under the present investigation are polycrystalline, the elastic constants are determined by applying the standard isotropic elastic medium approximation. The values of elastic constants are determined with the help of the following formulae [11]. The values of longitudinal sound velocity (V_L) and shear sound velocity (V_S) obtained from UPT technique are used in these formulae.

Longitudinal modulus $$L = \rho V_L^2$$

Shear modulus $$G = \rho V_S^2$$

Bulk modulus $$B = L - \frac{4}{3}G$$

Poisson's ratio $$\sigma = \frac{3B - 2G}{6B + 2G}$$

Young's modulus $$E = (1 + \sigma)2G$$

The measured values of elastic constants are summarized in Table 1. The sample has reasonably good values of elastic constants and these results are in good agreement with the values of similar rare earth manganites [10, 12].

Table 1. Longitudinal velocity (V_L), shear velocity (V_S), mean velocity (V_m), longitudinal modulus (L) shear modulus (G), bulk modulus (B), Young's modulus (E) and Poisson's ratio (σ) for $Ce_{0.67}Sr_{0.33}MnO_3$.

Sample	C	ρ_x ($\times 10^3$ g/cc)	ρ	V_L	V_S (m/s)	V_m	L	G (GPa)	B	E	σ
CSMO	**0.083**	**6.097**	**5.593**	**3488**	**2043**	**2265**	**68.04**	**23.34**	**36.92**	**57.84**	**0.239**

IV. CONCLUSIONS

A polycrystalline perovskite manganite $Ce_{0.7}Sr_{0.3}MnO_3$ was synthesized by solid state reaction method. The resistivity of the sample increases largely from 180 K to 140 K and the sample has insulator-to-metal transition at 140 K. The electrical resistivity dada (above T_{IM}) were fitted to the different equations which explain the conduction mechanism at $T>T_{IM}$. From the results, it is understood that Mott type of VRH mechanism is responsible for its electrical conduction in paramagnetic insulating region. Further, the values of elastic constants were calculated from ultrasonic longitudinal and shear velocities.

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