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Anisotropic magnetoresistance studies of polycrystalline $La_{0.67}Ca_{0.33}MnO_3$

Nagaiah Kambhala, S. Angappane *

Centre for Soft Matter Research, P. B. No.1329, Prof. U. R. Rao Road, Jalahalli, Bangalore-560013, India

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ABSTRACT

We have synthesized polycrystalline $La_{0.67}Ca_{0.33}MnO_3$ by solid state reaction method and studied the structural, morphological, resistivity, magnetoresistance and anisotropic magnetoresistance properties of it with detailed analysis of anisotropic magnetoresistance. The X-ray diffraction study of our sample confirms the single phase nature of the prepared material. The temperature dependence of the DC electrical resistivity shows a peak, corresponding to metal-insulating transition, at $T_{MI} \sim 264$ K. Under an applied low magnetic field, the resistivity decreases from zero field resistivity and we have calculated the magnetoresistance and anisotropic magnetoresistance of our polycrystalline $La_{0.67}Ca_{0.33}MnO_3$ with respect to temperature. We found high values of magnetoresistance and anisotropic magnetoresistance at low temperatures. We have also measured the angular dependence of resistivity at different temperatures for two different currents. We have found the effect of current on the anisotropic magnetoresistance which is essential in utilizing the polycrystalline $La_{0.67}Ca_{0.33}MnO_3$ in device applications.

1. Introduction

The mixed-valence manganites $Ln_{1-x}A_xMnO_3$ (where, Ln is a rare earth ion and A is a divalent ion such as Ca, Sr, Ba, etc.) are interesting compounds to study for various technological applications [1,2]. The coexistence of charge, orbital, lattice and magnetic degrees of freedom make them a passionate object for research point of view [3,4]. Numerous experiments were carried out to study the transport properties of manganites, including magnetoresistance (MR) and anisotropic magnetoresistance (AMR) [5,6]. Most of the studies were carried out for nominal doping concentration, wherein these materials show a metal to insulator transition upon varying temperature, accompanied by a ferromagnetic to paramagnetic transition. For other doping concentrations of manganites, there is a dominant interplay of spin, charge, orbital and lattice degrees of freedom. The MR is established to arise from the polarization of magnetic moments under the applied magnetic field, which enhances the charge transport. The AMR effect, comes from the spin–orbit coupling or magnetic anisotropy of the material, is the useful property of manganites, studied for applications in magnetic devices, such as magnetic read-heads and sensors [7]. In manganites, a large fraction of work was done on $La_{0.67}Ca_{0.33}MnO_3$ (LCMO) material, which is an intermediate band width material. However, the detailed mechanism for the origin of AMR in polycrystalline $La_{0.67}Ca_{0.33}MnO_3$ is still under debate. The AMR has been studied mainly on single crystals [8] and epitaxial thin films [9,10] using high magnetic fields. Nevertheless, more work is needed to clarify the origin of AMR in polycrystalline $La_{0.67}Ca_{0.33}MnO_3$, especially at low magnetic fields. Here we report the synthesis of $La_{0.67}Ca_{0.33}MnO_3$ polycrystalline material by solid state reaction and the study of MR and AMR of it under a low magnetic field.

2. Experimental

The polycrystalline LCMO samples were prepared by standard solid state reaction using La_2O_3 (99.999%), $CaCO_3$ (99.995%) and MnO_2 ($\geq$99.99%). In order to remove the moisture, La_2O_3 was preheated at 800 °C for 24 h. Subsequently the required amounts of chemicals were taken by stoichiometric calculations. The homogeneously mixed and grinded powder was calcined at 1050 °C for 24 h and the process was (mixing and calcinations) repeated three times. We have mixed high purity acetone during grinding for homogenization. In order to improve the inter-grain connectivity, the polyvinyl alcohol (PVA) (2 wt. % solution with millipore water) solution was mixed with the powder, which is known to serve as a binding material. Using the mixed and calcined powder, we have prepared pellets using a hydraulic press and die. These pressed pellets were first heated at 600 °C for 24 h to remove all carbonaceous materials and then sintered at 1400 °C for 72 h. The X-ray diffraction (XRD) measurement on powdered LCMO sample was carried out using a Smart Lab diffractometer (Rigaku Co., Japan). The surface of LCMO pellet was examined using a NanoSEM 600 (FEI Co., The Netherlands)

* Corresponding author. Tel.: +91 80 2838 6582; fax: +91 80 2838 2044.
E-mail address: angappane@csmr.res.in (S. Angappane).

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field emission scanning electron microscope (FESEM). The energy dispersive X-ray (EDX) analysis (EDAX, AMETEK Inc., USA), which is part of FESEM, was employed for examining the chemical composition of our LCMO pellet. The low temperature DC electrical resistivity was measured using a closed cycle refrigerator (CCR) of Janis Research Company, USA. A rectangular shaped sample, cut from the sintered circular pellet using a diamond wheel, was used for resistivity and magnetoresistivity measurements. For resistivity measurement, four linear Au contacts were deposited on the sample using DC magnetron sputtering. A low magnetic field of 1000 G was applied using $Nd_2Fe_{14}B$ standard bar magnets.

3. Results and discussions

3.1. X-ray diffraction studies

Fig. 1 shows the XRD data of our LCMO, which indicates the single phase nature and absence of any secondary phase. The crystal structure and space group are found to be orthorhombic and Pnma respectively. The Rigaku PDXL2 software refinement of data gives the lattice parameters, $a=5.445(19)$ Å, $b=7.709(13)$ Å and $c=5.464(4)$ Å. The volume of unit cell is 229.3(9) Å^3. All the peaks and the crystalline parameters of our LCMO material are matching well with JCPDS data of $La_{0.67}Ca_{0.33}MnO_3$ (No. 49-0416). The similar type of XRD results are observed in $La_{0.67}Ca_{0.33}MnO_3$ polycrystalline material prepared by solid state reaction [11].

3.2. Morphological studies

The SEM image, showing surface morphology of our LCMO pellet, is given in Fig. 2. The observed grains are found to have good grain connectivity and of very different sizes ranging from 5 to 37 μm. There are no segregated phases observed. The EDX data in the inset shows the presence of La, Ca, Mn and O chemical species in our polycrystalline $La_{0.67}Ca_{0.33}MnO_3$ compound and there are no impurity elements observed.

3.3. Low temperature resistivity measurement

Fig. 3 shows the temperature dependence of DC electrical resistivity of our polycrystalline LCMO with and without applied magnetic field. The resistivity data shows a peak at $T_{MI}\sim 264$ K, where $dR/dT=0$, which corresponds to the metal to insulator transition in polycrystalline LCMO. The value of T_{MI} matches well with other reports on polycrystalline LCMO [11]. The resistivity at T_{MI} is found to be 16.85 Ω-cm. With the applied magnetic field of 1000 G, the resistivity at T_{MI} decreases; when the field is applied perpendicular to current direction, $\rho_{\perp}=16.69$ Ω-cm and T_{MI} is 263 K, and for the field applied parallel to the current direction, T_{MI} is 264 K and corresponding resistivity, $\rho_{||}=16.58$ Ω-cm. We have observed $\rho_{||}<\rho_{\perp}$. The origin of this anisotropic magnetic field dependence of resistivity, is discussed in Section 3.5.

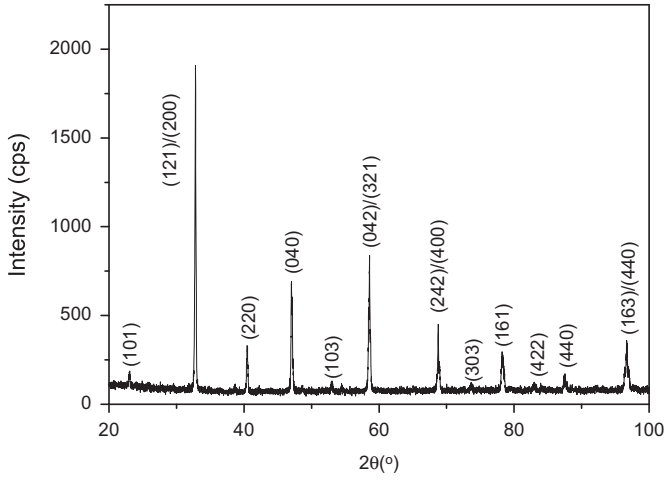

Fig. 1. The XRD data of $La_{0.67}Ca_{0.33}MnO_3$ powder indexed to orthorhombic crystal structure.

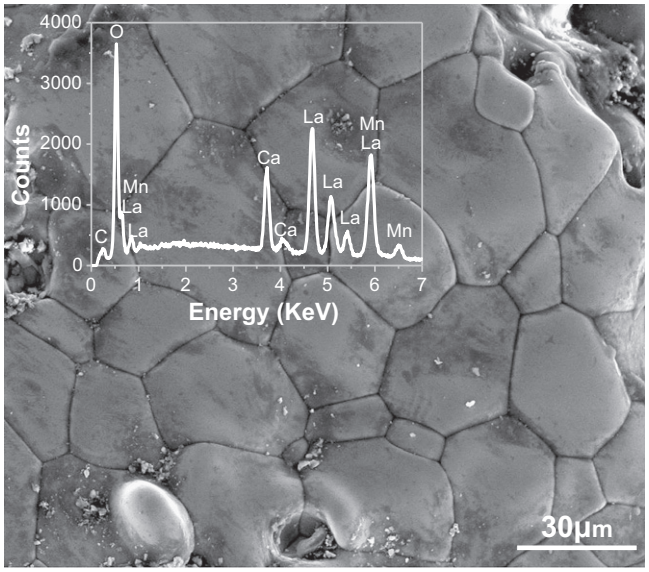

Fig. 2. The SEM image of $La_{0.67}Ca_{0.33}MnO_3$ pellet showing surface morphology. Inset shows the EDX data.

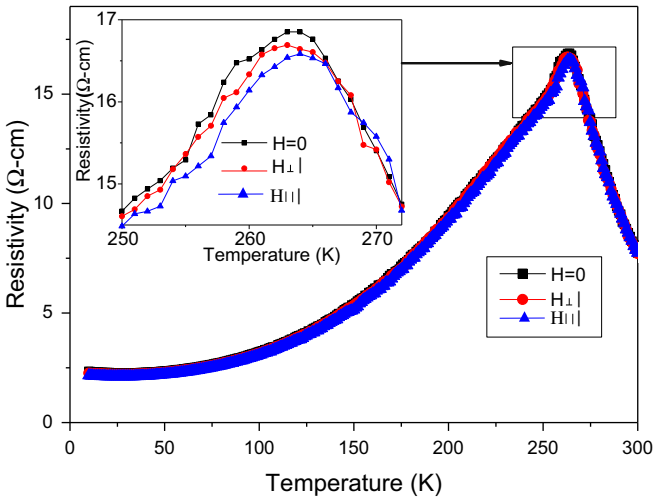

Fig. 3. The resistivity vs. temperature of $La_{0.67}Ca_{0.33}MnO_3$ for zero field and with magnetic field applied parallel ($H||I$) and perpendicular ($H\perp I$) to current directions. The applied magnetic field is 1000 G.

3.4. Magnetoresistance and anisotropic magnetoresistance

We have the calculated MR (%)$=(R_H-R_0)/R_0\times 100$ and AMR (%)$=(R_{||}-R_{\perp})/R_0\times 100$ for our LCMO sample using the resistivity data measured with the field parallel ($R_{||}$) and perpendicular ($R_{\perp}$) to current direction. Fig. 4 shows the temperature dependence of MR and AMR of our LCMO, indicating large values at low temperatures. When temperature increases both MR and AMR decreases almost linearly and at near T_{MI}, MR and AMR show a peak. Interestingly, the temperature dependence of AMR of our