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Enhanced temperature-independent magnetoresistance below the metal–insulator transition temperature of epitaxial $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ thin films

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Abstract. Epitaxial $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ thin films have been deposited at 800°C on $LaAlO_3$ substrate using pulsed laser deposition technique. The structural and magnetotransport properties of the films have been studied. The sharp peak in the temperature dependence of the resistance corresponding to metal-to-insulator transition (T_p) has been observed at a temperature of $T_p = 82$ K, 97 K and 110 K for 0 Oe, 20 kOe and 40 kOe magnetic fields, respectively. The film exhibits a large nearly temperature-independent magnetoresistance around 99% in the temperature regime below T_p. The zero field-cooled (ZFC) and field-cooled (FC) magnetization data at 50 Oe shows irreversibility between the ZFC and FC close to the ferromagnetic transition temperature $T_c = 250$ K. The ZFC temperature data of the film displays ferromagnetic behavior for higher temperature regime $T_c = 250\ \text{K} > T > T_p = 82$ K, and a decrease in magnetization with decreasing temperature up to 5 K below 82 K exhibiting a sort of antiferromagnetic behavior in the low temperature regime ($T < 82\ \text{K} = T_p = T_N$).

Keywords. Thin films; magnetoresistance; magnetization.

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1. Introduction

The giant and colossal magnetoresistance (GMR and CMR, respectively) effects in doped manganite films on $LaAlO_3$ substrate grown by pulsed laser deposition (PLD), has greatly attracted considerable attention due to its fundamental physics and new possible applications in the magnetic recording industry [1–3]. The GMR effects considerably larger than those in magnetic multilayers or alloys were observed in films [2–4] and bulk samples [5–8] of the perovskite-type manganite $R_{1-x}A_xMnO_3$ ($R =$ La, Nd; $A =$ Ca, Sr, Ba). The GMR effects in $R_{1-x}A_xMnO_3$ with $(\Delta R/R_0) \geq 90\%$ were obtained usually in high applied field (6–12 T) [2–8]. The motivation for this work is to achieve GMR effect up to 99% at low field ($H < 40$ kOe) in $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ thin films suitable for practical device application. In this paper, we report the electrical, magnetic and magnetoresistance behavior of novel $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ films grown on $LaAlO_3$ substrate.

2. Experimental

The epitaxial $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ (LNCMO) thin films used in this study were grown on a single crystalline (001) oriented $LaAlO_3$ substrate by pulsed laser deposition (PLD) technique. The bulk targets used had a nominal composition $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ and were made in-house using standard solid state reaction route by taking stoichiometric mixtures of respective high-purity metallic oxides and carbonates. A KrF excimer laser was employed and ablation was performed at a laser energy density of 1.9 J/cm^2. The substrate temperature was maintained at 800°C while the oxygen partial pressure was 400 mTorr during deposition. The film thickness was about 2000 Å.

The structure of the targets and films was characterized by X-ray diffraction (XRD) using Cu$K\alpha$ radiation. The resistance and magnetoresistance of the films were measured in the temperature range from 10 K to 300 K using a computer controlled four-point probe system with a maximum applied field of $H = 40$ kOe. The SQUID magnetometer was used to measure the magnetization of the film at a field of $H = 50$ Oe.

3. Results and discussion

The XRD measurements revealed that no impurity phases existed in the targets and the as-deposited $La_{0.2}Nd_{0.4}Ca_{0.4}MnO_3$ films. The temperature dependence of resistance for the LNCMO film at magnetic fields of 0 Oe, 20 kOe and 40 kOe is shown in figure 1. The film shows a sharp peak in the resistance vs. temperature relationship corresponding to metal-to-insulator transition (T_p) at 82 K for 0 Oe (figure 1); it exhibits insulating behavior (i.e. a negative dR/dT) above and metallic behavior (a positive dR/dT) below this peak temperature (T_p). Figure 1 also shows that the peak in resistance becomes smaller and shifts to higher temperature as the field is increased. For example, T_p for 20 kOe and 40 kOe shifts

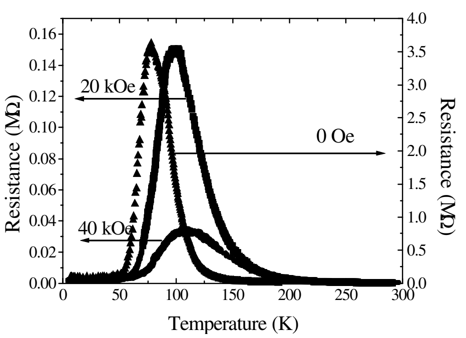

Figure 1. Temperature dependence of resistance at 0 Oe, 20 kOe and 40 kOe of LNCMO film.

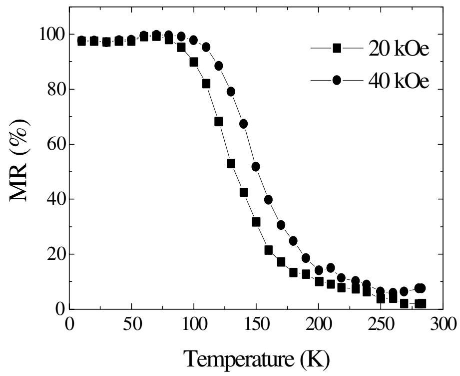

Figure 2. Temperature dependence of magnetoresistance at 20 kOe and 40 kOe of LNCMO film.

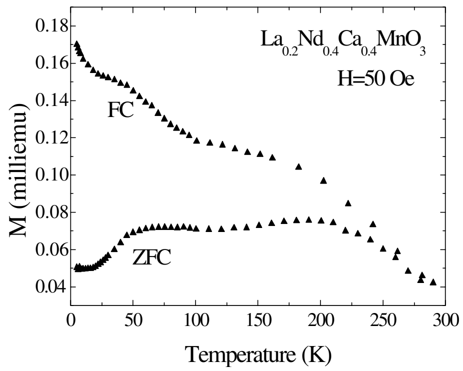

Figure 3. Temperature dependence of magnetization at 50 Oe of LNCMO film.

to 97 K and 117 K, respectively. The temperature dependence of magnetoresistance MR ($\Delta R/R_{(H=0)}$) calculated from figure 1 is shown in figure 2 for $H = 20$ kOe and 40 kOe. The film exhibits a large temperature-independent magnetoresistance value of 99% in the temperature regime below $T_{\rm p} = 97$ K and 117 K at $H = 20$ kOe and 40 kOe, respectively (figure 2). The present results significantly indicate that a high field greater than 20 kOe may not be necessary for the practical device application of the film.

Figure 3 displays the temperature dependence of the zero field-cooled (ZFC) and field-cooled (FC) magnetization at 50 Oe for the film. Irreversibility between the ZFC and FC magnetization is clearly seen close to the ferromagnetic transition temperature $T_{\rm c} = 250$ K. The ZFC vs. T data of the film exhibits ferromagnetic behavior for higher temperature regime $T_{\rm c} = 250$ K $< T <$ 82 K, and a decrease in magnetization with decreasing temperature up to 5 K below 82 K displaying a sort of antiferromagnetic behavior in the low temperature regime ($T <$ 82 K $= T_{\rm p} = T_{\rm N}$). The FC curve on the other hand, shows increasing ferromagnetic behavior with decreasing temperature. This magnetic behavior of thin film may be attributed to domain wall effect in the system.

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