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Voltage-induced resistance change in $La_{2/3}Sr_{1/3}MnO_3$ film

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The manganese oxides REMnO$_3$ (RE = trivalent rare earth elements) have the structure with perovskite type. If the trivalent rare earth element is partially doped with the divalent alkaline earth element A (A = Ca, Sr, Ba, Pb), the doped manganese oxides $RE_{1-x}A_x$MnO$_3$ have exhibited a colossal magnaetoresistance(CMR) effect [1–4]. The appearance of the ferromagnetic and metallic state in these systems is attributed to the double exchange model between the Mn^{3+} and Mn^{4+} ions [5]. But for more complete understanding of the physics of the manganites the electron-photon coupling has to be included [6]. The effect of the external field, such as x-ray [7], visible light [8], and an electric field [9] on the manganites has been studied. J. Klein *et al.* have observed the nonlinear current-voltage characteristics in $La_{2/3}Ca_{1/3}MO_3$ films and shown this behavior is due to the orbital ordering [10]. A. N. Pogorily *et al.* have shown that the current density results in the transition from a semi conducting to a metallic character of the conduction based on the phase separation [11]. Most of the current-voltage characteristic research have focused on the mixed-valent manganites with the charge ordering state and the phenomena is caused by the charge-ordered state collapses, but there are few reports about the voltage-induced character in the no charge-ordered manganites [12, 13]. In this paper, the transport character of the $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) film prepared by the magnetron sputtering on $LaAlO_3$ (100) substrate was investigated, and the influence of the electric field on the transport at different temperatures was studied.

The powder of $La_{2/3}Sr_{1/3}MnO_3$ was prepared from the analytically pure oxides of appropriate stoichiometric proportions by the solid-state reaction technique after repeated grinding and sintering at 1100°C for 10 h. The bulk target sample was pressed from the powder and sintered at 1250°C for 10 h. The X-ray diffraction shows that the bulk target has the structure with the pseudo-cubic phase. The film is deposited by the magnetron sputtering method. In order to get higher lattice matching, the substrate is single crystal $LaAlO_3$ (LAO) with crystal plane orientation (100). After sputtering, the film was annealed at 800°C in air for an hour to improve the epitaxial character. The design pattern of the sample is shown in Fig. 1. The distance between Ag electrodes is 1 mm and the width of the films is 2 mm. The thickness of thin films is about 70 nm (estimated by surface profilometer). The film sample is placed in a closed-circuit liquid nitrogen cryostat, the temperature range of which varies from 77 to 450 K. The film and the cryostat completely reach the heat balance, and the resistance caused by the current thermal effect has peaked. The x-ray diffraction pattern shown in Fig. 2 indicates that only diffraction peaks (100) and (200) of the film besides the diffraction peaks of LAO (100) and (200) substrate appear. This identifies the LSMO film, which is identical in crystal plane orientation (100) with the LAO substrate, having the single crystal structure.

The electrical transport of the film is shown in Fig. 3. The film exhibits the typical ferromagnetic metallic(FM)—paramagnetic insulating(PI) phase transition as the temperature is increased. In low temperature range (T < 255 K), the resistance-temperature dependence is fitted to the magnon scattering formula: $R = 187 + 0.0242 \times T^{3/2} + 3.7 \times 10^{-5}\, T^3$, and the results are shown by the solid curve in Fig. 3 [14]. This indicates that the film has the ferromagnetic and metallic conductivity character. With increasing the temperature, the resistance of the film begins to increase quickly and reaches the peak at 353 K, and then the electrical resistance gradually decreases. The film favors the insulating-type conduction at T > 353 K. These can be explained by the double exchange interaction, which causes the hopping conduction of the itinerant electrons e_g between Mn^{3+}– O^{2-}– Mn^{4+}, and the small polaron theory [15] due to the distortion of lattice caused by cooperative Jahn-Teller effect.

The voltage dependence of the resistance at different temperatures is shown in Fig. 4. The relative maximum change in resistance $\Delta R/R = (R_m - R)/R \times 100\%$, where R_m is the maximum resistance with application of the voltage and R is the resistance without voltage at the same temperature. At low temperature (T < 353 K), the resistance initially increases with increasing voltage in

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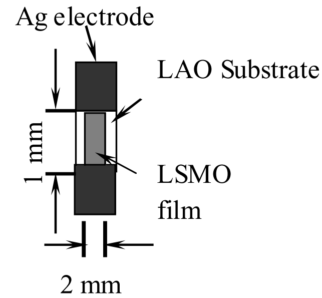

Figure 1 The schematic of the sample design geometry.

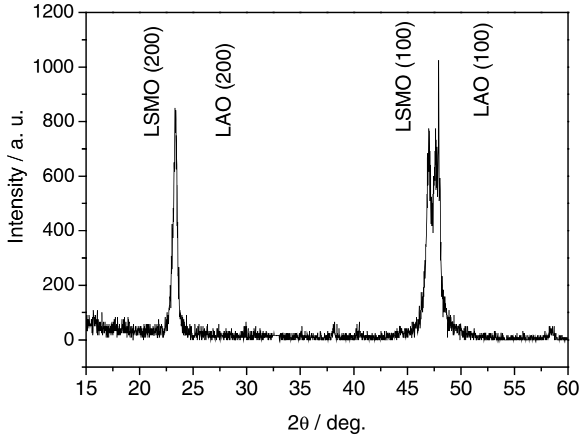

Figure 2 The X-ray diffraction of the film.

low-voltage range, followed by a decrease with a further increase of the voltage. But for $T = 119$, 139 and 179 K, no maximums are observed below 48 V that is the highest constant voltage available to our source. The voltages corresponding to the maximums are 42 V, 36 V, 30 V, 28 V, 22 V for $T = 239$ K, 259 K, 279 K, 299 K, 319 K, respectively. The resistance decreases with increasing voltage at $T = 359$ K. At lower voltage, the resistance increases with increasing temperature, and this is consistent with

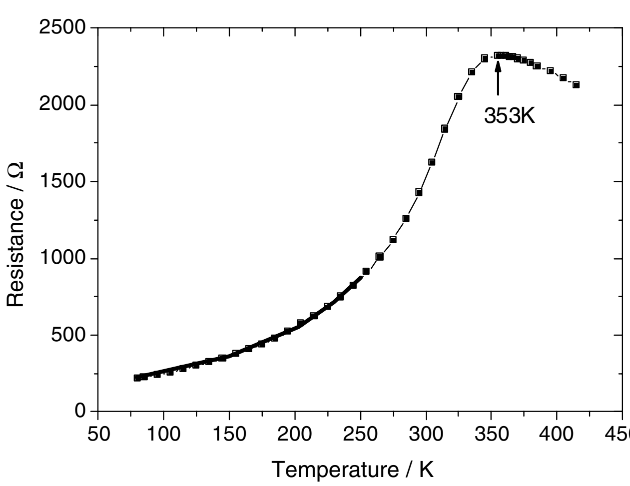

Figure 3 The temperature dependence of the resistance in LSMO film. The solid line is the fit to the magneton scattering formula.

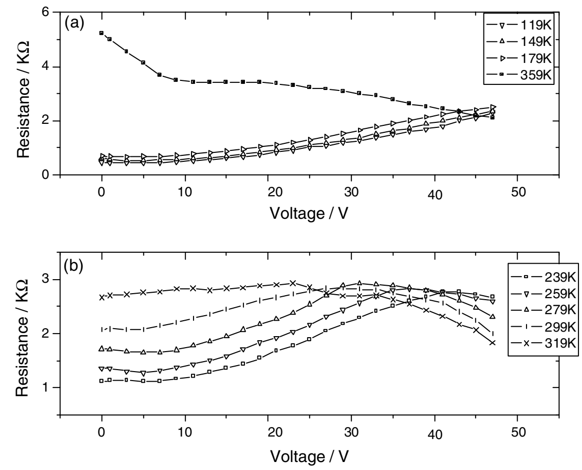

Figure 4 The voltage dependence of the resistance at different temperatures.

the results shown in Fig. 3. As shown in Fig. 5 the voltage corresponding to the maximum resistance (V_m) and the relative maximum change in resistance ($\Delta R/R$) decrease monotonically with increasing temperature from 239 to 319 K. The experimental observation can be attributed to the intrinsic characteristic of the manganites. The state is ferromagnetic phase at $T < 353$ K and the competition between the localization and delocalization of the e_g electrons is the important factor for the transport character. The electric field applied to the film causes the two effects: (i) it accelerates the electrons, and (ii) it causes the displacement of the ions, which results in the lattice distortion. This distortion is similar with the Jahn-Teller effect. The coupling between the e_g electrons and the distortion forms the small polarons, which bounds the transfer of the e_g electrons and induces the localization of the e_g electrons. Therefore the resistance increases with increasing the voltage. On the other hand, the inward distortion of the Mn^{3+}–O–Mn^{4+} bonds causes the decrease of the e_g bandwidth in $La_{2/3}Sr_{1/3}MnO_3$ manganites whereas the high electric field may induces a local

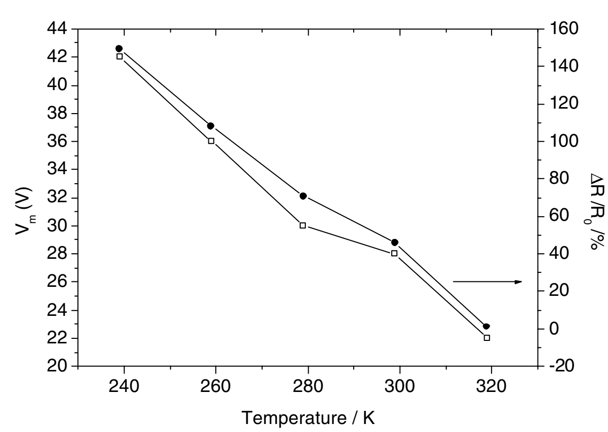

Figure 5 The temperature dependence of the voltage corresponding to the maximum resistance (V_m) and the relative maximum change in resistance ($\Delta R/R$).

electrical moment in the MnO_6 octahedra by modifying the spatial distribution of the charges and results in the increase of the e_g bandwidth. So the hopping probability and mobility of the carriers would be enhanced [16]. The delocalization of the e_g electrons induces the resistance decreasing. Based on such a picture, at lower temperature ($T < 353$ K), the double exchange effect is favorable and the localization effect of the low electric field is stronger. Therefore the resistance increases with increasing voltage. But when the electric field increases further, it may induces the increase of the e_g bandwidth and results in the decrease in resistance. The effect of the temperature on the change is obvious and the voltage corresponding to the maximum resistance decreases with increasing temperature. When the temperature is lowered well below peak temperature (Curie temperature), the double exchange interaction gradually becomes stronger and the ferromagnetic correlations are enhanced. Thus the high electric field may be required to induce delocalization via the double exchange. The temperature is higher and approaches to Curie temperature. The ferromagnetic correlations (double exchange) are weakened and the localization effect is stronger. The small voltage merely causes the delocalization of the e_g electrons. The temperature is 359 K, which is higher than the peak temperature (353 K). The electric field directly accelerates the small polarons and accordingly the resistance decreases with the voltage monotonically.

In conclusion, the voltage-induced change in resistance of the $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) film prepared using magnetron sputtering on the $LaAlO_3$ (100) substrate has been observed. At low temperature, the voltage causes the resistance increasing and then decreasing. The voltages corresponding to the peak resistance decrease with the increasing of the temperature. The effect of the voltage on the manganites is attributed to the status of the e_g electrons.

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