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Magneto- and Electroresistance of Ultrathin Anisotropically Strained La–Sr–MnO Films

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The magnetoresistance anisotropy of ultrathin $La_{0.83}Sr_{0.17}MnO_3$ films deposited on $NdGaO_3$ substrate by metalorganic chemical vapour deposition technique was investigated. The electric-field-induced resistance change was studied up to electric fields of 10 kV/cm using ns duration electrical pulses. It was found that in ultrathin (< 10 nm) and thin (> 50 nm) films the origin of electric-field-induced resistance change is thermal. However, the films with thicknesses of about 20 nm, exhibit negative electric-field-induced resistance change, having a pure electronic nature. This effect is explained in terms of two-layer systems with imperfections located at the interface between the layers.

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1. Introduction

The high Curie temperature of La–Sr–MnO_3 makes it an attractive material for vertical tunnel or artificial planar junction devices [1, 2]. However, further development of these devices requires better knowledge of the behaviour of the material at each interface, i.e. substrate/film, vertical junctions, or artificial structure interfaces [2]. This can be accomplished by studying electrical transport in La–Sr–MnO_3 ultrathin films. Such investigations revealed a strong increase in electrical resistivity of these films when film thickness was decreased below 20 nm [3].

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This 20 nm thick transition layer, called the "dead layer" [2], is responsible for thickness-dependent resistivity changes in ultrathin films.

In this paper, properties of the "dead layer" of moderate thickness (few tens of nm) and its influence on the transport properties of $La_{0.83}Sr_{0.17}MnO_3$ films deposited on $NdGaO_3$ (NGO) substrates by metalorganic chemical vapour deposition (MOCVD) technique are presented.

2. Experiment

The $La_{0.83}Sr_{0.17}MnO_3$ films were prepared on $NdGaO_3$ (001) substrates at 825°C using MOCVD from a liquid source solution having the composition $La_{0.78}Sr_{0.22}Mn_{0.733}$. The thickness of the films ranged from 4 to 60 nm. 6–8 mm long and 2–5 mm wide samples were co-planar with thin Ag electrodes placed at $d = 50$ μm distance relative to each other. These electrodes were deposited by thermal evaporation at 200°C and then annealed in an argon gas atmosphere at 400°C. Low-field resistance and magnetoresistance (MR) were measured at temperatures ranging from 5 to 300 K by applying dc electric and magnetic fields with a maximum of the latter of 0.8 T. To measure the electric-field-induced resistance change ("electroresistance" ER), the samples were connected in series to a 50 Ω impedance 18 GHz frequency transmission line and pulsed by 5–10 ns (0.5 ns rise time) rectangularly shaped electrical pulses with amplitudes up to 500 V.

The film structure was investigated using reflection high-energy electron diffraction (RHEED).

3. Results and discussion

The RHEED patterns recorded along the [110] zone-axis (with regard to the substrate) of a 4 nm sample are shown in Fig. 1a. Spots from the substrate have elongated shapes, in contrast to spots from the film, which have more rounded shapes with a little elongation in a direction parallel to the surface. Such shapes correspond to an orthorhombic face-centred phase structure with a lattice constant of $a = 4.06$ Å in plane and $c = 4.6$ Å out of plane. The patterns obtained from the 20 nm thickness film show cubic perovskite-like phase structure with lattice constant of about $a = 3.9$ Å. The diffraction pattern for the [110] zone--axis (Fig. 1b) shows a twofold superstructure, which consists of a perovskite-like cubic phase with vector [100] along [110] direction of the NGO substrate and an unknown phase producing spots with a similar intensity. RHEED patterns of the 60 nm thickness film demonstrated only the perovskite-like phase and showed no superstructure.

Typical resistivity (ρ) versus temperature (T) data plots of the investigated films exhibit maxima at particular temperatures (T_m). The value of T_m increases with film thickness up to 20 nm and then tends to saturate. At low film thickness,

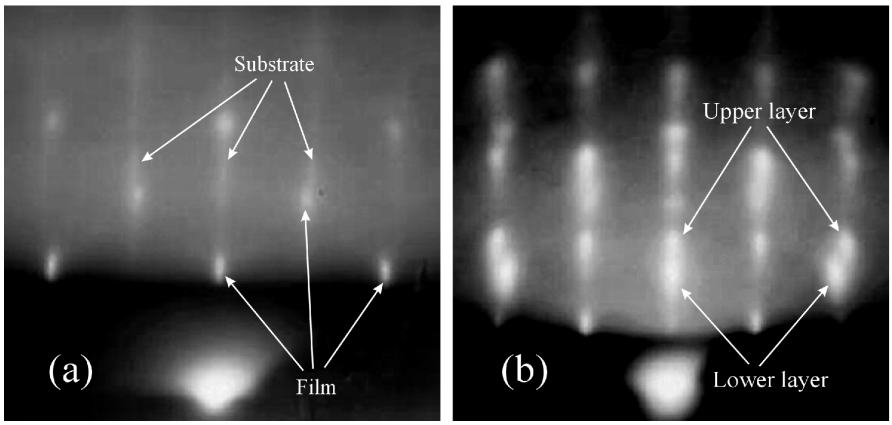

Fig. 1. Electron diffraction patterns recorded from the surface of samples with thicknesses of 4 nm (a) and 20 nm (b).

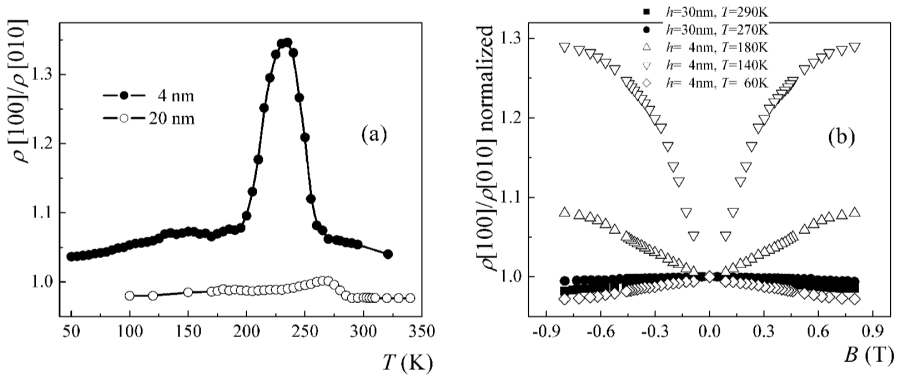

Fig. 2. (a) Temperature dependence of $\rho_{[100]}/\rho_{[010]}$ ratio for two films of different thicknesses. (b) $\rho(B)_{[100]}/\rho(B)_{[010]}$ (normalized to $\rho_{[100]}/\rho_{[010]}$ at zero magnetic field) vs. magnetic field inductance for films with two different thicknesses.

the resistivity is higher in compressed [100] and lower in stressed [010] directions. Figure 2a shows $\rho_{[100]}/\rho_{[010]}$ ratio as a function of T for two films of different thickness. It is evident that anisotropy of the resistivity (ρ) is higher at lower thickness and peaks at T_{m}.

Figure 2b shows the ratio $\rho(B)_{[100]}/\rho(B)_{[010]}$ (normalized to $\rho_{[100]}/\rho_{[010]}$ ratio obtained at zero magnetic field value) vs. magnetic field inductance (B) for two films with different thickness at various temperatures. MR anisotropy in the 4 nm thickness film increases when B is increased, reaching its highest value near T_{m}. In contrast, films thicker than 20 nm demonstrated very little MR anisotropy.

Investigation of ER was performed on films with three critical thicknesses: 8, 20, and 60 nm. For 8 and 60 nm thick films, the energy of strong electric fields dissipates mainly as a heat, producing a change in the resistance. At temperatures

below T_m, when films exhibit metallic electrical conductivity, the ER effect was positive. However, at $T > T_m$, when the films were in a semiconducting state, the ER was negative. The ER in 20 nm thick film was negative at all temperatures below T_m. Figure 3a,b shows ER (defined as ER $= \{[R(E) - R(0)]/R(0)\} \times 100\%$) vs. electric field strength E for the 20 nm film at different temperatures in two perpendicular directions to the substrate plane. Here $R(E)$ and $R(0)$ are resistances of the film in a strong and weak electric field, respectively. The electric field was defined as $E = V/d$, where V is the bias voltage, d is the gap between the contacts.

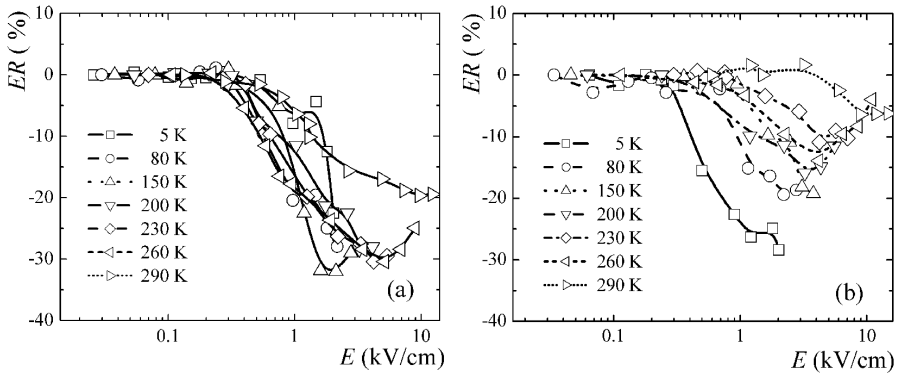

Fig. 3. Electroresistance vs. electric field strength at different temperatures for 20 nm thickness $La_{0.83}Sr_{0.17}MnO_3$ films in two perpendicular directions in the substrate plane, [100] (a) and [010] (b).

In conclusion, the origin of difference in parameters (electrical conductivity and T_m) between ultrathin and thin $La_{0.83}Sr_{0.17}MnO_3$ films comes from the different structure of these films. The low field resistivity and magnetoresistance effects at the substrate–film interface region are anisotropic due to the anisotropy of the strain induced by the $NdGaO_3$ substrate. Films with moderate thickness (20 nm) exhibit negative electroresistance in strong electric fields due to structural imperfections located between the "dead layer" and the rest of the film.

Acknowledgments

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