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Magnetoresistive Properties of Manganite-Based Heterojunctions

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Hole-doped $La_{2/3}Ba_{1/3}MnO_3$ (LBaMO), $La_{2/3}Ca_{1/3}MnO_3$ (LCaMO) and $La_{2/3}Ce_{1/3}MnO_3$ (LCeMO) thin films were grown heteroepitaxially on 0.1 wt.% Nb-doped $SrTiO_3$(100) (STON) substrates by magnetron sputtering. The prepared LBaMO/STON, LCaMO/STON, LCeMO/STON heterostructures demonstrated nonlinear rectifying current–voltage characteristics. Negative magnetorestance values have been indicated at low bias, meanwhile bias-dependent magnetoresistance has been measured at positive bias voltage values $U > U_{\mathrm{d}}$ where U_{d} is the interfacial potential, corresponding to a steep current increase at a forward bias.

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1. Introduction

Thin films of colossal magnetoresistance manganites are promising for the fabrication of magnetic field sensors suitable particularly for measuring strong pulsed magnetic fields. However, increasing attention is attributed also to heterojunctions based on p-type manganite films grown on conductive substrates such as n-type Nb-doped $SrTiO_3$ [1–6]. Significant magnetic field effect on both interface resistance and I–U characteristics of the heterojunctions could be promising for the fabrication of magnetic field sensor arrays.

In this work, we concentrate on current–voltage relations and magnetoresistive properties of manganite heterojunctions formed by growing heteroepitaxially $La_{2/3}Ba_{1/3}MnO_3$ (LBaMO), $La_{2/3}Ca_{1/3}MnO_3$ (LCaMO) and $La_{2/3}Ce_{1/3}MnO_3$ (LCeMO) thin films on Nb-doped $SrTiO_3$ (STON) substrates.

2. Preparation of the heterostructures

The LBaMO, LCaMO, LCeMO thin films with thickness d ranging typically from 150 nm to 200 nm were synthesized *in situ* at 750°C on commercially available crystalline Nb(0.1 wt.%)-doped $SrTiO_3$ substrates using DC magnetron sputtering (MS). Four-probe method with current passing perpendicularly to a film plane (CPP geometry) was undertaken to investigate the junction resistance, R_{J}, and the current–voltage (I–U) characteristics of the LBaMO/STON, LCaMO/STON and LCeMO/STON heterostructures. Ag coatings (2.0×2.0 mm^2) magnetron sputtered onto the tape-like manganite films and tapes of metallic In were used as low contact resistance electrodes for the manganite films and STON substrates, respectively.

3. Results and discussion

Both the measured reflection high-energy electron diffraction (RHEED) patterns and X-ray diffraction (XRD) spectra revealed perfect epitaxial growth of the LCaMO and LBaMO films on lattice-matched STON(100). Θ–2Θ XRD scans measured for the LCeMO films demonstrated highly (100)-axis oriented material although presence of weak additional reflexes indicated relatively low content of CeO_2 oxide as an impurity phase.

In-plane resistance measurements of the prepared manganite films demonstrated clearly defined peak-like $R(T)$ dependences which are observed usually for high crystalline quality manganite films in the vicinity of their paramagnetic–ferromagnetic (PM–FM) transition temperature, T_{c}. The characteristic resistivity peaks at $T = T_{\mathrm{p}} = 280$, 260 and 250 K have been indicated in this work for the LBaMO, LCaMO and LCeMO films, respectively.

Figure 1a shows the junction resistance, R_{J} (normalized to maximum values), measured for the heterostructures in a wide temperature range by passing fixed current (of about 0.01 mA) perpendicular to a film plane. Additional $R_{\mathrm{J}}(T)$ anomaly has been indicated for the LCeMO/STON heterojunction at about 160 K (see curve 3 in Fig. 1a) while $R_{\mathrm{J}}(T)$ curves measured for the LBaMO/STON and LCaMO/STON junctions were similar to the corresponding $R(T)$ dependences of the LBaMO and LCaMO films. Additional R_{J}(T) anomaly seen for the LCeMO/STON heterojunction at $T = 160$ K demonstrates, probably, doping instability of Ce-doped compound in a case of built-in electrical field and possible interfacial strain inducing reduced carrier density at the LCeMO/STON interface.

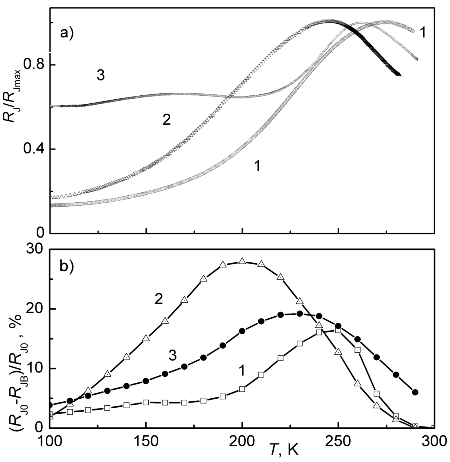

Fig. 1. Junction resistance (a) and magnetoresistance (at low bias voltage and $B = 1$ T) (b) measured for the LBaMO/STON (1), LCaMO/STON (2) and LCeMO/STON (3) heterostructures.

Figure 1b shows magnetoresistance of the LBaMO/STON, LCaMO/STON and LCeMO/STON heterojunctions (at $B = 1$ T) defined hereafter as $(R_{\mathrm{J}0} - R_{\mathrm{J}B})/R_{\mathrm{J}0}$. It can be seen from the figure that significant negative magnetoresistance values were measured for all the heterostructures at low voltage values in a relatively wide temperature range.

The current–voltage (I–U) characteristics of the heterojunctions were similar to those of semiconductor p–n junctions. They exhibited temperature-dependent nonlinear properties and clearly defined rectifying behavior over a wide temperature range both above and below the characteristic Curie temperature T_{c} of the manganite films. The I–U curves measured for the LBMO/STON heterojunction at various temperatures in a case of a forward ($U > 0$) and reverse ($U < 0$) bias are displayed in Fig. 2.

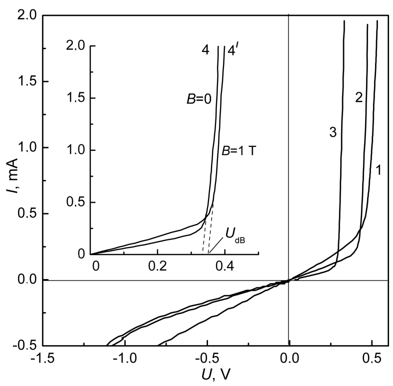

Fig. 2. Current–voltage characteristics of the LBaMO/STON heterojunction at $B = 0$ T; T, [K]: 295 (1), 260 (2), 78 (3) and 230 (4); the $I(U)$ relations at 230 K, $B = 0$ and $B = 1$ T are shown in the inset.

Linear I–U relations were observed for the heterostructures at low bias voltages ($U \ll 0.3$ V). However, an abrupt increase of current passing in a forward direction was indicated for the heterostructures at a certain voltage U_{d} corresponding to a built-in interfacial potential and known from p–n junction theory as a diffusion voltage. It is important to note significant shift of U_{d} values with temperature decreasing (see curves 1–4 in Fig. 2) and certain increase of the interfacial potential, U_{d}, with applied magnetic field (see the corresponding I–U relations for the LBaMO/STON heterostructure displayed in the inset to Fig. 2).

Additional electrical measurements of the hererostructures using rf current ($\nu = 1$ MHz) certified significant decrease of the junction resistance at $U \cong U_{\mathrm{d}}$ and certain increase of the junction capacity with U increasing from 0 up to U_{d}. Rectifying behavior of the I–U curves and the observed voltage-dependent junction capacity demonstrate unambiguously presence of a depletion layer and built-in electrical field at the manganite–STON interface.

It can be seen from the inset to Fig. 2 that an increase of current and the resultant decrease of the junction resistance, R_{J} (negative magnetoresistance), under applied magnetic field are characteristic for the LBaMO/STON heterostructure at low forward bias values ($U < U_{\mathrm{d}}$). However, a certain (almost parallel) shift of the I–U curves to higher voltages with applied magnetic field (resulting positive junction magnetoresistance values) can be seen for $U > U_{\mathrm{d}}$. Relative increase of U_{d} values measured in this work for the LCaMO/STON, LCeMO/STON and LBaMO/STON heterojunctions by applying magnetic field $B = 1$ T is shown in Fig. 3. Peak-like ($\Delta U_{\mathrm{d}}/U_{\mathrm{d}0}$) versus T curves seen from the figure can be explained taking into account unusually strong dependence of the interfacial potential on magnetic field in a temperature region just below the ferromagnetic to paramagnetic phase transition of the manganites.

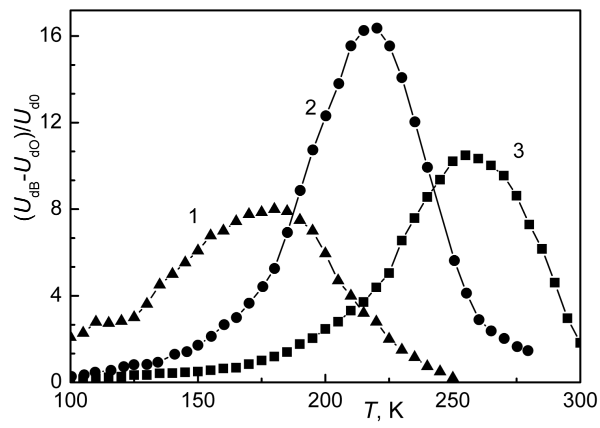

Fig. 3. Increase of the diffusion voltage U_{d} under applied magnetic field $B = 1$ T measured for the LCaMO/STON (1), LCeMO/STON (2) and LBaMO/n-STON (3) heterojunctions.

Summarizing our results we conclude that the manganite *p–n* heterojunctions could be promising for the fabrication of planar magnetic field sensor arrays. The heterojunctions demonstrate negative magnetoresistance values at low bias ($U \ll U_\mathrm{d}$), meanwhile positive bias-dependent magnetoresistance has been indicated for the heterostructures at $U > U_\mathrm{d}$ where U_d is the interfacial potential, corresponding to a steep current increase at a forward bias.

Acknowledgments

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