Vol. **113** (2008) *ACTA PHYSICA POLONICA A* No. 3

Proceedings of the 13th International Symposium UFPS, Vilnius, Lithuania 2007

Growth and Investigation of p-$La_{2/3}Ca_{1/3}MnO_3$/n-Si Heterostructures

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We report the fabrication and investigation of p–n diode structures based on thin hole-doped $La_{2/3}Ca_{1/3}MnO_3$ films grown on n-type silicon substrates. $La_{2/3}Ca_{1/3}MnO_3$ films with typical thickness of about 400 nm were prepared using pulsed laser deposition. Reflection high-energy electron diffraction measurements revealed polycrystalline quality of $La_{2/3}Ca_{1/3}MnO_3$ thin films on Si substrates. The surface roughness of $La_{2/3}Ca_{1/3}MnO_3$ films investigated by atomic force microscopy was found to be in the range of $25 \div 30$ nm. Studies of electrical properties showed that $La_{2/3}Ca_{1/3}MnO_3$/Si heterostructures exhibit nonlinear asymmetric I–V characteristics both at room temperature and at 78 K. Furthemore, it was shown that these I–V dependences are sensitive to magnetic field, especially at lower voltages.

PACS numbers: 71.30.+h, 73.43.Qt, 75.47.Lx, 81.15.Fg

1. Introduction

Perovskite-like lanthanum manganites, $La_{1-x}A_xMnO_3$, A = Sr, Ba, Ca, exhibiting colossal magnetoresistance effect are actively investigated for elaboration of magnetic field sensors [1]. During the last few years, there was an increasing interest in both manganite/insulator/manganite heterostructures demonstrating significant tunneling magnetoresistance and, particularly, in p–n junctions based on hole- and electron-doped oxide films. Rectifying behavior has been reported for p–i–n junction composed of n-type $La_{0.05}Sr_{0.95}TiO_3$, p-type $La_{0.7}Sr_{0.3}MnO_3$, and insulating $SrTiO_3$ interlayer, as well as various heterojunctions formed between hole-doped manganite films and conducting n-type $SrTiO_3\langle Nb\rangle$ used as a substrate [2]. In order to use the manganite films for various device applications, it is important to grow high quality manganite films on Si. $La_{0.67}Ca_{0.33}MnO_3$

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films have been grown recently on Si substrates coated by yttria-stabilized zirconia (YSZ) [3, 4]. $La_{0.67}Sr_{0.33}MnO_3$ films were also deposited on YSZ buffered Si with a thin $Bi_4Ti_3O_{12}$ template layer providing perfect lattice matching for manganite film growth.

In this work, we report results on preparation and investigation of electrical and magnetic properties of $p{-}n$ heterostructures composed of hole-doped $La_{0.67}Ca_{0.33}MnO_3$ (LCMO) films deposited directly onto electronically doped Si substrate.

2. Experiment

Nd-YAG laser ($\lambda = 532$ nm) operating in a doubled frequency mode with a repetition rate of 12.5 Hz was used for film deposition. The duration and energy of laser pulses were 8 ns and 50 mJ, respectively. For the preparation of $p{-}n$ structures, Si(111) substrates with few different carrier densities were selected. The substrate temperature was kept at 750°C during film growth. Deposition was performed in an oxygen gas at a pressure of about 25 Pa. The as prepared LCMO films ($d \approx 400$ nm) were additionally annealed in oxygen ambience with pressure of 1 atm. Structural properties and surface morphology of thin LCMO films and heterostructures were characterized by reflection high-energy electron diffraction (RHEED) and atomic force microscopy (AFM). Resistance versus temperature of the films was investigated by applying a standard four point-probe method with dc current of about 0.01 mA passing in a film plane (CIP geometry). At the same time, current perpendicular to plane (CPP) geometry was used to investigate the junction resistance, R_J, as well as the current–voltage ($I{-}V$) characteristics of the LCMO/Si heterostructures. Magnetoresistance of the films and heterostructures was investigated by applying magnetic field ($B = 1.0$ T) oriented in parallel direction to the film plane.

3. Results and discussion

RHEED measurements revealed the polycrystalline growth of thin LCMO films on n-type Si substrates. The surface roughness of LCMO films investigated by AFM has been found to be in the range of $25 \div 30$ nm.

Figure 1 shows resistance versus temperature of the LCMO films measured by four point-probe method by passing current in parallel direction to a film plane. It can be seen from Fig. 1 that with decreasing temperature, resistance increases, but at about 185 K (corresponding to the observed resistance curve maximum) the characteristic transition from a paramagnetic to a ferromagnetic state appeared for the manganite films. The magnetoresistance values (presented in the same figure with the corresponding axis on the right side) increased in the whole temperature range. In the vicinity of room temperature the magnetoresistance was close to 0% while it increased up to 20% at 78 K.

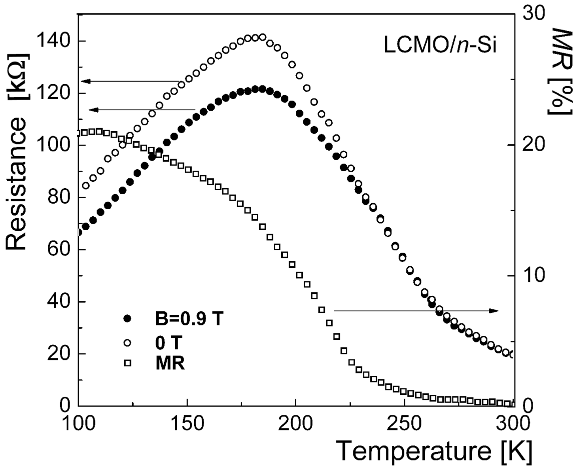

Fig. 1. Resistance vs temperature of thin LCMO film grown on n-type Si substrate at zero magnetic field (open circles) and at magnetic field of 0.9 T (filled circles). Curve shown by squares presents magnetoresistance dependence on temperature.

At the same time, the LCMO/Si heterostructures exhibiting significantly higher resistance values at 300 K demonstrated semiconductor-like resistance increase in the whole temperature range (T = 300–78 K). The measurements of magnetoresistance effect of the LCMO/Si heterostructures demonstrated the ratio of about 5% near liquid nitrogen temperature.

The current–voltage curves, measured for the LCMO/Si heterostructures at room temperature and T = 78 K, are displayed in Fig. 2. It can be seen that in both cases the heterostructure exhibits rectifying current–voltage characteristics. Differential resistance of the heterostructure (at zero bias) was found to decrease with cooling from 300 K down to 78 K. The inset to Fig. 2 demonstrates a set of $I-V$ curves measured for the heterostructure at 78 K in a case of forward bias at zero magnetic field and at 0.9 T. The most striking feature of these heterostructures is the observed dependence of current–voltage characteristic at lower voltages on magnetic field. The actual magnetic field dependence on the $I-V$ curves has been indicated for the applied voltage exceeding 0.3 V. However, beyond a critical voltage of about 1 V, the influence of magnetic field on $I-V$ behavior was found to be negligible. It can be seen from the inset that both $I-V$ characteristics consist of three different parts which could be attributed to different conducting mechanisms. We suppose that one of the factors effecting to the $I-V$ dependence at low V values could be formation of insulating SiO_2 interlayer during film growth.

Summarizing, we point out the growth of $p-n$ heterostructures composed of hole-doped LCMO film deposited directly onto electronically doped Si substrate. Studies of electrical properties showed that LCMO/Si heterostructures exhibit

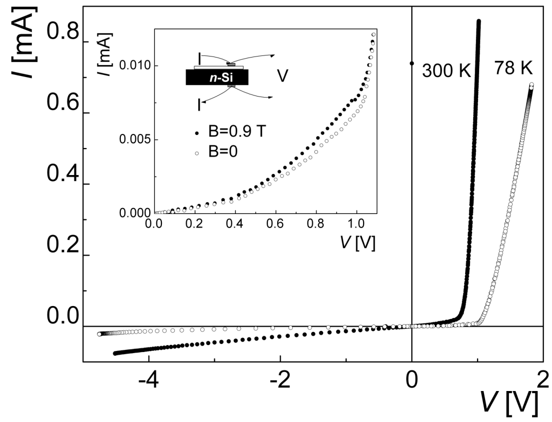

Fig. 2. I–V characteristics LCMO/Si heterostructure measured at T = 300 K and 78 K by tuning bias current in the absence of magnetic field. Inset shows the area of low bias voltages in zero magnetic field and 0.9 T.

rectifying I–V characteristics both at room temperature and at 78 K. It was shown that the I–V dependences measured at 78 K are sensitive to magnetic field, in particular, at low voltage values (0.3–1.0 V).

Acknowledgments

The authors acknowledge financial support of the Lithuanian State Science and Studies Foundation (grant No. T-102/07 and grant No. C 18/2007 project MULTIMA).

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