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Fabrication and characterization of all-perovskite oxide p–n junctions based on $La_{1-x}Sr_xMnO_3$ and Nb-1wt% doped $SrTiO_3$

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Abstract

All-perovskite oxide p–n junctions have been fabricated by pulsed laser deposition. Semiconducting p-type $La_{1-x}Sr_xMnO_3$ (LSMO) and n-type Nb-1 wt% doped $SrTiO_3$ (NSTO) were used. Thin films of LSMO were epitaxially grown on (1 0 0) NSTO single crystal substrate at 650 °C and under an ambient oxygen pressure of 100 mTorr. Heteroepitaxial relationship of $(1\,0\,0)_{LSMO}||(1\,0\,0)_{NSTO}$ has been obtained. Good electrical rectifying characteristics have been observed at room temperature. LSMO is a well known colossal magnetoresistive material with a Curie temperature T_c at around room temperature. The *I*–*V* characteristics of the p-LSMO/n-NSTO junction were studied under the temperature range of 77–700 K and an applied magnetic field of up to 1 T.

Keywords: Films; Electrical properties; Transition metal oxides; p–n junction

1. Introduction

Perovskite oxides have attracted a lot of attention due to their diverse properties such as piezoelectricity, ferroelectricity, superconductivity, and magnetoresistance (MR) effect. Recently the fabrication of all-oxide p–n junction is one of the much sought-after research interests.[1–4] Due to the large bandgap thermal stability of oxide, it is believed that the operation of an all-oxide p–n junction will be stable even at temperatures up to several hundred degree Celsius; whereas common commercial diodes can function reliably at several tens of degree Celsius only. Indeed, the temperature dependence of the rectifying property of all-oxide p–n junction diode has been reported in several publications.[1,2]

Colossal magnetoresistance (CMR) effect has been observed in the family of manganese perovskite oxides.[5,6] $LaMnO_3$ is an antiferromagnetic insulator; however with the doping of divalent ions, p-type conducting oxide is formed. $La_{1-x}A_xMnO_3$ (A = Ca, Sr, Ba, etc.) has a phase transformation at the Curie temperature (T_c): ferromagnetic phase at low temperature ($T \le T_c$), and paramagnetic phase at high temperature ($T \ge T_c$). In addition, it exhibits a strong negative MR effect. Recently manganite based p–n junctions have also been fabricated.[2–4] Sun et al. studied the magnetic field dependent rectifying characteristic of $La_{0.32}Pr_{0.35}Ca_{0.33}MnO_3$/Nb-$SrTiO_3$ junction.[4] They showed the band gap of $La_{0.32}Pr_{0.35}Ca_{0.33}MnO_3$ ($e_g\uparrow$–$e_g\downarrow$) varied with the magnetic state. The spin deviation of Mn^{4+} ions from fully ferromagnetic alignment caused a reduction of energy gap between e_g, and hence lowered the turn-on voltage of the junction.

We have fabricated all-oxide p–n junctions utilizing p-$La_{1-x}Sr_xMnO_3$ (LSMO) thin film grown on n-Nb-$SrTiO_3$ (NSTO) single crystal. In fact epitaxial LSMO thin film could be easily grown on NSTO by pulsed laser deposition (PLD). Two different compositions of LSMO thin films were studied: $La_{0.7}Sr_{0.3}MnO_3$ and $La_{0.85}Sr_{0.15}MnO_3$. $La_{0.7}Sr_{0.3}MnO_3$ is metallic-like at low temperature ($T \le T_c$) and semi-conducting-like at high temperature ($T \ge T_c$).[2] With a well control of the deposition oxygen pressure, T_c of the films could be varied.[7] We prepared $La_{0.7}Sr_{0.3}MnO_3$ thin films at different deposition pressure from 60 to 150 mTorr, and checked their value of T_c carefully. In all subsequent p–n junctions fabrication, the deposition pressure was purposely adjusted for T_c to occur at around room temperature

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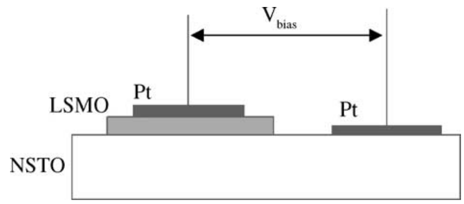

Fig. 1. Schematic side view of the LSMO/NSTO p–n junction.

and hence the effect of phase transition on the rectifying property could be investigated more easily. $La_{0.85}Sr_{0.15}MnO_3$ thin film was also grown as our p-layer. It has a completely different electric property compared with $La_{0.7}Sr_{0.3}MnO_3$. It is semi-conducting-like throughout the temperature range studied and the absolute resistivity is nearly six orders of magnitude larger than that of $La_{0.7}Sr_{0.3}MnO_3$. Two p–n junctions, namely $La_{0.7}Sr_{0.3}MnO_3$/NSTO and $La_{0.85}Sr_{0.15}MnO_3$/NSTO, have been fabricated. The influence of MR effect on the junction characteristics has been studied. We have also measured the current–voltage (*I*–*V*) characteristic at temperatures up to 700 K in order to evaluate the thermal stability of these junctions.

2. Experiment

The bulk $La_{0.7}Sr_{0.3}MnO_3$ and $La_{0.85}Sr_{0.15}MnO_3$ targets were fabricated by the standard solid state reaction of constituent oxides with the final sintering at 1320 °C in air for 10 h. Their structural properties and compositions were investigated by X-ray diffraction (XRD) and energy dispersive X-ray (EDX). LSMO films, having a spot area of 2.5×10^{-4} cm^2 as defined by the mask pattern, were grown on (1 0 0) NSTO single crystal substrate by PLD. A KrF excimer laser ($\lambda = 248$ nm) with a repetition rate of 10 Hz and laser fluence of ∼5 J/cm^2 was used. The substrate to target distance was 4 cm. Before the deposition, the chamber was evacuated by rotary pump to approximately 1 mTorr. The deposition process was carried out under a substrate temperature of 650 °C and an ambient oxygen pressure of 100 mTorr for 10 min. Films with thickness of ∼200 nm were formed. Post-annealing for 10 min at the same deposition atmosphere was carried out for all deposited oxide films to ensure good crystallinity. At last, Pt electrodes were grown on both the LSMO and NSTO. The schematic side view of these p–n junctions is shown in Fig. 1. We used XRD to characterize the structural properties of the LSMO films. The rectifying property of these junction diodes was measured at a temperature range of 77–700 K and under a 1 T magnetic field at room temperature.

3. Results and discussion

Fig. 2 shows the *I*–*V* characteristic of the two junctions Pt/LSMO and Pt/NSTO. Linear relationships traversing the

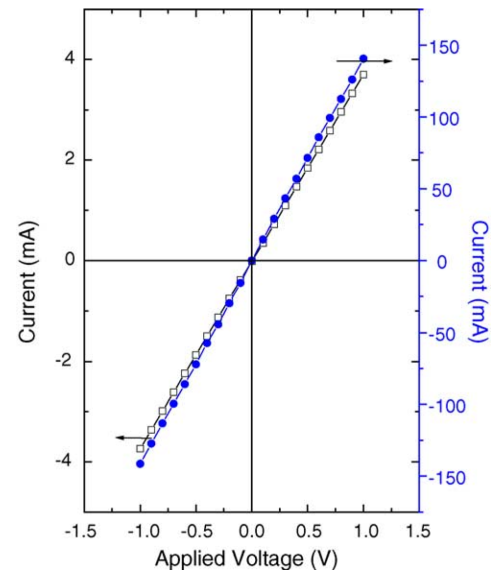

Fig. 2. Current–voltage characteristic curves of Pt/LSMO/Pt (□) and Pt/NSTO/Pt (●).

origin indicate good ohmic contact in these junctions. Scanning probe microscope (SPM) image of the LSMO film suggests a surface roughness of only ∼1 nm. Fig. 3a shows the θ–2θ XRD patterns of the PLD grown LSMO thin films on NSTO single crystal substrate. However, the lattice constant of LSMO ($a = 3.89$ Å) is so close to that of NSTO ($a = 3.9$ Å),

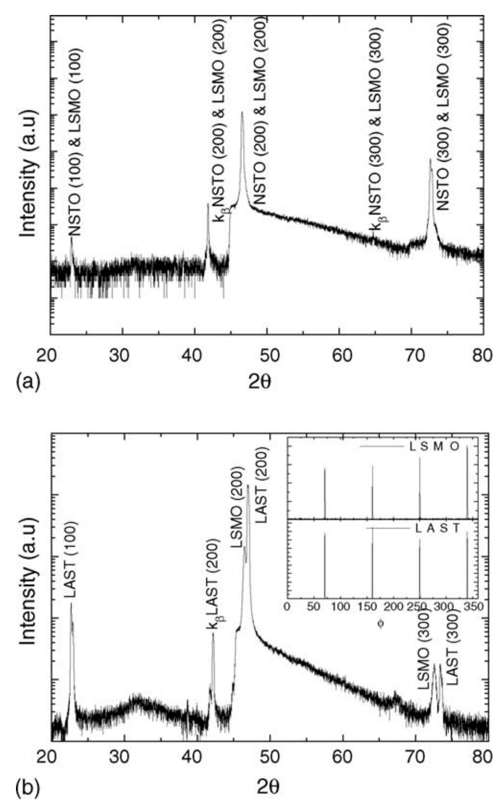

Fig. 3. X-ray diffraction patterns of LSMO films grown on (a) NSTO and (b) LAST.