Temperature-Dependent Transport Properties in Oxide $p-n$ Junction above Room Temperature *

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Oxide $p-n$ junctions of p-$SrIn_{0.1}Ti_{0.9}O_3$/n-$SrNb_{0.01}Ti_{0.99}O_3$ (SITO/SNTO) are fabricated by laser molecular beam epitaxy. The current-voltage characteristics of the SITO/SNTO $p-n$ junction are investigated mainly in the temperature range of 300–400 K. The SITO/SNTO junction exhibited good rectifying behaviour over the whole temperature range. Our results indicate a possibility of application of oxide $p-n$ junction in higher temperatures in future electronic devices.

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The $p-n$ junctions based on perovskite oxides have attracted more intensive attention for their multifunctional characteristics, such as ferroelectricity, ferromagnetism, ultrafast photovoltaic effect and positive magnetoresistance effect,[1−4] compared with the conventional semiconductor $p-n$ junctions. Moreover, the perovskite oxide $p-n$ junctions are possible to work at higher temperatures because most of the perovskite oxide materials have larger band gaps. Therefore, considerable efforts have been devoted to investigating the characteristics of the junctions composed of oxide/oxide or oxide/silicon[5−11] due to their potential applications. As we know, almost all the previous works about oxide $p-n$ junctions focused on the transport properties in the temperature range of 5–300 K. However, it is important to investigate the current-voltage ($I-V$) behaviour of the oxide $p-n$ junctions above room temperature for future applications. In this Letter, we report the I–V characteristics of p-$SrIn_{0.1}Ti_{0.9}O_3$/n-$SrNb_{0.01}Ti_{0.99}O_3$ (SITO/SNTO) junction in the temperature range of 300–400 K.

The SITO/SNTO $p-n$ junctions were prepared by epitaxial growth of 280-nm-thick SITO thin films on SNTO (001) substrates using laser molecular beam epitaxy. A polycrystalline SITO ceramic was used as the target. During the deposition, the substrate temperature was fixed at 680°C and the oxygen pressure was kept at 1×10^{-2} Pa. The laser energy density and frequency were 1 J/cm^2 and 2 Hz, respectively. Hall measurement indicates that the carrier concentrations were $7.34\times10^{19}\,\mathrm{cm}^{-3}$[12] and $1.63\times10^{20}\,\mathrm{cm}^{-3}$ for the p-type SITO thin film and the n-type SNTO substrate, respectively. The crystal structure of the SITO film was characterized by x-ray diffraction (XRD) with Cu K_α radiation. For electrical measurement, the In electrodes with area of 0.5 mm^2 were placed on the surfaces of the SITO thin film and SNTO substrate. The $I-V$ behaviour of the junction was measured by a Keithley 2400 voltage source.

Figure 1 shows the XRD pattern of a SITO thin film on the SNTO substrate. The pattern only shows the (00l) peaks of the thin film except those from the substrate, no impurity phases or randomly oriented grains were observed. This means that the SITO thin film is of single phase with the c-axis orientation.

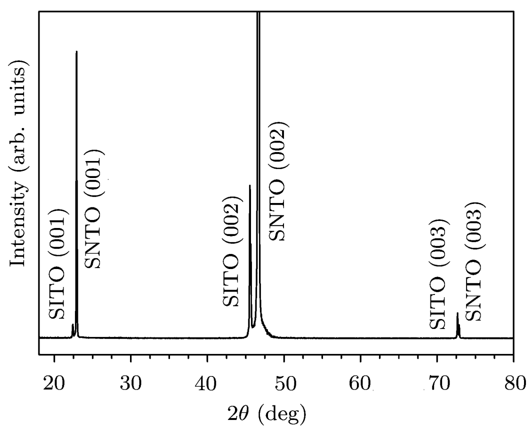

Fig. 1. XRD $\theta-2\theta$ scan curve of a SITO/SNTO $p-n$ junction.

The I–V curves of the SITO/SNTO junction at 300–400 K is shown in Fig. 2. Forward bias $I-V$ curves at temperatures 200–300 K is shown in the upper inset, and the schematic circuit diagram of the measurement is shown in the lower inset. The I–V curves show good rectifying property and no obvious leakage current can be observed in the temperature range 300–400 K. The ratio of forward current at bias voltage of 0.54 V to reverse current at −0.54 V is 80

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even at 400 K. In addition, it is also found that the slope of the $I-V$ curves under forward bias becomes steeper with increasing temperature in the temperature range of 200–400 K.

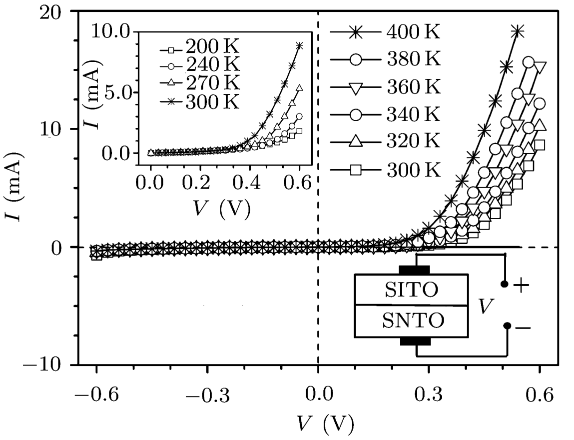

Fig. 2. I–V curves of the SITO/SNTO $p-n$ junction at 300–400 K. The upper inset shows the forward-bias $I-V$ curves at 200–300 K and the lower inset is the schematic circuit of the measurement.

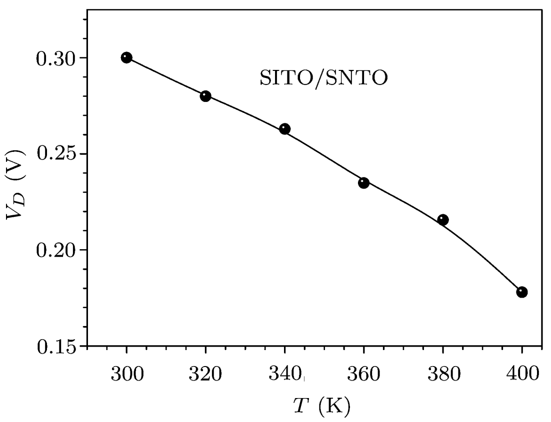

Fig. 3. Temperature dependence of the threshold voltage V_D of the SITO/SNTO $p-n$ junction.

The effect of temperature on the slope of the I–V curves under forward bias conditions for the $p-n$ junction can be understood by considering the temperature-dependent barrier. We define the voltage V_D as the threshold voltage, at which the forward current reaches 0.1 mA. Figure 3 shows the temperature dependence of the threshold voltage V_D. The threshold voltage V_D decreases almost linearly with the increasing temperature. Similar to the conventional $p-n$ junction, the width of the depletion layer and the barrier height in a $p-n$ junction decrease with the increasing temperature.[13] The results are in agreement with our previous observations by electron holography.[14] The junction resistance defined as $R_j = dV/dI$ decreases correspondingly because more carriers can be easily driven across the junction interface in higher temperatures. Therefore, the slope of the I–V curves under forward bias becomes steeper with the increasing temperature.

In conclusion, we have investigated the transport properties of the SITO/SNTO $p-n$ junction above room temperature. The SITO/SNTO junction exhibits good rectifying characteristics and no obvious leakage current is observed in the temperature range 300–400 K. For the forward bias voltage, the $I-V$ curves of the junction become steeper at higher temperatures, which can be understood by considering the temperature-dependent barrier. The present results indicate the possibility of applications of oxide $p-n$ junctions in higher temperatures in future electronic devices.

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