Effect of applied magnetic field on the rectifying characteristics in self-doped La$_{0.9}$MnO$_3$/0.8 wt % Nb–SrTiO$_3$ heteroepitaxial junctions

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The epitaxial self-doped La$_{0.9}$MnO$_3$ thin film was deposited on a 0.8 wt % Nb-doped SrTiO$_3$ substrate by pulse laser deposition method to form a bilayer $p$-n junction with an area of 8 mm$^2$. The isothermal current-voltage loops measured from 10 to 380 K with an interval of 10 K in applied magnetic fields up to 7 T show typical temperature-dependent rectifying characteristic and asymmetrical hysteresis. The effect of magnetic field on the rectifying property is very small for the temperature above 150 K and a strong asymmetrical effect on the rectifying property below 150 K. In the low temperature region, although the diffusive voltage $V_d$ is not affected by the applied magnetic field, the breakdown voltage $V_b$ decreases with the increasing of magnetic field. At 10 K, the relative ratio of voltage $(V_b(0)/V_b(7 T))/V_b(0)$ is about 14%, showing a magnetically tunable property. These results reveal the great potential of the manganites in configuring artificial devices. © 2008 American Institute of Physics. [DOI: 10.1063/1.2836964]

INTRODUCTION

The manganite heteroepitaxial junction, showing a good rectifying behavior, was reported by Kawai et al.\textsuperscript{1,2} at first. Due to the high sensitivity of electronic and magnetic properties of manganese to external magnetic field\textsuperscript{3} and electric field,\textsuperscript{4} the variance of resistance and diffusion potential may also make these simple $p$-$n$ junctions promising for various novel applications. Recently, the effect of magnetic field,\textsuperscript{5} electric field,\textsuperscript{1} and light\textsuperscript{6} on the $p$-$n$ junctions has been reported. The external field greatly affected the rectifying property and the resistance of the junction, causing an extremely large magnetoresistance.\textsuperscript{5} The magnetically tunable properties of $p$-$n$ junction is of special interest from the viewpoint of application. In the doped manganites, the carriers dependent on the oxygen content is an open question. Generally, the self-doped La$_{0.9}$MnO$_3$–$\delta$ (LMO) material shows the characteristic of holes. What will be the behavior of the bilayer junction composed of this kind of manganites under external field is an interesting question for us. In this paper, we constructed a bilayer junction using the self-doped LMO film and the 0.8 wt % Nb-doped SrTiO$_3$ (STON) crystal (LMO/STON junction), and focused on its behavior under magnetic field. The breakdown voltage $V_b$ decreases with the increasing of magnetic field at low temperature region, showing a magnetically tunable property.

SAMPLES AND EXPERIMENTAL

The epitaxial self-doped La$_{0.9}$MnO$_3$ (LMO) thin films ($\sim 100$ nm) were deposited on the heating 0.8 wt % Nb–SrTiO$_3$ (STON) and SrTiO$_3$ (STO) single crystal substrates ($\sim 720$ °C) in 1 mbar pure oxygen gas by pulse laser deposition technique and annealed in air at 900 °C for 1 h. The junction area is about $4 \times 2$ mm$^2$. A four-probe method was used to measure the RT curves for LMO/STO sample and the current-voltage ($I$-$V$) loops for the manganite heterojunction. For the LMO/STON junction, two evaporated silver electrodes (thickness of $\sim 200$ nm) are on LMO film and the other two pressed indium electrodes are on STON substrate. In this simple heteroepitaxial junction, the hole conducting LMO is used as the $p$-type region, while the electron conducting STON as $n$-type region. The isothermal $I$-$V$ loops measured from 10 to 380 K with an interval of 10 K in an applied magnetic field up to 7 T were performed on a Quantum Design physical property measurement system (PPMS-9). The measuring current increases from $\sim 0.05$ to 0.05 mA then from 0.05 to $\sim 0.05$ mA in a period of 11.2 s for 256 points. The magnetic field was applied perpendicular to the surface of thin film.

RESULTS AND DISCUSSIONS

Before we present the behavior of the LMO/STON junction under magnetic field, we display the colossal magnetoresistance (CMR) characteristic of LMO/STO thin film measured at $H=0$, 0.5, 1, 3, 5, and 7 T, respectively, as shown in Fig. 1. The temperature-dependent resistivity of the La$_{0.9}$MnO$_3$–$\delta$ thin film under applied magnetic field shows a typical CMR characteristic with metal-insulator transitions at 306.5 K at 0 T and 364 K at 7 T. The temperature of metal-insulator transition increases with the increasing of applied magnetic field. The field dependence of peak temperature $T_p^{RT}$ obtained from RT curves is shown in Fig. 1(b). The field-induced metal-insulator transition temperature increases
linearly with the increasing of applied field. If we defined \( MR = [R(0) - R(H)]/R(H) \), we can calculate the temperature-dependent MR for each field from Fig. 1(a), as shown in the inset of Fig. 1(a). The maximum of MR occurs 289.7 K at 1 T and 296 K at 7 T. The peak temperature \( T_p^{\text{CMR}} \) obtained from CMR curves increases also with the increasing of applied magnetic field. Our results show that the field dependence of peak temperature \( T_p^{\text{CMR}} \) obtained from CMR curves. Inset: field dependence of peak temperature \( T_p^{\text{CMR}} \) obtained from CMR curves.

The isothermal current-voltage loops of the heteroepitaxial LMO/STON junction were measured from 380 to 10 K with an interval of 10 K in the applied magnetic fields (a) \( H=0 \) T and (b) \( H=7 \) T, respectively. Inset of Fig. 1(a): isothermal current-voltage loops measured at 10 K and 0 T. LMO/STON junction has a \( p-n \)-like property. Both the diffusive potential \( V_d \) and the breakdown voltage \( V_b \) increase with the decreasing of the temperature for the temperature above 50 K. When the temperature is lower than 50 K, the breakdown voltage \( V_b \) is almost same. In addition, from Fig. 2, we can see that all of \( I-V \) loops do not come from the initial point \( (I=0, V=0) \), showing a large asymmetrical hysteretic loop. To see it clearly, we have replotted the \( I-V \) curve at 10 K, as shown in the inset of Fig. 1(a).

To explore the effect of applied magnetic field on the rectifying behavior, we replotted the isothermal current-voltage loops of the heteroepitaxial LMO/STON junction measured at several fixed temperature \( T=380 \) (magenta lines), 240 (blue lines), 150 (green lines), 100 (red lines) and 10 K (black lines) for various magnetic fields, respectively, as shown in Fig. 3.
of magnetic field on the rectifying property is very small for the temperature above 150 K. However, the external field greatly affected the rectifying property below 150 K; meanwhile, the magnetic field has a strong asymmetrical effect on the rectifying property. For the part of positive voltage, the diffusive voltage $V_d$ is not affected by the applied magnetic field. However, for the other part, the breakdown voltage $V_b$ decreases with the increasing of magnetic field. To see the field effect clearly, we have replotted the negative part of $I$-$V$ curves measured at 10 K for various magnetic fields, respectively, as shown in the inset of Fig. 3. Due to the limit of voltage $V=5$ V for $I$-$V$ measurement in the PPMS, we cannot get the accurate breakdown voltage $V_b$. If we defined the voltage at $I=50$ $\mu$A as the breakdown voltage $V_b$, we can obtain the field dependence of the breakdown voltage $V_b$ at $T=150$, 100, 50, and 10 K, respectively, as shown in Fig. 4(a). From Fig. 4(a), we can see that the absolute breakdown voltage $V_b$ decreases linearly with the applied magnetic field. When the temperature is lower than 50 K, the breakdown voltage $V_b$ is tuned by the applied magnetic field. If we defined the voltage at $I=50$ $\mu$A as the breakdown voltage $V_b$, we can obtain the field dependence of the breakdown voltage $V_b$ at $T=150$, 100, 50, and 10 K, respectively, as shown in Fig. 4(a). The field dependence of the relative ratio of breakdown voltage is shown in Fig. 4(b). At 10 K, the relative ratio of voltage $[V_b(0)−V_b(7 T)]/V_b(0)$ is about 14%. These results reveal the great potential of the manganites in configuring artificial devices.

CONCLUSIONS

The epitaxial self-doped La$_{0.8}$MnO$_3/0.8$ wt % Nb–SrTiO$_3$ junction shows a typical temperature-dependent rectifying characteristics and asymmetrical hysteresis. Above 150 K, the effect of magnetic field on the rectifying property is very small. However, the magnetic field has a strong asymmetrical effect on the rectifying property below 150 K. The breakdown voltage $V_b$ decreases with the increasing of magnetic field, showing a magnetically tunable. At 10 K, the relative ratio of voltage $[V_b(0)−V_b(7 T)]/V_b(0)$ is about 14% at 7 T. The magnetic field effect maybe related with the spin glass state. These results reveal the great potential of the manganites in configuring artificial devices.

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