Effect of temperature on the La$_{1-x}$Ca$_x$MnO$_3$/SrTiO$_3$:Nb (x=0–0.75) heterojunctions

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Influence of temperature on the La$_{1-x}$Ca$_x$MnO$_3$/SrTiO$_3$:Nb heterojunctions with the Ca content ranging from 0 to 0.75 has been experimentally studied. Obvious temperature effect occurs in the junction with a Ca content of 0.1. As experimentally shown, the interfacial barrier is insensitive to temperature below 340 K, and experiences a decrease from ~1.24 to 0.85 eV as temperature grows from 340 to 375 K. However, the temperature effect in other junctions is weak, and the energy barrier change is typically ~0.03–0.08 eV. In the scenario of temperature-driven orbital-order-disorder transition in the La$_{0.9}$Ca$_{0.1}$MnO$_3$ film, the temperature effect can be qualitatively understood. © 2010 American Institute of Physics. [doi:10.1063/1.3462322]

The interfacial effect of the Mott insulator has been a topic of intensive study in recent years. Different from the bulk, the interface usually exhibits unexpected behavior. The most typical examples are the enhancement of superconductivity and ionic conductivity at the interface. Dramatic magnetic and resistive changes accompanying the interfacial orbital-and-charge ordering were also observed in manganite films.

La$_{1-x}$Ca$_x$MnO$_3$ (LCMO) is a typical system that shows an well orbital ordering below a critical temperature ranging from 300 and 780 K, varying with Ca content. TheLMCO-based heterojunction could be a suitable sample for interface study based on the following reasons: First, the interfacial barrier (Φ$_b$) in the junction provides a feasible measure to interface state, through which the evolution of the electronic structure can be traced. Second, manganite junction may exhibit abundant effects due to the presence of the spin, charge, and orbital degrees of freedom and the order-disorder transition associated with either degree of freedom.

There are intensive studies on the LCMO junctions with the hole content of 0.33 or above, and diverse behaviors associated with special magnetic and transport processes have been observed. As well established, however, the robust orbital ordering occurs only when the Ca content is low. It is, therefore, worthwhile to explore the effect of phase transition of the LCMO film with a low Ca content on the corresponding junctions. Based on this consideration, in this paper, we performed a systematic study on the LCMO/SrTiO$_3$:Nb(0.05wt %Nb) (STON) junction with a Ca content between 0 and 0.75, with a focus on the influence of temperature on interfacial barrier. Strong temperature effect is observed in the junction of x=0.1, as demonstrated by the rapid decrease in the Φ$_b$ from ~1.25 to 0.85 eV as temperature grows from 295 to 375 K. In contrast, the barrier change in other junctions is relatively small, and ΔΦ$_b$ ~0.03–0.08 eV. In the scenario of temperature-driven orbital-order-disorder transition in LCMO of x=0.1, the temperature effect can be qualitatively understood.

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LCMO/STON junctions were fabricated by growing, via the pulsed laser ablation technique, LCMO films with the Ca content of 0, 0.1, 0.2, 0.33, 0.67, and 0.75, respectively, on (001)-STON. During the deposition, the temperature of the substrate was kept at 720 °C, and the oxygen pressure at 10 Pa, for x=0, 30 Pa, for x=0.1, 50 Pa, for x=0.2, or 80 Pa, for x≥0.33. The film thickness is ~150 nm, controlled by deposition time.

The lateral size of the junction is 1 × 1 mm$^2$, fabricated by the photolithographic technique. As electrodes, two copper pads were deposited on LCMO and STON, respectively, and the contact resistance is ~15 Ω for the Cu-STON contact and ~150 Ω for the Cu-LCMO contact. Laser with a wavelength between 532 and 980 nm was used in the present experiment. The spot size of the laser is ~1 mm in diameter. Photocurrent, I$_p$, yielded by laser illumination was acquired by a Keithley 2611 SourceMeter.

Figure 1 presents the temperature dependence of the photocurrent for two selected junctions of x=0.1 and 0.33. For clarity, only the data acquired at the temperatures of 295 and 355 K are shown. As expected, I$_p$ exhibits a strong dependence on photon energy, and the typical value for the...
When the temperature changes from 295 to 355 K, as shown in Figs. 1(a) and 1(b), the photocurrent for a fixed wavelength shows a remarkable dependence on Ca content. The latter is a feature that appears only for x=0.1, and the former is larger or smaller than 0.1, is nearly invariant with temperature for junction x=0.1. The influence of temperature is weak below 340 K, and only a slight change in interfacial barrier reduces from 0.85 eV, is observed from 295 to 340 K. Considerable temperature effect, characterized by a rapid decrease in $\Phi_B$, emerges and develops when the temperature exceeds ~340 K, and the interfacial barrier reduces from ~1.25 to 0.85 eV when the temperature increases from 340 to 375 K. The tendency to decreasing for $\Phi_B$ does not stop up to 375 K, the maximal temperature of the present experiment. We repeated the experiments several times with different electrode setups, and obtained essentially the same results.

As well known, both the SrTiO$_3$ and the La$_{1-x}$Ca$_x$MnO$_3$ are typical thermoelectric materials. We found that the maximal thermopower of LCMO/STON is ~10 mV, obtained by optimizing the position of the lead lines on the Cu barier is presented in the inset plot of Fig. 3(b). Two distinctive features can be identified from these data. The first one is the monotonic increase of the barrier height with Ca content, which is consistent with the results deduced from the current-voltage analysis in our previous work, and the second one is the great reduction of the interfacial barrier at high temperatures for the junction x=0.1 ($\Delta\Phi_B \approx 0.36$ eV). The latter is a feature that appears only for x=0.1, and the energy barrier in other junctions, which can have a Ca content either larger or smaller than 0.1, is nearly invariant against temperature ($\Delta\Phi_B \approx 0.03–0.08$ eV).

To get a clear picture about the temperature effect, in Fig. 4 we present the interfacial barrier as a function of temperature for junction x=0.1. The influence of temperature is weak below 340 K, and only a slight change in interfacial potential, $\Delta\Phi_B \approx 0.02$ eV, is observed from 295 to 340 K. Considerable temperature effect, characterized by a rapid decrease in $\Phi_B$, emerges and develops when the temperature exceeds ~340 K, and the interfacial barrier reduces from ~1.25 to 0.85 eV when the temperature increases from 340 to 375 K. The tendency to decreasing for $\Phi_B$ does not stop up to 375 K, the maximal temperature of the present experiment. We repeated the experiments several times with different electrode setups, and obtained essentially the same results.

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electrode. This is a value much lower than $\Delta \Phi_B / e \sim 0.4$ V. This result indicates that the variation in $\Phi_B$ cannot be ascribed to thermoelectric effect.

Considering the close relation of the built-in potential with the electronic structures of the junction, the obvious change in $\Phi_B$ of LCMO/STON may suggest a variation of the band structure of either LCMO or STON. In general, the change of the electronic structure of the materials with temperature is rather small and smooth. The presence of a critical temperature for the temperature effect in LCMO ($x=0.1$)/STON reminds us of phase transition. As well documented, STON is insensitive to temperature in the temperature range investigated here. However, LCMO can experience an orbital order-disorder transition upon warming. The most typical orbital ordering occurs in LaMnO$_3$ below the temperature of $\sim 780$ K, yielding a sudden increase in resistivity. Correspondingly, the resistive anomaly becomes weak, and no signature of phase transition can be identified as $x$ approaches $\sim 0.17$. The transition temperature is very high for LMO, beyond the scope of our experiment. This may be the reason for the absence of significant temperature effect in the corresponding junction. In contrast, the transition temperature is $\sim 400$ K in the case of $x=0.1$, which is close to the threshold temperature for the significant $\Phi_B$ decrease. As well established, the orbital disordering can produce a structure change due to the disappearance of cooperative Jahn–Teller distortions. This will in turn affect both the interfacial states and the Fermi level. This may be the reason for the $\Phi_B$ drop upon warming. Indeed, it has been found that, for the La$_{1/8}$Sr$_{7/8}$MnO$_3$/STON junction, a transition from the orbital ordered to disordered state can occur accompanying a considerable reduction in $\Phi_B$. We noted that the $\Phi_B$-$x$ dependence observed here is much smoother than that expected from the $\mu$-$x$ relation of the LCMO film, which may indicate a pinning of the Fermi level by interfacial states, where $\mu$ is the chemical potential of LCMO. It is possible that the phase transition in LCMO ($x=0.1$) modifies $\Phi_B$ via affecting the Fermi level pinning.

We have measured the in-plane resistance of LCMO ($x=0.1$) to identify the signature of phase transition. Acti-