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Electrical Properties of Oxide Junctions under Light Irradiation

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Introduction

Transition metal oxides have been studied for many years as an attractive material series for the research of electron correlations. Among them, the perovskite oxides have attracted much attention due to the various fascinating phenomena including high T_C superconductivity and colossal magnetoresistance. Controlling the carrier density in such materials is a central topic not only from the perspective of fundamental physics, but also for electronics applications. Photocarrier injection[1] is one method to control the carrier density using a heterointerface structure with light irradiation. Depending on the band alignment of the heterointerfaces, photo-generated electrons or holes are selectively injected across the junction. This induces dramatic changes in the physical properties of the carrier injected material. The advantage of this method is the feasibility to continuously control the carrier doping level without inducing large lattice disorder.

Previous studies were mainly focused on the phenomenology of the photocarrier injected materials, however for precise control of carrier doping, it is also necessary to identify the fundamental electrical properties of the junctions. In this study, in order to obtain detailed understanding of the photocarrier injection process, we studied the electrical properties of several junctions with $SrTiO_3$ under light irradiation.

First, the large photoconductivity and associated effects on the junction characteristics induced by light irradiation was studied with Au/$SrTiO_3$ junctions. Next, we studied the effect of the electric field dependent permittivity of $SrTiO_3$[2] on the efficiency of the photocarrier injection process with Au/ Nb:$SrTiO_3$ junctions. Finally we investigated the junction electrical and the photovoltaic properties of $La_{1-x}Sr_xMnO_3$/Nb:$SrTiO_3$ junctions as typical cases of junctions using correlated oxides.

Results and Discussion

Photoirradiation effects in Au/$SrTiO_3$ junctions

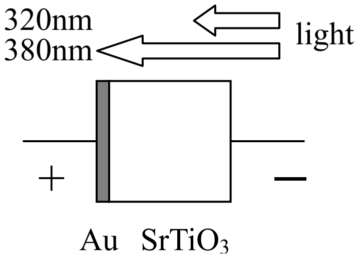

Fig.1: Measurement geometry. Light was irradiated from the back side of the Au/$SrTiO_3$ junction.

When a semiconductor is in contact with a metal, band bending inside the semiconductor occurs as seen in Schottky junctions. When an insulator and a metal are attached, because of the absence of fixed charges in the insulator, band bending should not occur. By using the spectral dependence of the absorption coefficient in $SrTiO_3$, we varied the penetration depth of the light to vary the spatial volume of the charge generating region. The light was irradiated from the back side of Au/$SrTiO_3$ junctions as shown in Fig. 1. Al was wire-bonded as the back contact.

Fig. 2 shows the current-voltage (*I-V*) characteristics of Au/$SrTiO_3$ junction under light irradiation by λ =320 nm and 380 nm at 10 K. At 320 nm irradiation, the carriers are generated only near the surface of $SrTiO_3$, whereas under irradiation at 380 nm, the carriers are generated not only at the surface but at the interface due to the long optical penetration depth. *I-V* characteristics under λ = 320 nm irradiation shows bulk limited conduction. If only the series resistance changes at different wavelength of irradiation light, only the change in the magnitude of the current is expected. However, the *I-V* characteristics at λ = 380 nm irradiation exponentially increase at forward bias voltage and it is similar to a Schottky junction. Temperature dependence of the *I-V* characteristics at λ = 380 nm irradiation were also measured and similar behavior to Au/Nb:$SrTiO_3$ Schottky junctions were observed.

These results indicate the presence of band bending when carriers are generated in the vicinity of the interface. One possible origin of the band bending at λ = 380 nm irradiation is the localization of photo-generated holes acting as the fixed charges.

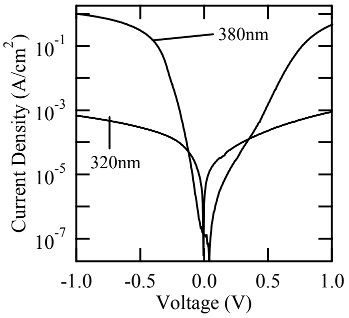

Fig.2: *I-V* characteristics of Au/$SrTiO_3$ junction under light irradiation. Measurement was carried out at 10 K.

Electrical and photovoltaic properties of Au/Nb:$SrTiO_3$ junctions

The current transport process at a Schottky junction is described by carriers traversing over the barrier (thermionic emission) at high temperatures, quantum mechanical tunneling through the barrier (field emission) at low temperatures, and the contribution of both at intermediate temperatures (thermoionic field emission). Here the temperature is compared with respect to the electrostatic potential created dependent on the doping concentration of the semiconductor. The temperature dependent *I-V* characteristics of Au/Nb:$SrTiO_3$ is well described by thermionic-field emission (T-F emission) between 300 K and 100 K, but at low temperatures, the *I-V* characteristics deviate from pure field emission, indicating the presence of an additional current process (Fig.3 (a)). The origin of this additional current is attributed to the sharpening of the band bending by the strong electric field dependent permittivity of the $SrTiO_3$.

The temperature dependence of the open circuit voltage (V_{OC}) in Au/Nb:$SrTiO_3$ is shown in Fig. 3 (b). Intensity of the irradiated light was fixed to about 0.5 mW and the wavelength to 340 nm. V_{OC} at room temperature is less than 100 μV, which dramatically increases with decreasing temperature, but further decrease in temperature results in reduced V_{OC}. The number of injected carriers is directly related to V_{OC} and the junction capacitance, so this decrease in V_{OC} is regarded as the reduction in the efficiency of photocarrier injection. From the measured short circuit current, we calculated the temperature dependence of V_{OC} as shown in Fig. 3(b) on the assumption that *I-V* characteristics are expressed with T-F emission at intermediate temperatures and field emission at low temperatures. This calculation predicts no reduction in V_{OC} at low temperatures. This shows that the origin of the reduction in V_{OC} likely originates from the excess tunneling caused by the field dependent permittivity of $SrTiO_3$.

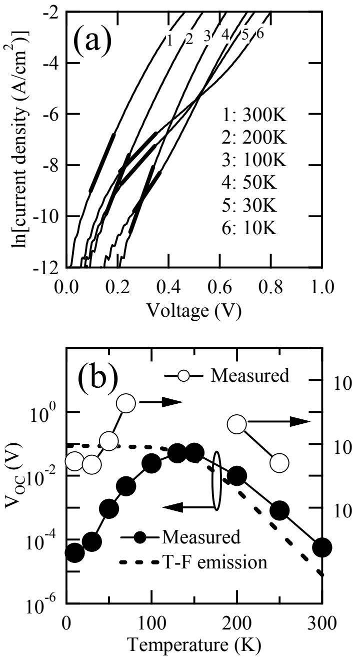

Fig. 3: (a) *I-V* characteristics of Au/Nb:$SrTiO_3$. (b) Temperature dependence of V_{OC} and lifetime of injected carriers.

We also measured the temperature dependent lifetime of the injected carriers from the transient decay of V_{OC} shown in Fig. 3 (b) as open circles. The spatial separation of electrons and holes makes the lifetime appear larger than the lifetime in bulk $SrTiO_3$, but at low temperatures, a reduction in the lifetime is observed. The mechanism of this reduction can be thought as follows. Holes are injected to Au, but electrons also flow into Au by tunneling. This inefficiency of the spatial separation of electrons and holes increases the recombination rate resulting in the reduction of V_{OC}.

These results indicate that the efficiency of photocarrier injection is strongly reduced because of the electric field dependent permittivity of $SrTiO_3$ especially at low temperatures. For obtaining large V_{OC} at low temperatures using $SrTiO_3$, it is necessary to design structures to reduce the excess tunneling current.

Electrical and photovoltaic properties of $La_{1-x}Sr_xMnO_3$/Nb:$SrTiO_3$ junctions

$La_{1-x}Sr_xMnO_3$ is one of the typical series of materials in which electron correlation affects their physical properties. $LaMnO_3$ is a Mott insulator and by substitution of La for Sr, holes are induced. At x = 0.17, $La_{1-x}Sr_xMnO_3$ undergoes an insulator to metal transition, and at x = 0.3, $La_{1-x}Sr_xMnO_3$ is a metal.

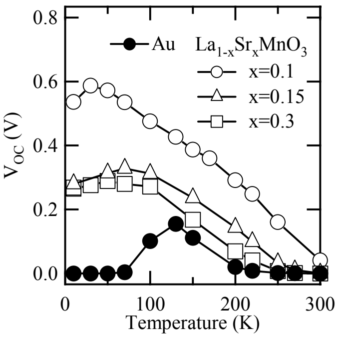

Fig.4: Temperature dependence of V_{OC} of $La_{1-x}Sr_xMnO_3$/Nb:$SrTiO_3$ junctions

Fig. 4 shows the measured temperature dependence of V_{OC} in $La_{1-x}Sr_xMnO_3$/Nb:$SrTiO_3$ junctions for different x as a function of temperature. V_{OC} increases with decrease in temperature in all cases. In the case of x = 0.3 and x = 0.15, a slight reduction of V_{OC} is observed at low temperature but much smaller than observed in the case of Au/Nb:$SrTiO_3$. The measured lifetime of injected carriers in these junctions indicated no reduction in their lifetime at low temperatures. However, the intermediate and low temperature *I-V* characteristics in the case of x = 0.15 and x = 0.3 are well explained within the T-F and field emission models, so the temperature dependence of V_{OC} are consistent with the *I-V* characteristics. However excess tunneling caused by sharpening of the band bending was not observed from the *I-V* results. The built-in potential of 0.6 eV was obtained from the capacitance voltage (*C-V*) measurements implying that the band bending is steeper than that of Au/Nb:$SrTiO_3$, (built-in potential 1.2 eV). The smaller built-in potential enhances more tunneling current, which is opposite to the experimental results. One of the possible origins of the absence of excess tunneling current is due to the complex band structure of $La_{1-x}Sr_xMnO_3$. The band structure is different from simple metal such as Au and as a result, tunneling probability from $SrTiO_3$ conduction band to $La_{1-x}Sr_xMnO_3$ is reduced.

Conclusion

In order to effectively apply the photocarrier injection technique in oxide materials, electrical properties of oxide junctions were studied from different aspects and we have found (1) the possibility of band bending by the photocarrier doping in insulating $SrTiO_3$, (2) the important role of the electric field dependent permittivity resulting in reducing the efficiency of photocarrier injection, and (3) the importance of understanding the electrical properties of oxide junctions.

References

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Presentation

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