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First Demonstration of Rectifying Property of P-I-N Heterojunctions Fabricated by Tri-Layered Semiconducting Oxides

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1. Introduction

We have been studying semiconducting oxide materials and their layered structures with related crystals. This study will open a way to the <u>active oxide devices</u> partly surpassing the existing semiconductor devices.

In the present work, we have succeeded in fabricating *p-i-n* diodes with good rectifying property by growing *p*-$La_{0.85}Sr_{0.15}MnO_3$/*i*-$SrTiO_3$/*n*-$La_{0.05}Sr_{0.95}TiO_3$ heterostructure on (100) $SrTiO_3$ substrate using ArF-excimer (193nm) laser ablation method. All three layeres have perovskite structure and, besides, were well lattice-matched with each other (lattice constant 3.9 Å). According to our band model calculation, injected electrons from *n*-$La_{0.05}Sr_{0.95}TiO_3$ transfer the *i*-layer and recombine in *p*-$La_{0.85}Sr_{0.15}MnO_3$. Hole injection is prohibited by presence of *p-i* heterojunction barrier. This prediction was experimentally verified.

In this paper, we report fabrication of oxide *p-i-n* diode and its characteristics, particularly the rectifying property and optical irradiation effects.

2. Experimental

Details concerning the deposition conditions are summarized in Table 1. Improved laser ablation named "Eclipse Method" was employed throughout this work. By virtue of the eclipse method, we obtained good films free from droplets and RHEED showed much better ordering in their diffraction patterns [1].

We paid attentions a lot for selection of the substrate material. The (100) $SrTiO_3$ substrate has lattice constant of 3.9 Å, just matching to grown layers. On (100) $SrTiO_3$ substrate, we got excellent epitaxial films with acceptable quality for electronics application.

As to $SrTiO_3$ growth, we used a special technique which is characterized by addition of Ar to the host O_2 ambient of the eclipse PLD. In our previous study, we checked importance of Ar-addition for $SrTiO_3$ growth having the permittivity as high as 350 ε_0 [1].

The thickness of *p*-layer and *n*-layer is about 1500 Å, and i-layer is about 3000 Å. Figure 1 shows schematically the structure of the *p-i-n* diode. Cr electrode was used because of its low ohmic-contact resistivity with both *p*-$La_{0.85}Sr_{0.15}MnO_3$ and *n*-$La_{0.05}Sr_{0.95}TiO_3$.

Table.1. Deposition Conditions.

	$La_{0.85}Sr_{0.15}MnO_3$	$SrTiO_3$	$La_{0.05}Sr_{0.95}TiO_3$
type	p	i	n
Laser	ArF-excimer(193nm)		
Substrate	(100)$SrTiO_3$		
Substrate temperature	650℃		
Frequency	10Hz		
Gas pressure	O_2:0.1Torr	O_2+Ar: 0.1Torr	O_2:0.1Torr
Deposition time	60min	120min	60min

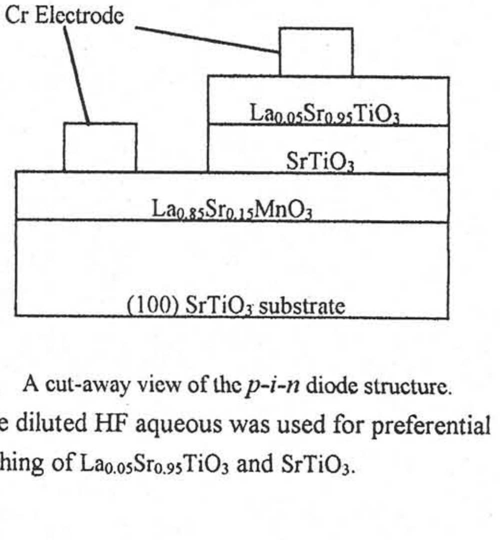


Fig.1. A cut-away view of the *p-i-n* diode structure.

The diluted HF aqueous was used for preferential etching of $La_{0.05}Sr_{0.95}TiO_3$ and $SrTiO_3$.

3. Results and discussion

Prepared *p-i-n* diodes exhibited clearly the rectifying *I-V* curves. It was indeed the first demonstration of the active performance of all oxide device. The typical *I-V* curve (taken by the transistor curve tracer) is given in Fig.2.

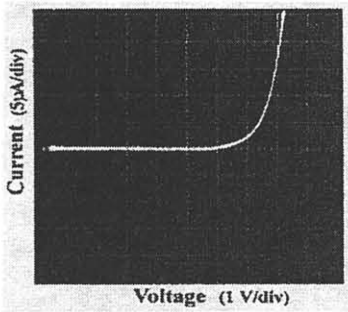


Fig.2. The *I-V* characteristic of the diode.

Figure 3 shows the band diagram of the *p-i-n* structure that we have supposed. $SrTiO_3$ has an (optical) energy gap of 3.2eV[3,4] and that of $La_{0.05}Sr_{0.95}TiO_3$ is thought to be very close to $SrTiO_3$. As to the gap value of $La_{0.85}Sr_{0.15}MnO_3$, we used the value of $LaMnO_3$ (1.7eV). Both $La_{0.85}Sr_{0.15}MnO_3$ and $La_{0.05}Sr_{0.95}TiO_3$ are degenerate semiconductors because both of them have very high carrier density.

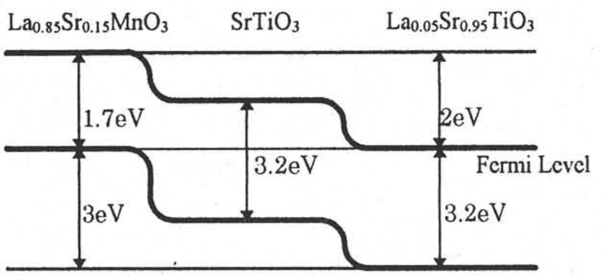
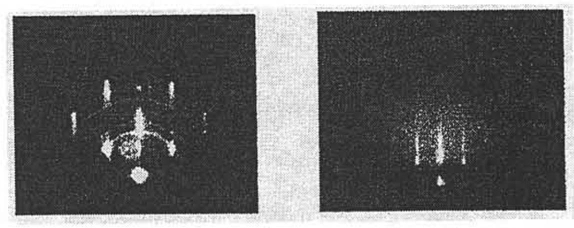


Fig.3. The band diagram of the *p-i-n* structure.
Thermal equilibrium state.

From Fig.3, we can expect that the current of *p-i-n* diode starts increasing at about 2~3V[5]. Actually, we observed the built-in voltage of 2~3V in Fig.2 which is just in accordance with the present expectation. We can say that this is the consistent result.

When we used (100) MgO substrate, the crystal quality got worse (Fig.4) because MgO lattice constant (4.2Å) is different from the three layers. This lattice mismatch induced a number of lattice-defects in the *i*-$SrTiO_3$ layer and, as a result, the *I-V* curve obeyed the space-charge-limitation (SCL) rule[6]. Here, we like to place an emphasis that the original *I-V* property of the *p-i-n* oxide diode surely appeared not when MgO substrate was used but when $SrTiO_3$ was.



(a) (b)

Fig.4. The RHEED pattern of the *p-i-n* structure.
(a) Films were grown on (100) MgO substrate and (b) on (100) $SrTiO_3$ substrate.

4. Conclusions

We tried to fabricate *p-i-n* heterojunctions diode by semiconducting oxides and characterized its *I-V* property with the band diagram we supposed.

All three layeres were well lattice-matched with each other and the *I-V* curves showed as same as we had predicted. This is the first step for the new active oxide devices.

References

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