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InP/InGaAs/InP Double Hetero-junction Solar Cells with Increased Open-Circuit Voltage

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1. Introduction

InP lattice-matched InGaAs is very suitable material for thermo-photo-voltaic devices and bottom cell of the InP based tandem solar cells because of its low band gap (0.75 eV) characteristic.

The performance of solar cells is characterized by open-circuit voltage (V_{oc}), short-circuit current (J_{sc}) and fill-factor (FF). As the dark current is decreased, the open circuit voltage of solar cells is increased. Therefore, if the dark current is reduced, we can increase the open-circuit voltage. In this paper, we investigated double hetero-junction structure to increase the open-circuit voltage by the reduction of the dark current.

As shown in Fig. 1, the conventional InGaAs solar cell structures are p-n or p-i-n homo structures and double hetero structures [1-2]. The double hetero-structure solar cells have front surface field (or window) and back surface field (BSF) layer to increase the open-circuit voltage and the short-circuit current [3-5].

Our p(InP)-i(InGaAs)-n(InP) double hetero-junction structure in this paper is shown in Fig. 1-(c). This structure is same as the homo and hetero structure except for the InGaAs emitter and base layer to be replaced by InP layer.

The dark current is proportional to the number of minority carriers of the emitter and base layer. The number of minority carrier density is related to the bandgap as

$$N = \left[\alpha \cdot \exp\left(-\frac{E_G}{kT}\right) \right]^{1/2} = \beta \left[J_0 \right]^{1/2} \quad (1)$$

where α, β is constant, J_0 is the dark current, E_G is the band gap and kT is the thermal energy. And also the V_{oc} is related to the dark current as

$$V_{oc} = \varphi_T \ln\left(\frac{J_L}{J_0} + 1\right) \quad (2)$$

where ϕ_T is the thermal voltage and J_L is the light generated current. The dark current of the double hetero-junction solar cells is lower than that of the homo and double hetero structure solar cells, because the emitter and base layer band gap of the double hetero-junction solar cells is larger than that of homo and double hetero structure solar cells. Therefore, the open-circuit voltage can be improved.

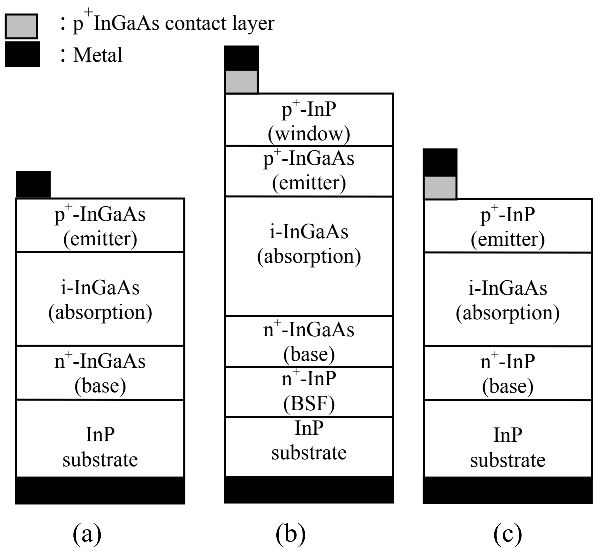

Fig. 1 (a) Homo InGaAs/InP solar cell structure and (b) double hetero InGaAs/InP solar cell structure. (C) Proposed double hetero-junction InP/InGaAs/InP solar cell structure in this paper.

2. Experiments

Three kinds of InGaAs/InP solar cells were grown by MOCVD (Metal Organic Chemical Vapor Deposition) shown in Table I. The BSF layer is not contained all structures of the epitaxial layers.

The growth temperature and pressure were 650 ℃ and 20 mbar respectively. Trimethylindium, trimethylgallium, arsine and phosphine were used source materials. Di methlyzinc was used for P-type doping, and silane was for low and high N-type doping respectively.

Table I Epitaxial layers of three kinds of InGaAs/InP solar cell structures

	Homo	Double Hetero	Double Hetero-Junction
Contact (1000 Å)	p-InGaAs 1e19	p-InGaAs 1e19	p-InGaAs 1e19
window (700 Å)	None	p-InP 1e18	None
emitter (2500 Å)	p-InGaAs 1e19	p-InGaAs 1e19	p-InP 1e18
absorption (10000 Å)	InGaAs undoped	InGaAs undoped	InGaAs undoped
base (5000 Å)	n-InGaAs 1e19	n-InGaAs 1e19	n-InP 1e18
(100) substrate (300 ㎛)	n-InP 1e18	n-InP 1e18	n-InP 1e18

Following the epitaxial growth and before characterization, metal deposition, photolithography, plating and mesa opening were performed. The cell area (mesa opening area) is 0.1 cm^2. The front contact is metal grid and front grid showing was 5% for the 0.1 cm^2 area cells. Finally, the dark I-V, photo I-V (AM1.5) and spectral response characteristics were measured.

3. Results and discussion

The dark I-V characteristics of the three kinds of structures are shown in Fig. 2. The double hetero-junction structure cell has lower dark current than other structures. This is due to the fact that the emitter and base layer have higher band gap than those of the other structure cells.

Table Ⅱ shows that the V_{oc} of the double hetero-junction structure cell has higher than that of the other structure cells. This result also can be expected from the dark I-V characteristics.

The double hetero structure cell had low fill factor since contact metal was over-etched, but low fill factor is not affect the V_{oc} and J_{sc}. The double hetero structure cell has higher value of V_{oc} than that of the homo structure solar cell because of the InP window layer. The improvement of quantum efficiency by InP window layer is shown in Fig. 3. The double hetero structure cell has the highest external quantum efficiency for all wavelengths. Therefore the J_{sc} of the double hetero structure cells have the highest value. And also V_{oc} of the double hetero structure cell is slightly increased compared to the homo structure cell.

The double hetero-junction structure cells have the highest efficiency by the increased V_{oc} compared to the homo and double hetero structure cells. This result is due to the fact that the improvement of V_{oc} of the double hetero-junction structure cell surpasses the improvement of V_{oc} and J_{sc} of the double hetero structure cell.

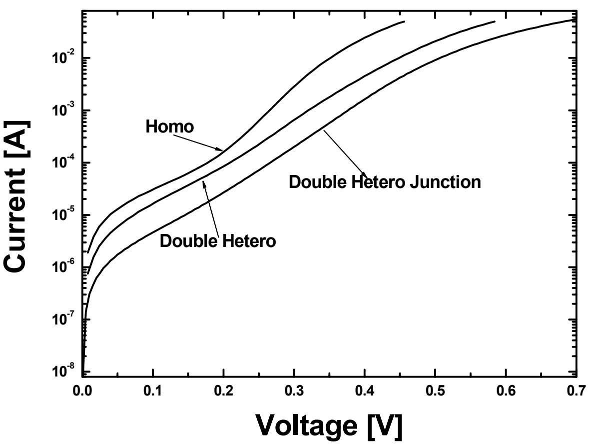

Fig. 2 Dark I-V curve of the three kinds of the cell structures

Table Ⅱ Photo I-V characteristics

	Homo	Double Hetero	Double Hetero-Junction
V_{oc}[V]	0.304	0.335	0.396
J_{sc}[mA/cm^2]	38.79	43.7	38.69
FF	0.68	0.43	0.65
Efficiency[%]	8.11	6.35	10.05

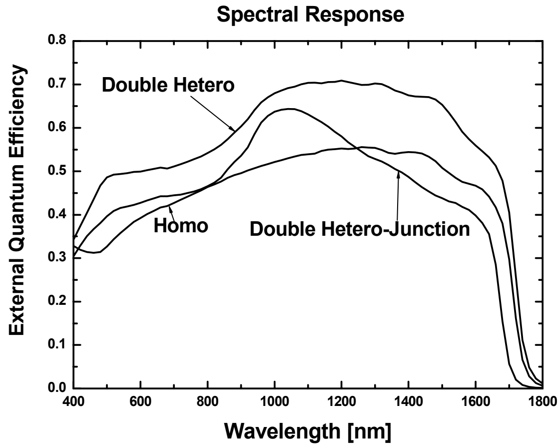

Fig. 3 Spectral response of the three kinds of the cell structures.

4. Conclusion

From the above results and discussion, we can conclude that the double hetero-junction structure increase the open circuit voltage and also increase the efficiency of the solar cells

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