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Built-in Electric Field Study and Optical Properties of GaInP p-i-n Solar Cells

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1. Introduction

Solar cell devices, which convert solar energy directly into electricity, play an important role for renewable energies. In recent years, tandem structure solar cells such as GaInP/GaInAs/Ge [1][2] triple junction cell have attracted increasing attention for their very high conversion efficiencies. Tandem structure multijunctions are stacked by multiple subcells with different band gaps to absorb and convert the sun light in different spectral range. A strong built-in electric field is needed to separate the electrons and holes and deliver them into an electrical circuit. Although it plays a critical role in solar cell devices, but no detailed study has been reported. We grew a series of GaInP p-i-n solar cells by metal-organic chemical vapor deposition (MOCVD) system. The main structure is presented in Fig. 1. (a) On the top of n-GaAs substrate, a n-GaAs buffer layer and a n-AlGaInP back surface field (BSF) layer were grown, then the main GaInP p-i-n structure and a p-AlGaInP window layer were followed. This series samples base on the main solar cell structure with different intrinsic layer thickness of 0.25, 0.5, 0.75 and 1 μm, which are designated as samples A, B, C and D, respectively. This series samples were designed to find the optimized thickness of intrinsic layer and to study the built-in electric field strength in the intrinsic region. We have performed photoluminescence (PL) measurements to detect the energy band gap of GaInP layers and photocurrent (PC) spectra to understand the absorption behavior of these devices. External quantum efficiency (EQE) is one of the important parameters to evaluate the performance of solar cells, we show the results in this article as well. It is well known that the built-in electric field in the depletion region for pn structure or in the intrinsic region for p-i-n structure is the engine to drive out the electrons and holes stimulated by light illumination and generate electric power. Because the built-in electric field is located at the pn junction or intrinsic layer embedded in the device, it is hard to detect by electric method. We employed electroreflectance (ER) spectroscopy to measure the period of Franz-Keldysh oscillations (FKOs) and reveal the built-in electric field strength. From the ER spectra, we find the built-in electric field strength decreases with increasing the thickness of intrinsic layer. A bias voltage is applied on the solar cells to change the built-in electric field. The results can tell us the effective intrinsic layer thickness. A key strength of built-in electric field is necessary to extract the photo-generated electrons and holes for generating electric power. Current-voltage (I-V) relation is a popular and powerful tool to study the optoelectric characteristics such as short circuit current, open circuit voltage, series resistance, filling factor and efficiency. Comparing the information taken by different techniques, a clear picture of the built-in electric field and an optimized intrinsic layer thickness in InGaP p-i-n solar cells are presented.

2. Results and discussion

The PL spectra of samples A, B, C, and D with peaks at 1.9 eV are shown in Fig. 1. (b) The PL signals come from the i-GaInP layer. The PL amplitude increases as the i-layer thickness is increased from 0.25 to 0.75 μm, while the PL signal of sample D is weak. This result reflects that the crystal quality could be degraded due to the large i-layer thickness.

Fig. 2. (a) shows the PC spectra of these four samples. Form this figure, we can see that the photo-induced current starts at 1.9 eV and has same attitude as we just mentioned above. Sample C with 0.75 μm-thick i-layer provides maximum photocurrent. We also measure the spectral power and calculate the external quantum efficiency. The maximum efficiency of sample C (without anti-reflection coatings) is 55 %.

In Fig. 2. (b) we present the ER spectra and calculate the built-in electric field strength (F) from FKO periods.[3] The ER lineshape is given approximately by :

$$\frac{\Delta R}{R} \propto \exp\left(\frac{-\Gamma(E-Eg)^{1/2}}{(\hbar\Omega)^{3/2}}\right)\cos\left(\frac{2}{3}\left[\frac{E-Eg}{\hbar\Omega}\right]^{3/2}+\theta\right)$$

Where E is photon energy, Γ a damping parameter and θ is a phase factor. The cosine term has extrema at energies Ej given by :

$$[Ej-Eg]^{3/2} = \frac{3}{2}[\hbar\Omega]^{3/2}(j\pi-\theta) \quad j=0,1,2,3,.....,$$

The carriers have a resulting electro-optic energy :

$$\hbar\Omega = \left(\frac{\ell^2\hbar^2F^2}{8\mu}\right)^{1/3}$$

where ℓ is the electronic charge, $\hbar$ the Planck constant and μ is the interband reduced effective mass in the field direction. The built-in electric field strength are determined to be 90 , 49, 32 and 31 kV/cm for samples A, B, C and D, respectively. Furthermore, we have performed the ER measurements at various reversed biases to determine the change of built-in electric field. The results are shown in Fig. 3. (a) Because the voltage will mainly be applied on the i-GaInP layer, so the theoretical value of the change rate of built-in electric field can be estimated using the applied voltage divide by the thickness of i-GaInP layer. The theoretical and experimental values are listed in Table I.[4] It can be found that the experimental values match well to the theoretical values as the thickness of i-GaInP layer is smaller than 0.75 μ m. For sample D, the crystal quality of the thick i-GaInP layer has been degraded due to the increase of point defects.

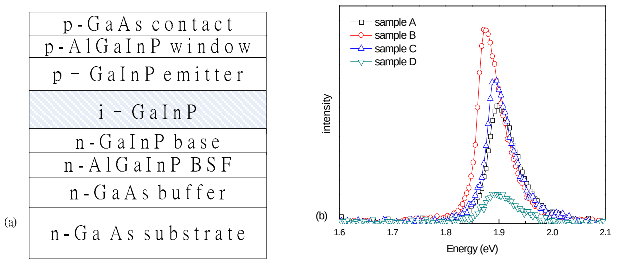

Fig.1 (a) GaInP solar cell structure and (b) Photoluminescence spectra of GaInP solar cell at room temperature

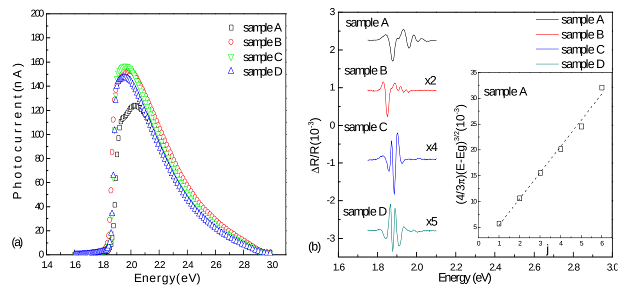

Fig. 2. (a) Photocurrent spectra of sample A, B, C and D at room temperature and (b) Electroreflectance spectra of samples at room temperature and Fit curve of ER of sample A

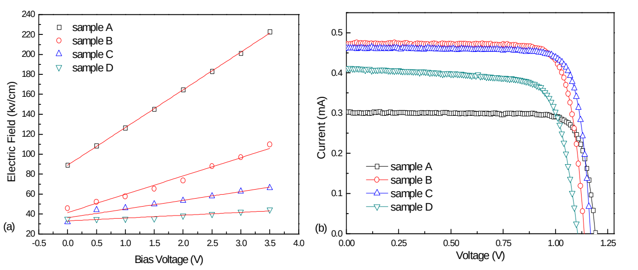

Fig. 3 (a) Electric Field strength with different bias voltage and (b) I-V curves of samples under one sun intensity

Table I Increasing rate of built-in electric field strength of samples A, B, C and D

	Electric Field(kv/cm)			
	A	B	C	D
Theoretical Value	40	20	13.3	10
Experiment Value	37.85	18.35	8.77	2.85

Fig. 3. (b) shows the I-V characteristics of samples A to D at one sun illumination.[5] The important device parameters are listed in Table II.

Table II Solar cell efficiencies of samples A, B, C and D

	A	B	C	D
V_{oc}(V)	1.19	1.14	1.17	1.11
I_{sc}(mA)	0.36	0.36	0.36	0.36
V_{max}(V)	1.02	0.98	1.03	0.93
I_{max}(mA)	0.29	0.44	0.43	0.36
P_{max}(mW)	0.30	0.43	0.44	0.34
FF(%)	82.02	80.66	81.53	74.06
η(%)	3.28	4.82	4.88	3.76
R_{sh}(KΩ)	147.0	137.1	107.0	82.2
R_s(Ω)	123.46	126.90	128.53	246.31

3. Conclusions

We have presented the study of built-in electric field and their optical properties on a series of GaInP p-i-n solar cells with different intrinsic layer thickness. The optimized intrinsic layer thickness is around 0.75 μ m. Below this value, solar cells could not absorb all of sun light, hence the short circuit current and output power will be low. Beyond this thickness, a lot of point defects are generated and the built-in electric field is not high enough to drive out all of photo-induced current. Using ER spectroscopy, the built-in electric filed strengths are determined precisely and their increasing rate can be used to reveal the intrinsic layer quality.

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