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Optical Characterization of GaInP p-i-n Solar Cells

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Abstract

Three p-i-n GaInP solar cells were grown by metal organic chemical vapor deposition (MOCVD) with different intrinsic layer thicknesses. These samples were designed to find the optimized thickness of intrinsic layer and study the built-in electric field strength in the intrinsic region. The built-in electric field strength was studied by electroreflectance (ER) measurement. The photoluminescence (PL) spectra and photocurrent (PC) spectra under various bias voltages were performed to study the effect of built in electric fields on the collection of photogenerated carriers. The current distribution of solar cell under different bias voltages was presented by light beam induced current (LBIC) mapping.

1. Introduction

Solar cells with a typical p-n or p-i-n structure can convert sunlight into electric power effectively. In recent years, the tandem structures such as three-junction structure have been developed for high efficiency solar cells. These were stacked by multiple sub cells with different band gaps to absorb the sun light in different spectral ranges and convert them into electric power. In the process of converting sunlight into electric power, there are two steps for the collection of carriers induced by solar light. The first step is the separation of the electron-hole pairs by the built-in electric field. The second step is the collection of the separated carriers by grids on the top surface and the metal on the bottom pad. To optimize the efficiency of solar cells, the built-in electric fields which control the separation of photo generated carriers are important. [1] In this paper we present a method of ER to determine the built-in electric field with different bias voltages in GaInP solar cells. The PL and PC spectra under various bias voltages were used to show the effect of built in electric fields on solar cells. [2][3] In addition, the LBIC mappings present the current distribution on solar cell at different bias voltages. [4] The effect of built-in electric fields on the collection of carrier and efficiency was discussed.

2. Experiments

Three p-i-n GaInP solar cells were grown by metaloganic chemical vapor deposition (MOCVD) with different intrinsic (i) layer thickness. On the top of the n-GaAs substrate, the first grown layer is a n-GaAs buffer layer, followed by a n-AlGaInP back surface field layer(0.1 μm), n-GaInP base (0.3μm), an i-GaInP layer, a p-GaInP emitter layer (0.1μm), a AlGaInP window layer (0.03μm) and a p-GaAs contact layer (0.3 μm). The thicknesses of i-layers for the three samples are 0.25, 0.75, and 1 μm, respectively, which are designated as samples A, B, and C.

In the ER measurement, a 130 W halogen lamp was equipped with a PTI monochromator for providing the monochromatic light that was chopped by a mechanical chopper at a frequency of 200 Hz. A lock-in amplifier and a Si detector were used to detect the reflective light from the sample surface and to analyze the signal coming from Si detector.

A solid-state-diode-pumped (SSDP) laser with wavelength of 532 nm was used as exciting source for the PL measurements. And the Avaspec-2048 spectrometer was used to detect the PL spectra under various bias voltages. In the photocurrent measurements, a 100W halogen lamp was equipped with a PTI monochromator to provide the monochromatic light, and the photocurrents of solar cells were measured by a Keithley 6485 picoamperemeter.

The LBIC system uses a SSDP laser with wavelength of 532 nm which was focused by a 20X objective as exciting source. And the spot size was about 60 to 100 μm in the full width at half maximum (FWHM). The sample was mounted on a z-axis stage which was fixed on a xy-stage. We can adjust the z-axis stage to a right position to get an optimized focus point on the sample surface.

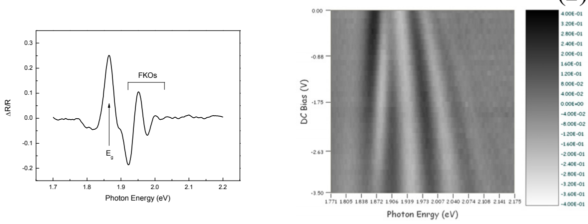
3. Results

In order to understand the effect of built-in electric field in solar cell under various bias voltages, Fig. 1(a) shows the ER spectra of sample A at 0 V. The band gap feature appears at 1.88 eV. And the Fig. 1(b) presents the electroreflectance bias-wavelength (ERBW) mapping from 0 to -3.5 V. It is obvious that the periods of Franz-Keldysh oscillations (FKOs) increased with increasing bias voltage. This result indicates an increasing value of built-in electric field F.

The ER spectra were fitted by eq. (1) and eq. (2) to extract the built-in electric fields.

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

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



(a) (b)

Fig. 1 ER spectra of sample A GaInP solar cell (a) at 0V (b) ERBW mapping

Fig. 2 show the built-in electric fields of the three investigated GaInP solar cells with various reverse bias voltages. As the reverse bias voltage increased, a corresponding increase in the electric field strength has been observed. This effect makes the extraction of photogenerated carriers become easier. Sample A has the smallest i-layer thickness, so that the increasing rate of built-in electric field is the most obvious one.

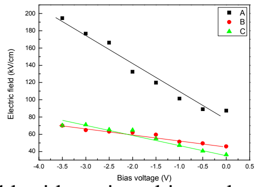
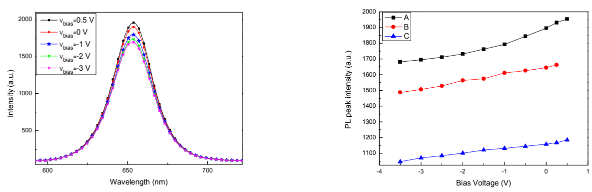


Fig. 2 Electric field with various bias voltages for samples A, B and C

Fig. 3(a) shows that the PL spectra of sample A Fig. 3(b) presents the PL peak intensity of sample A, which indicates a decreasing trend as the reverse bias voltage is increased from 0.0 to -3.5 V. This is because the built-in electric field in the i-layer region is increased by the reverse bias, which makes an easier extraction of the photogenerated carriers and a weaken electron-hole recombination

The PC spectra with different reverse bias voltages are shown in Fig. 4, the results show an opposite effect comparing to the PL spectra. The increasing built-in electric field helps the collection of photogenerated carriers and increases the PC intensity.



(a) (b)

Fig. 3 (a) PL spectra of sample A at different bias voltages (b) PL peak intensity at different bias voltages.

The result of LBIC mappings are shown in Fig.5. The blue color areas indicate a low current area where the laser is focused out of sample or on the metal grids. It is found that the photocurrent intensity at zero bias is higher than that at a forward bias of 0.5 V. This effect indicated that the forward bias reduced the electric field and caused the carrier extraction more difficult. In addition, we have measured the efficiency of GaInP solar cells by using a solar simulator under an AM 1.5 spectrum, the result is listed in Table I. We found that the sample A, which has the largest built-in electric field, has higher efficiency than others.

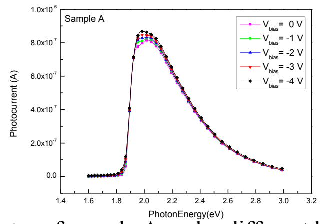
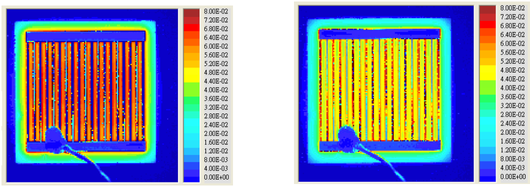


Fig. 4 PC spectra of sample A under different bias voltages



(a) V= 0V (b) V= 0.5V

Fig. 5 LBIC mapping of sample A with different bias voltage

Table I Efficiency of samples A, B, and C

Sample	A	B	C
Voc (V)	1.225	1.062	0.908
Isc (mA)	0.611	0.624	0.549
FF (%)	78.7	77.2	64.86
Efficiency η (%)	6.28	5.64	4.29

4. Conclusions

We investigated the ER spectra in GaInP solar cells under different bias voltages, and found that the built-in electric field is an import parameter for the efficiency of solar cells. The PL and PC spectra have obvious change under different values of electric field. The results provide evidences that higher built-in electric field is helpful for the collection of photogenerated carriers in the i-layer region.

ERBW and LBIC mappings are convenient and useful tools for studying the solar cell performance and defects.

Acknowledgements

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