Optics Communications 417 (2018) 37–41

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

# Laser induced non-monotonic degradation in short-circuit current of triple-junction solar cells

Dou Peng-Cheng *, Feng Guo-Bin, Zhang Jian-Min, Song Ming-Ying, Zhang Zhen, Li Yun-Peng, Shi Yu-Bin

*State Key Laboratory of Laser Interaction with Matter, Northwest Institute of Nuclear Technology, Xi'an 710024, Shaanxi, China*

A R T I C L E I N F O

*OCIS:*
140.0140
140.3390

*Keywords:*
Laser radiation effects
Continuous wave laser
Triple-junction solar cells
Damage mechanism

A B S T R A C T

In order to study the continuous wave (CW) laser radiation effects and mechanism of GaInP/GaAs/Ge triple-junction solar cells (TJSCs), 1-on-1 mode irradiation experiments were carried out. It was found that the post-irradiation short circuit current ($I_{SC}$) of the TJSCs initially decreased and then increased with increasing of irradiation laser power intensity. To explain this phenomenon, a theoretical model had been established and then verified by post-damage tests and equivalent circuit simulations. Conclusion was drawn that laser induced alterations in the surface reflection and shunt resistance were the main causes for the observed non-monotonic decrease in the $I_{SC}$ of the TJSCs.

## 1. Introduction

Lasers are used commonly in the solar cell industry for both characterization [1,2] and fabrication. To date, of the use of lasers in solar cell fabrication have included laser doping [3], annealing [4], patterning [5], drilling [6] and welding [7]. Meantime, side effects of the temperature elevating near adjacency caused by heat transfer during laser processing have also been studied [8,9]. Over-heating can induce defects in *pn* junctions, which affect the lifetime of minority carriers and consequently reduces the performance of solar cells [10]. Therefore, it is essential to understand the degradation processes within solar cells that are induced by temperature elevation, so as to evaluate the influence of laser processing on solar cells.

In this research, GaInP/GaAs/Ge solar cells were irradiated with a CW laser (808 nm) for 60 s. The laser power intensity was varied in order to investigate the degradation of $I$–$V$ characteristics, and the degradation mechanism was studied using theoretical calculations, post-event analysis and equivalent circuit model simulations.

## 2. Experimental

In this research, we took the form of initially obtaining a response of the TJSC through acquisition of its $I$–$V$ characteristics. Subsequently, the device was subject to a CW laser insult of 808 nm. After which, the device was again investigated as to its $I$–$V$ behavior and further examined in both surface reflectance spectrum and quantum efficiency. To more specifically describe this process, the following outlines the investigated device, the irradiation experiment, and the post-damage failure techniques that were utilized.

### 2.1. GaInP/GaAs/Ge solar cell

Commercially available GaInP/GaAs/Ge solar cells served as the base device for the investigation, as shown schematically in Fig. 1. The devices consisted of monolithic stacks with three *n*-on-*p* type mono-junction sub-cells that had increasing band gaps from the bottom of the stack to the top. Each of the two sub-cells were connected via a tunnel junction. Solar cells with this structure minimize thermal loss when irradiated with sunlight and thus exhibit enhanced photoelectric efficiency. Normally, GaInP/GaAs/Ge solar cells are grown in a metal organic chemical vapor deposition (MOCVD) reactor using trimethylgallium (TMG), trimethylindium (TMI), arsine, and phosphine in a Pd-purified $H_2$ carrier gas [11].

Based on the structure described above, the output current ($I_{out}$) and voltage ($V_{out}$) of a TJSC can be formulated as follows

$$I_{out} = I_{top}(V_{top}) = I_{middle}(V_{middle}) = I_{bottom}(V_{bottom}) \tag{1}$$

$$V_{out} = V_{top} + V_{middle} + V_{bottom}. \tag{2}$$

Eqs. (1)~(2) show that the $I_{out}$ and $V_{out}$ of a TJSC are determined by all sub-cells together. Therefore, decoupling the sub-cells is a key step when analyzing the damage mechanism.

* Corresponding author.
*E-mail address:* doupengcheng@nint.ac.cn (P.-C. Dou).

https://doi.org/10.1016/j.optcom.2018.02.015
Received 28 November 2017; Received in revised form 24 January 2018; Accepted 5 February 2018

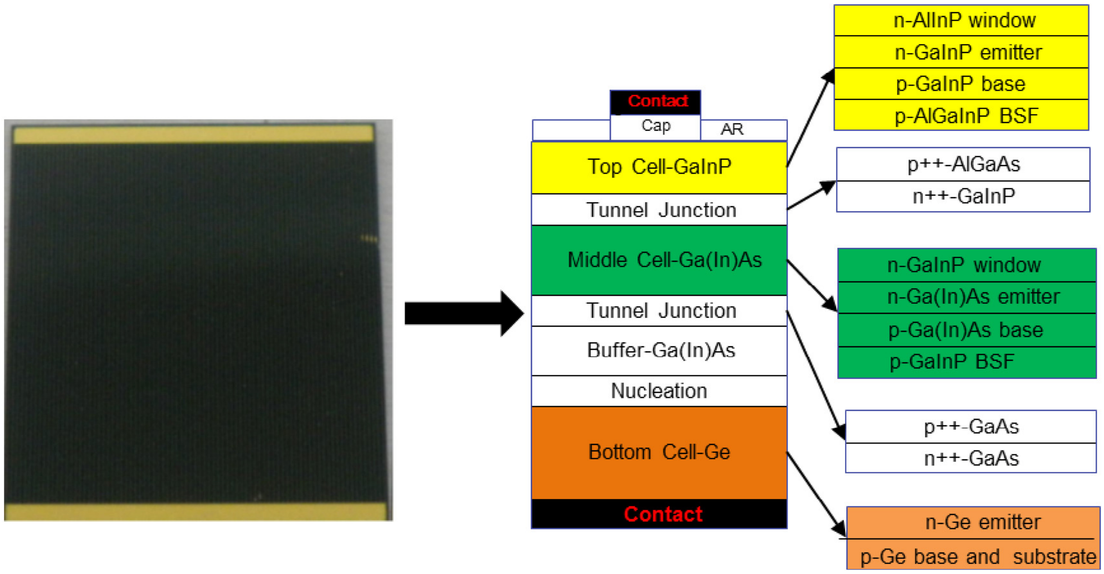


**Fig. 1.** Plane-view and cross section schematic of GaInP/GaAs/Ge solar cells.

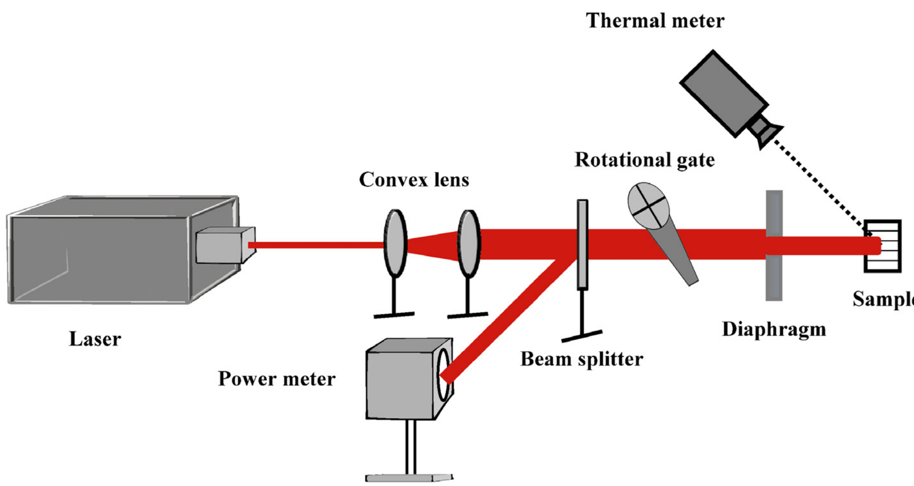


**Fig. 2.** Schematic of laser irradiation experiment.

### 2.2. Irradiation experiment

The laser irradiation (808 nm) initially had a beam diameter of 2 mm, which was then expanded by two convex lenses. Subsequently, a small fraction of the laser power was reflected by a beam splitter and detected using a power meter for an online power monitor. The remaining power was shaped by a rectangular diaphragm (8 mm × 9 mm) before irradiating the solar cell. The exposure time to the laser was set as 60 s by a signal generator-controlled chopper. The experimental arrangement is illustrated schematically in Fig. 2.

### 2.3. Post-damage analysis

Identification of the damage mechanisms requires an investigation into how the device changes and the physical mechanism driving these alterations. For this purpose, 3 different measurements were applied to the device after the laser event: (1) the $I$–$V$ characteristics of the device were measured using a digital source meter, under conditions of *AM0* spectral irradiation, to determine any alterations in device performance. (2) Changes in the reflectance spectrum ($R$) of the device from 300 nm to 1800 nm were examined using a spectrophotometer and (3) the internal quantum efficiency (IQE) of each sub-cell was measured. A proper bias voltage was required to avoid artifacts when measuring the sub-cell IQE [12].

## 3. Results and discussion

### 3.1. Alteration in performance

The changes observed in the $I$–$V$ characteristics and parameters were different at different laser power intensities, as shown in Fig. 3. Samples 1 to 3 correspond to three levels of laser illumination intensity. Sample 1 (laser power intensity = 9 W/cm$^2$) exhibited slight changes in its $I$–$V$ characteristics when compared with the sample that was not irradiated (green line, Fig. 3(a)). This sample exhibited a slight decrease in both open circuit voltage ($V_{oc}$) and fill factor ($FF$). Sample 2 (laser power intensity = 10.4 W/cm$^2$) exhibited significant degradation in its $I$–$V$ characteristics (red line, Fig. 3(a)), with both the $I_{sc}$ and $V_{oc}$ being reduced by 20%, which led to a 50% decrease in its maximum output power ($P_{max}$). Interestingly, when the laser power intensity was increased to 11.8 W/cm$^2$ (sample 3) the $I_{SC}$ increased from 5.3 mA to 8 mA, which compensated for the observed decrease in its $V_{OC}$. This resulted in a $P_{max}$ that was identical to sample 2. The corresponding temperatures that the different devices were subjected to at the different laser power intensities are shown in Fig. 3(c).