Results in Physics 8 (2018) 257–261

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

Effect of the depth base along the vertical on the electrical parameters of a vertical parallel silicon solar cell in open and short circuit

Gokhan Sahin *, Genber Kerimli

Electric and Electronic Engineering Department, IĞDIR University, Iğdır 76000, Turkey

ARTICLE INFO

Article history:
Received 27 July 2017
Received in revised form 18 September 2017
Accepted 10 December 2017
Available online 14 December 2017

Keywords:
Depth base
Conversion efficiency
Electrical parameters
Open circuit
Short circuit

ABSTRACT

This article presented a modeling study of effect of the depth base initiating on vertical parallel silicon solar cell's photovoltaic conversion efficiency. After the resolution of the continuity equation of excess minority carriers, we calculated the electrical parameters such as the photocurrent density, the photovoltage, series resistance and shunt resistances, diffusion capacitance, electric power, fill factor and the photovoltaic conversion efficiency. We determined the maximum electric power, the operating point of the solar cell and photovoltaic conversion efficiency according to the depth z in the base. We showed that the photocurrent density decreases with the depth z. The photovoltage decreased when the depth base increases. Series and shunt resistances were deduced from electrical model and were influenced and the applied the depth base. The capacity decreased with the depth z of the base. We had studied the influence of the variation of the depth z on the electrical parameters in the base.

Introduction

Solar cell is the device that allows the direct conversion of sunlight to electricity. This conversion process is based on excess minority carrier's collection leading to a current flow but this carriers collection is perturbed by recombination phenomena. That is why many studies [1–6] have been made on solar cells to improve the conversion efficiency. Photovoltaic (PV) systems generate green energy with no pollution and have a long life time. In the past, the energy photovoltaic conversion efficiency of PV modules was 10%–14% [7]. Recently, efficiency has been increased to 15%–22% in commercially available PV modules and a research laboratory reported that the efficiency of solar cells is up to 44.7% [8].

The purpose of this article is to do a study on a parallel vertical junction silicon solar cell under multispectral illumination in static regime [9]. A theoretical study of the excess minority carriers in the base of the solar cell is produced through continuity equation. With help of the boundary conditions at the junction and at the middle of the base, excess minority carriers density are studied and lead to the expression of photocurrent density and photovoltage. From, the well-known I-V characteristic of the solar cell under illumination, electrical equivalent model is established for low and high junction recombination values giving respectively ideal generator source of tension and current. The present work can be allowing a measurement of the parasitic resistances (series and shunt resistance) and effect of the depth base on the electrical parameters of a parallel vertical junction solar cell under polychromatic illumination [10].

The aims of this article we studied modeling of the influence of the depth z on the vertical parallel silicon solar cell's photovoltaic conversion efficiency. From the diffusion-recombination equation the excess minority carrier's density, the photocurrent density and the photovoltage will be determined. In the last part of this work we calculated the solar cell photovoltaic conversion efficiency and our simulation results.

Theory

For these types of solar cells, the bases are connected to each other and the emitters to each other. Each base is framed by two junctions as well as the transmitters. The solar rays fall on the cell parallel to the junction. We present on Fig. 1 a unit cell of a vertical junction's silicon solar cell under various wavelengths. H is the base width, θ is the illumination incidence angle and x is the depth in the base [11,12].

To understand the functioning of such a structure, we will extract from this network an elementary cell or basic cell which we present in Fig. 2.

The contribution of the base to the photocurrent is larger than that of the emitter [13] and our analysis will only be developed in the base region. Taking into account the generation, recombina-

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* Corresponding author.
E-mail address: gokhan.sahin@igdir.edu.tr (G. Sahin).

https://doi.org/10.1016/j.rinp.2017.12.021
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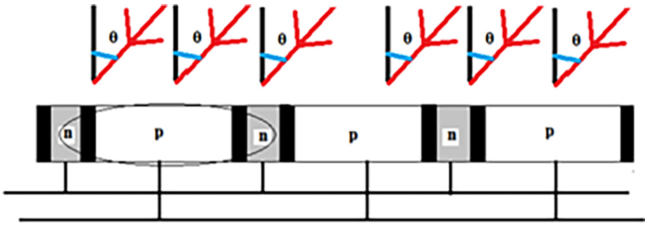

Fig. 1. Vertical parallel junction silicon solar cell.

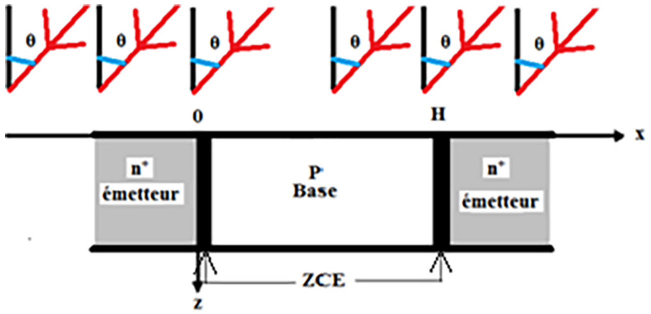

Fig. 2. Diagram of solar cell in parallel vertical junction in the base.

tion and diffusion phenomena in the base, the equation governing the variation of the minority carriers density δ(x,y,z,t) under modulation frequency is:

$$D(\omega)\cdot\frac{\partial^2\delta(x,\theta,z,t)}{\partial x^2}-\frac{\delta(x,\theta,z,t)}{\tau}=-G(z,\theta,t)+\frac{\partial\delta(x,\theta,z,t)}{\partial t} \qquad (1)$$

D(ω) [14] and τ are respectively, the excess minority carrier diffusion constant and lifetime.

The excess minority carriers' density can be written as:

$$\delta(x,t)=\delta(x)\exp(-j\omega t) \qquad (2)$$

Carrier generation rate G (z, θ, t) is given by:

$$G(z,\theta,\lambda,t)=g(z,\theta,\lambda)\times\exp(-j\omega t) \qquad (3)$$

where

$$g(z,\theta,\lambda)=\alpha(\lambda)(1-R(\lambda))\times\phi(\lambda)\times\exp(-\alpha(\lambda)\times z)\times\cos(\theta) \qquad (4)$$

ω is the angular frequency, θ is the incidence angle, z the base depth according to the vertical axis; Sf is the junction recombination velocity and λ the illumination wavelength.

If we replace Eq. (2) into Eq. (1), the temporary part is eliminated and we obtain:

$$\frac{\partial^2\delta(x)}{\partial x^2}-\frac{\delta(x,\theta,z,t)}{L(\omega)^2}=-\frac{g(z,\theta)}{D(\omega)} \qquad (5)$$

The solution of this equation is:

$$\delta(x,\omega,\theta,z,Sf,\lambda)=A\cosh\left(\frac{x}{L(\omega)}\right)+B\sinh\left(\frac{x}{L(\omega)}\right)+\frac{L(\omega)^2}{D(\omega)}\cdot\alpha(\lambda)(1-R(\lambda))\cdot\phi(\lambda)\cdot\exp(\alpha(\lambda)\cdot z)\cdot\cos(\theta) \qquad (6)$$

Coefficients A and B are determined through the following boundary conditions [15]:

- at the junction (x = 0):

$$D(\omega)\cdot\left.\frac{\partial\delta(x,\omega,\theta,z)}{\partial x}\right|_{x=0}=Sf\cdot\delta(x,\omega,\theta,z)|_{x=0} \qquad (7)$$

Sf is the excess minority carrier's recombination velocity at each junction [16].

- at the middle of the base (x = H/2):

$$D(\omega)\cdot\left.\frac{\partial\delta(x,\omega,\theta,z)}{\partial x}\right|_{x=\frac{H}{2}}=0 \qquad (8)$$

Results and discussion

The excess minority carriers density

In this section, we will study the density of minority carriers generated in the base. It will show the effect of, vertical depth, on the profile of the density of the load carriers as a function of the depth in the base. Fig. 3 represents the variation of the minority carriers density in the base versus thickness x for various depth z.

On Fig. 3, the excess minority carriers density in the base increases to reach a maximum corresponding to the thickness x_o in the base, but it decreases for a depth (z) $x > x_o$. It also decreases in amplitude as a function of the depth according to the vertical of the illumination. From this remark, we distinguish three zones:

- a first zone $0 \le x \le x_o$; the gradient of the excess minority carriers' density in the base of the photovoltaic cell is positive: this corresponds to the passage of an electron flux causing a photocurrent through the emitter-base junction,
- a second zone: $x = x_o$; The modulus of the excess minority carrier's density in the base is maximal and the gradient is zero, so there is a storage of excess minority carrier's density negative charges which will create a variation of the space charge area which extends from the junction to the value x_o,
- a third zone: $x_o \le x \le H$; The modulus of excess minority carrier's density decreases in the base, thus implying a negative gradient.

We note that as one enters the base z, the density of the minority carrier's decreases. Indeed, the variation of the density of the minority carrier's according to depth (z), is governed by the rate of generation which follows a Beer Lambert law: an exponential decay as one penetrates inwards. This situation predicts the capacitive phenomena evolution.

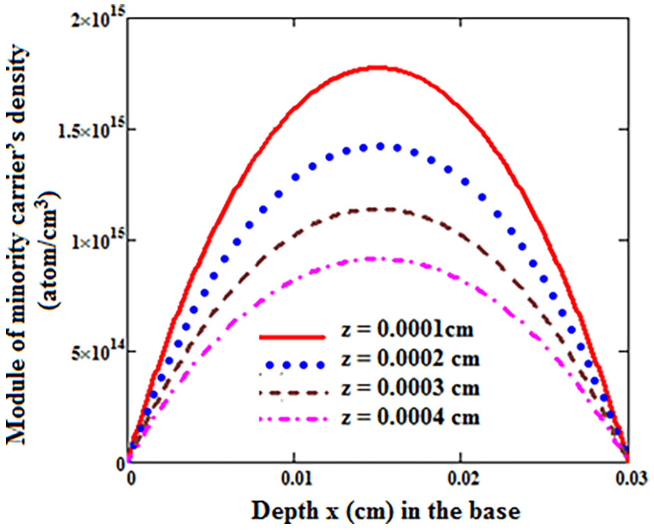

Fig. 3. Module of minority carrier's density versus thickness x in the base for various depth z, Sf = 3.10^3 cm/s. H = 0.03 cm; L_o = 0.02 cm, D_o = 26 cm^2/s, θ = 20^0, λ = 0.52 μm, ω = 10^3 rad/s.