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Research Article

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Static Mode Study of the Magnetic Field Effect on Shunt Resistance of a Parallel Vertical Junction Silicon Solar Cell under Monochromatic Illumination and under Irradiation

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Abstract In this paper, we made a theoretical study of a parallel vertical junction solar cell under monochromatic illumination, in static mode, under irradiation and under magnetic field.

The resolution of the continuity equation that governs the generation, the recombination's and the process of diffusion of the electrons in the base, helped us to establish the expression of the electrons density in the base and deduce expressions of the photocurrent density and the phototension depending on the wavelength λ, the recombination velocity at the junction Sf, the magnetic field and the irradiation parameters.

The expression of Shunt resistance has been established from those of phototension and photocurrent density

We studied the influence of a magnetic field on the density of the minority carriers density in the base, the diffusion length and finally on the Shunt resistance.

Keywords silicon solar cell, vertical junction, magnetic field, irradiation, Shunt resistance

1. Introduction

We will perform, through this paper a theoretical study of a parallel vertical junction solar cell under monochromatic illumination, in static mode, under irradiation and under magnetic field.

The resolution of the continuity equation will enable us to establish the expression of the minority density charge carriers in the base and to deduce those of the photocurrent density and the phototension.

The expression of the Shunt resistance will be subsequently obtained.

We will study, in this article, the influence of the variation of an applied magnetic field on the density of the minority carriers in the base, the diffusion length of these carriers and finally on the Shunt resistance.

2. Theory

We consider a solar cell type of parallel vertical junction n + -p-p whose structure may be represented as follows:

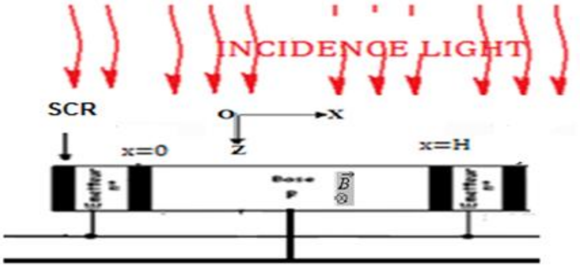

Figure 1: parallel vertical junctions of a solar cell

When the solar cell is illuminated, there is creation of electron-hole pairs in the base.

The behavior of the minority carriers in the base (the electrons) is governed by the continuity equation integrating the generation, diffusion and recombination phenomena which cause the variation of the electrons density according to the width x of the base, its depth z , the recombination velocity at the junction, of the wavelength, applied magnetic field and irradiation parameters.

Solving this equation will allow us subsequently to have initially expressed the minority carrier density of the base and deduce those of the quantities and other solar cell electrical parameters.

The continuity equation in static mode is presented under the form:

$$D(B)\cdot\frac{\partial^2\delta(x,kl,\phi,\lambda,z,B)}{\partial x^2}-\frac{\delta(x,kl,\phi,\lambda,z,B)}{\tau(kl,\phi)}=-G(z,\lambda) \tag{1}$$

$\delta(x,kl,\phi,\lambda,z,B))$ describes the photogenerated minority charge carriers.

$D(B)=\dfrac{D_o}{\sqrt{1+(\mu B)^2}}$ [1] is the diffusion coefficient according to the magnetic field. B, the magnetic field, D_o, the diffusion coefficient with the absence of magnetic field, μ denotes the mobility of the charge carriers. τ(kl, φ) is the average lifetime of carriers.

We have the relationship: $\dfrac{1}{\tau(kl,\phi)}=\dfrac{1}{\tau_0}+kl\phi$ [2]

(H. W. Kraner et al, 1983), k1 and φ respectively denote the damage coefficient and the irradiation energy. τ_o is the average lifetime of carriers with the absence of irradiation.

G (z, λ) is the overall generation rate of the minority charge carriers according to the depth z of the base and wavelength λ.

The continuity equation can still be written as follows:

$$\frac{\partial^2\delta(x,kl,\phi,\lambda,z,B))}{\partial x^2}-\frac{\delta(x,kl,\phi,\lambda,z,B))}{L(kl,\phi)^2}+\frac{G(z,\lambda)}{D(B)}=0 \tag{2}$$

$$L(kl,\phi,B)=\sqrt{D(B)\times\tau(kl,\phi)} \tag{3}$$

is the diffusion length.

The expression of the overall generation rate of the minority charge carriers is of the form[3]:

$$G(z,\lambda)=\alpha_t(1-R(\lambda))\cdot F\cdot\exp(-\alpha_t\cdot z) \tag{4}$$

R (λ) is the coefficient monochromatic reflection; F is the incident photons flux from a monochromatic radiation.

α is the coefficient of monochromatic absorption.

2.1. Solution of the continuity equation

- Special solution:

$$\delta_1(x)=\frac{L^2}{D}\alpha_t(1-R(\lambda)).F.\exp(-\alpha_t.z) \tag{5}$$

-Solution of the equation with second member:

$$\delta_2(x)=A\cosh\left(\frac{x}{L}\right)+B\sinh\left(\frac{x}{L}\right) \tag{6}$$

-As the general solution is:

$$\delta(x,z,\lambda,Sf,kl,\phi,B)=\left[\begin{array}{l}A\cosh\left(\dfrac{x}{L(kl,\phi)}\right)+B\sinh\left(\dfrac{x}{L(kl,\phi)}\right)+\\ \dfrac{L(kl,\phi)^2}{D(B)}\cdot\alpha_t(1-R(\lambda)).F.\exp(-\alpha_t z)\end{array}\right] \tag{7}$$

2.2. - Search for coefficients A and B:

- The boundary conditions:

-As at the junction (x = 0) we have:

$$D \cdot \left. \frac{\partial \delta(x, z, \lambda, kl, \phi, B)}{\partial x} \right|_{x=0} = Sf \cdot \delta(x, z, \lambda, kl, \phi, B)\Big|_{x=0} \tag{8}$$

Sf is the recombination velocity at the junction. This is a phenomenological parameter that describes how the base minority carriers cross the junction. It can be split in two terms[4].

We have: $Sf = Sf_O + Sf_j$

Sf_O induced by shunt resistance, is the intrinsic recombination velocity. It depends solely on the intrinsic parameters of the solar cell.

Sf_j reflects the current flow imposed by an external charge and defines the operating point of the solar cell

-In the middle of the base $(x = \frac{H}{2})$ .The structure of the solar cell, with two identical junctions on both sides of the base, suggests equation **(9)** below:

$$D \cdot \left. \frac{\partial \delta(x, z, \lambda, kl, \phi, B)}{\partial x} \right|_{x=H/2} = 0 \tag{9}$$

H is the thickness of the solar cell's base.

3. Results and Discussion

3.1. Diffusion length profile

Figures 2a, 2b, 2c and 2d show the profile of the diffusion length according to coefficient of damage for different values of the magnetic field

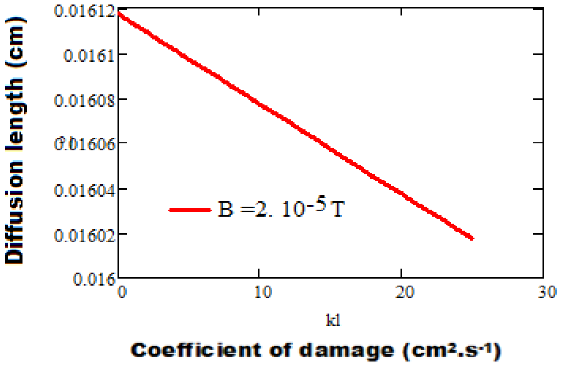

Figure 2a: Diffusion length according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50 Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

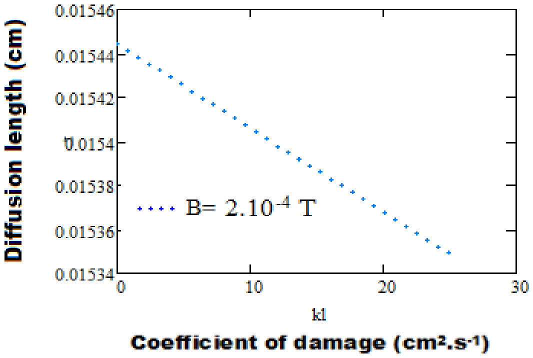

Figure 2b: Diffusion length according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50 Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

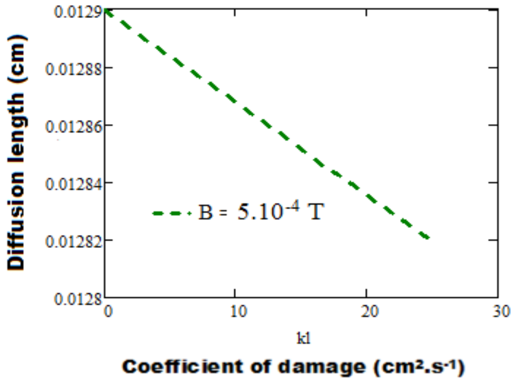

Figure 2c: Diffusion length according to the coefficient of damage

H=0.03 cm, Z =0.0001cm, L_o=0.01cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50Mev, µ = 1000 $cm^2.V^{-1}.s^{-1}$

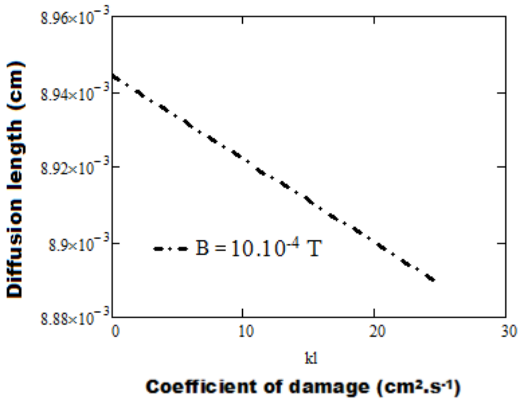

Figure 2d: Diffusion length according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50Mev, µ = 1000 $cm^2.V^{-1}.s^{-1}$

The analysis of the curves shows that the diffusion length decreases according to the coefficient of damage, but also according to the intensity of the applied magnetic field.

The irradiation increases the centers recombination centers, which reduces the average distance covered by the charge carriers before the recombination is done.

The dynamic effect of the Lorentz magnetic force is demonstratedby a deviation in the path of the charge carriers, which results in a decrease in the diffusion length.

3.2. Minority carriers density profile

Figures 3a, 3b, 3c and 3d show the profile of the minority carriers charge density according to coefficient of damage for different values of the magnetic field

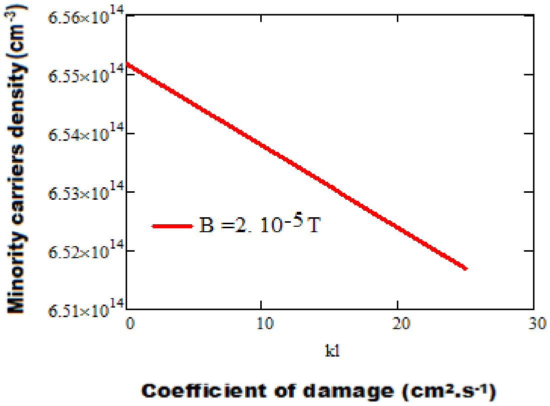

Figure 3a: Minority carriers charge density according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50 Mev, µ = 1000 $cm^2.V^{-1}.s^{-1}$

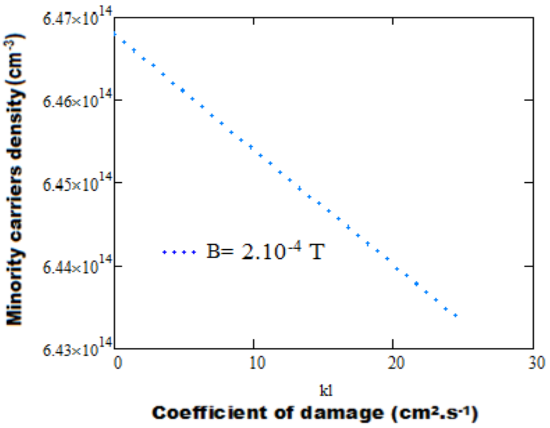

Figure 3b: Minority carriers charge density according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, $\lambda = 0.5$ µm, kl = 10 cm^2/s**,** ϕ=50Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

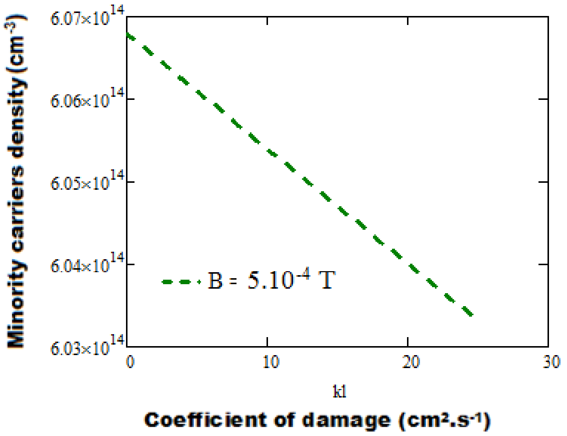

Figure 3c: Minority carriers charge density according to the coefficient of damage

H=0.03cm, Z =0.0001 cm, L_o=0.01 cm, $\lambda = 0.5$ µm, kl = 10 cm^2/s**,** ϕ=50 Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

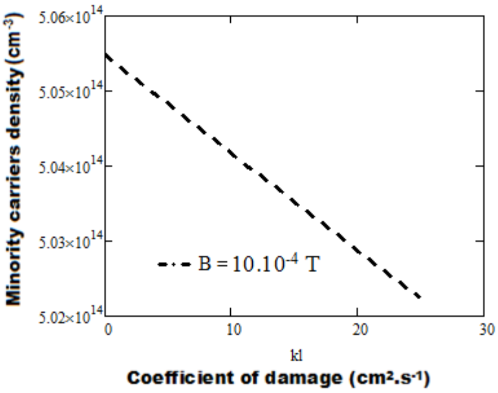

Figure 3c: Minority carriers charge density according to the coefficient of damage

H=0.03cm, Z =0.0001cm, L_o=0.01cm, $\lambda = 0.5$ µm, kl = 10 cm^2/s**,** ϕ=50Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

The analysis of the figures shows that the density of the minority carriers of charges in the base decreases according not only to the damage coefficient, but also to the intensity of the applied magnetic field.

In fact, the irradiation increases the recombination rate, which reduces the density of the minority carriers of charges.

The dynamic effect of the Lorentz magnetic force, which increases with the intensity of the magnetic field, reduces the density at the junction levels.

The more the magnetic field increases, fewer carriers arrive at the junctions.

3.3. Current-voltage characteristic:

Figure 4 below shows the profile of photocurrent density according to the phototension.

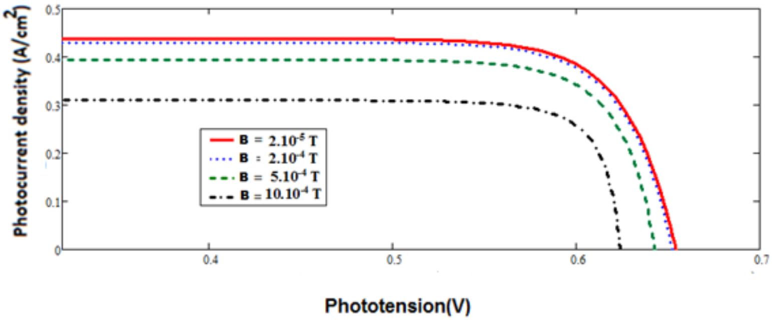

Figure 4: I-V characteristic of the solar cell

The characteristic analysis shows that the phototension is not independent of the photocurrent.

The solar cell operates as a real voltage generator in the vicinity of the open circuit and as a real current generator in the vicinity of the short circuit.

For each mode of operation, an electrical circuit equivalent to the solar cell is proposed.

3.4. Shunt Resistance

Below is the electric model which is equivalent to the solar cell and operating as a real current generator:

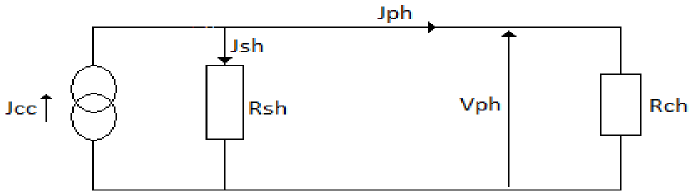

Figure 5: Equivalent circuit of the solar cell (real current generator)

From the study of this electrical circuit, the expression of the shunt resistance is deduced:

$$R_{SH}\left(S_f,\lambda,kl,\phi,z,B\right)=\frac{V_{PH}\left(S_f,\lambda,kl,\phi,z,B\right)}{J_{CC}(\lambda,kl,\phi,z,B)-J_{PH}\left(S_f,\lambda,kl,\phi,z,B\right)} \qquad (10)$$

The volume, surface and interface recombinations (base-emitter, base-contact, and contact-emitter) create the Shunt resistor which models the leakage currents in the solar cell.

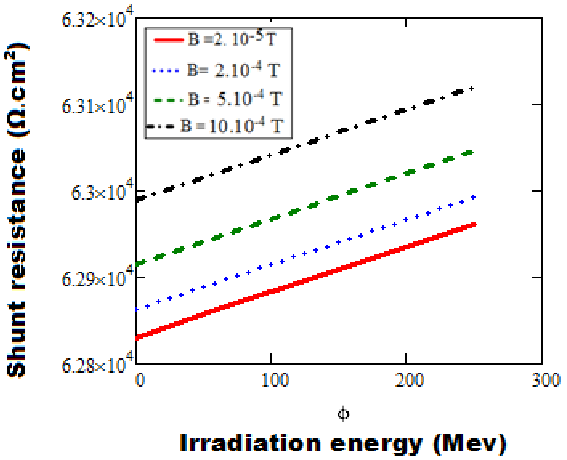

Figure 6: Variation of the Shunt resistance according to the irradiation energy for different values of the magnetic field

H=0.03cm, Z =0.0001cm, L_o=0.01cm, λ = 0, 5 μm, kl = 10 cm^2/s, **ϕ**=50 Mev, μ = 1000 $cm^2.V^{-1}.s^{-1}$

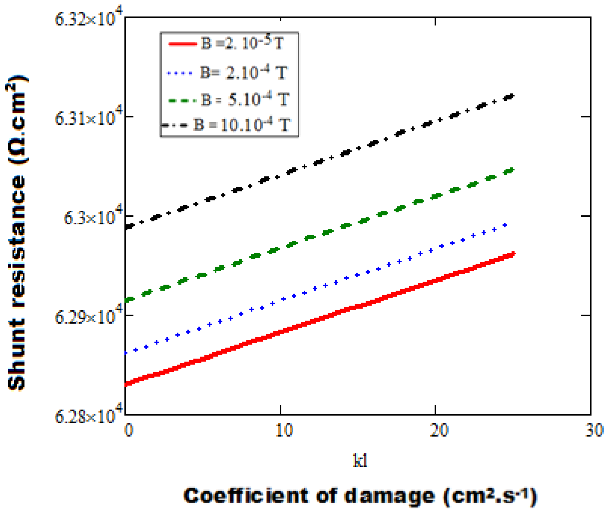

Figure 7: Variation of the Shunt resistance according to the coefficient of damage for different values of the magnetic field

H=0.03 cm, Z =0.0001cm, L_o=0.01 cm, λ = 0.5 µm, kl = 10 cm^2/s, ϕ=50 Mev, µ = 1000 $cm^2.V^{-1}.s^{-1}$

The analysis of the figures 6 and 7 shows that the shunt resistance increases according not only to the magnetic field but also to the irradiation parameters.

Irradiation reduces leakage currents by increasing the rate of recombination

We have the linear relation $R_{SH}(kl,\phi,B)=a.X+R_{SH}(B)$(12)

where X denotes either kl or φ.

$R_{SH}(B)$ is the Shunt resistance to the lack of irradiation. We have recorded in the table below the variations of according to the magnetic field:

Table 1: Variation of the Shunt resistance according to the magnetic field with the absence of irradiation.

B (T)	2.10^{-5}	2.10^{-4}	5.10^{-4}	10.10^{-4}
$R_{SH}(B)$ ($\Omega.cm^2$).10^{14}	6.283	6.285	6.292	6.298

$R_{SH}(B)$ increases according to the magnetic field. The increase in the intensity of the magnetic field causes a growth of the recombinations, which explains the increase of the Shunt resistance.

4. Conclusion

The resolution of the continuity equation helped us to obtain the expression of the density of the electrons in the base, from which we deduced those of the photocurrent density and the phototension.

From the electrical model equivalent to the photocell when operating in the vicinity of the short circuit, we established the expression of the Shunt resistance.

We have studied in this paper the impact of the variation of an applied magnetic field on the density of the minority carriers in the base, on the diffusion length of these carriers and finally on the Shunt resistance.

The study showed the presence of a magnetic field which influences the density of minority carriers in the base.

The dynamic effect of the Lorentz force reduces the spread of the load carriers to the transmitters, which results in a reduction of the density of these carriers at the junction levels.

This effect of the Lorentz force resulting in the phenomena of recombination accentuated by the irradiation explains the increase of the Shunt resistance.

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