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Study of the Diode Current of a Silicon Solar cell in Dynamic Frequency Regime under Monochromatic Illumination in the Presence of the Magnetic Field and the Irradiation Energy

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ABSTRACT: In this work, we studied the influence of the irradiation energy and the magnetic field on the diode current of a solar cell in frequency dynamic regime under monochromatic illumination. After solving the minority charge carrier continuity equation in the presence of irradiation energy and magnetic field, we derive new expressions for the minority charge carrier density and the diode current. Starting from these equations, we have represented the profiles of the latter according to some parameters finally to highlight the effect of the irradiation energy and the magnetic field on the diode current.

KEYWORDS: Silicon Solar Cell; Frequency Modulation; Irradiation Energy; Magnetic Field; Diode Current.

1 INTRODUCTION

A photovoltaic cell or solar cell is a semiconductor optoelectronic device that directly converts sunlight into electrical energy. Indeed, photovoltaic operation is based on the principle of the photoelectric effect: under the effect of light, a semiconductor material can release electrons and create a direct electric current. Among the materials that can achieve this energy conversion, silicon has the best efficiency and wide availability on earth, however, given the low efficiency of these photovoltaic cells, the researchers have invested in various research works by proposing several techniques for characterizing the semi-automatic material. Among the most important parameters in the different characterization techniques, we can cite: the diffusion coefficient [1-2], the global carrier generation rate G [3], the lifetime of the carriers, the length of diffusion of carriers L and recombination speeds (at the Sf junction, on the back face Sb) [4-5]. These characterization techniques are based on the measurement of the optical and electrical effects of the imperfections contained in the solar cell maintained in static mode or in dynamic mode. From theoretical studies, we propose in this article, a method for determining the diode current of a silicon solar cell under monochromatic illumination in frequency dynamic regime, under irradiation and magnetic field.

2 THEORY

The solar cell considered is of the n+pp+ type and its structure is presented in figure 1.

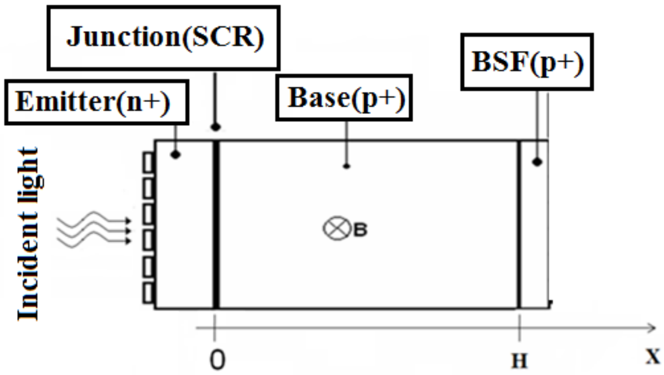

Fig. 1. An n+-p-p+ structure of a silicon solar cell

Under the effect of excitation (optical or electrical), charge carriers are generated in the base of the solar cell. The carriers thus generated can either cross the space charge zone where they participate in the external current, or they undergo surface or volume recombinations. These are due to defects (grain boundaries, uncontrolled impurities, dislocations, etc.) related to the manufacture of the solar cell. Taking into account the phenomena of generation, recombination and diffusion within the solar cell, the continuity equation of the minority charge carriers in the base at the abscissa x in frequency dynamic regime is of the form:

$$\frac{\partial^2\delta(x,t)}{\partial x^2}-\frac{1}{D}\frac{\partial\delta(x,t)}{\partial t}-\frac{\partial\delta(x,t)}{D\tau}=-\frac{G(x,t)}{D} \quad (01)$$

Where is the density of electrons generated in the base at depth x in the base, [6] is the diffusion coefficient, G [7] the overall carrier generation rate and [8] the carrier lifetime. For the resolution of the continuity equation, the global generation rate and the density of the minority carriers can be put respectively in the following form.

$$\delta(x,t)=\delta(x)\ \exp(j\omega t) \quad (02)$$

$$G(x,t)=g(x)\ \exp(j\omega t) \quad (03)$$

$$g(x)=\varphi_t\alpha_t(1-R_t)\exp(-\alpha_t x) \quad (04)$$

The expressions of the diffusion coefficient and of the diffusion length as a function of the irradiation energy and of the damage coefficient kl in the dynamic frequency regime are given respectively by the following equations [8]

$$D^*(\omega,Kl,\varphi_p,B)=D(Kl,\varphi_p)\frac{\left[1+\tau^2(\omega_c^2+\omega^2)+j\omega\tau\left[\tau^2(\omega_c^2-\omega^2)-1\right]\right]}{4\tau^2\omega^2+\left[1+\tau^2(\omega_c^2-\omega^2)\right]^2} \quad (05)$$

Avec:

$$D(kl,\varphi_p)=\frac{L(kl,\varphi_p)^2}{\tau} \quad (06)$$

$$L(K_l,\varphi_p)=\frac{1}{\sqrt{\frac{1}{L_0^2}+K_l\varphi_p}} \quad (07)$$

$$L_0=\sqrt{D_0\tau} \quad (08)$$

$$L\ \ (Kl,\varphi_p,\omega)=L(kl,\varphi_p).\sqrt{\frac{1-j.\omega.\tau}{1+(\tau.\omega)^2}} \quad (09)$$

$D(Kl,\varphi)$ is the diffusion coefficient depending on the damage coefficient and the irradiation flux.

$L(Kl,\varphi)$ is the scattering length as a function of the damage coefficient and the irradiation flux.

L0 is the scattering length in the absence of pulsation, irradiation and magnetic field.

D0 is the diffusion coefficient in the absence of pulsation, irradiation and magnetic field

$L(Kl,\varphi,B)$ is the scattering length as a function of the damage coefficient, the irradiation flux and the magnetic field.

Thus equation (1) can be put in the form:

$$\frac{\partial^2 (x)}{\partial x^2} - \frac{1}{L^2 (\omega)} \partial (x) = - \frac{g (x)}{D^*} \quad (10)$$

The equation (04) being a differential of the second degree with second member therefore the general solution is:

$$\delta (x) = A \cosh\left(\frac{x}{L}\right) + B \sinh\left(\frac{x}{L}\right) - \frac{\alpha I_0 (1-R) L^2}{D (\alpha^2 L^2 - 1)} \exp (-\alpha x) \quad (11)$$

To determine the coefficients A and B, the following boundary conditions [7] are used.

At the junction (x = 0) $\frac{\partial \delta(0)}{\partial x} = \frac{Sf}{D^*} \delta(0)$ (12)

On the back side (x = H) $\frac{\partial \delta(H)}{\partial x} = - \frac{Sb}{D^*} \delta(H)$ (13)

Where, Sf and Sb are the recombination rates of the minority charge carriers at the junction and at the back face, respectively; H the thickness of the base. Sf is the sum of two contributions [8].

$$Sf = Sf_0 + Sf_j \quad (14)$$

3 RESULTS AND DISCUSSIONS

3.1 DIODE CURRENT EXPRESSION

The diode current is a leakage current, it is established when the charge carriers are injected or photo generated in the solar cell. Thus, for an illuminated solar cell, this current characterizes the losses of generated carriers and depends on the voltage, the absorption coefficient and the recombination speeds. It is given by the following expression:

$$Id_n = q.Sf_{0.}\delta_n (0)$$

Where Sfo is the intrinsic recombination rate at the junction.

3.1.1 STUDY OF THE DIODE CURRENT AS A FUNCTION OF THE PULSATION

We present in Figure 02 the variations of the modulus of the diode current as a function of the logarithm of the pulsation for different values of the magnetic field.

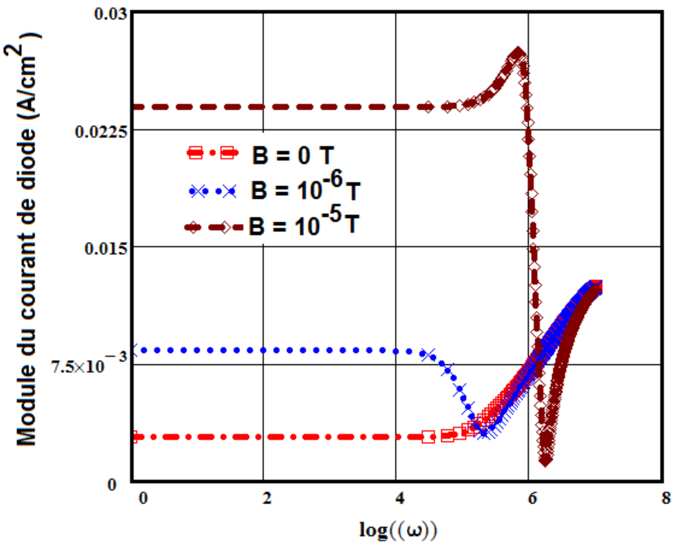

Fig. 2. Variation of the module of the diode current according to the logarithm of the pulsation for various values of the magnetic field. Kl=10 $MeV^{-1}.s^{-1}$; λ=0,6µm; φ=100MeV

We notice that the modulus of the diode current is constant when we are at low values of the pulsation. Indeed, the low values of the pulsation correspond to the static regime, which justifies the constancy of the modulus of the diode current in this part. In addition, as soon as we are in the dynamic frequency regime, the influence of the frequency is felt by the appearance of resonance peaks with the application of the magnetic field. Moreover, it can be seen that the modulus of the diode current is minimal in the absence of a magnetic field. This can be explained by the fact that an increase in the magnetic field leads to an accumulation of carriers at the junction, which would increase the leakage current when the magnetic field is increased.

In figure 03 we represent the profiles of the modulus of the diode current as a function of the logarithm of the pulsation for different values of the irradiation energy.

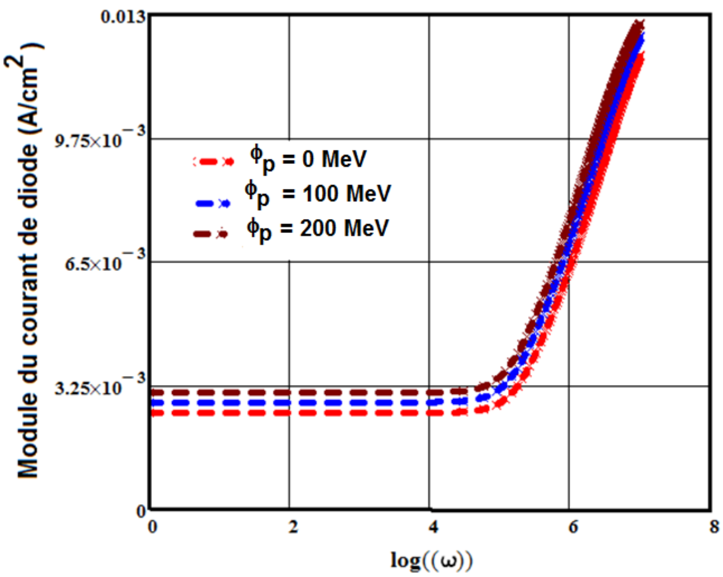

Fig. 3. Variation of the diode current modulus as a function of the logarithm of the pulsation for different values of the irradiation energy. Kl=10 $MeV^{-1}.s^{-1}$; λ=0,6µm; B = 10^{-5}T

For pulses less than or equal to 104 rad/s, the leakage current modulus remains constant, we are in a quasi-static regime. This value of the diode current increases when the irradiation energy increases. From 105 rad/s, there is a clear increase in the diode current as a function of the logarithm of the pulsation up to a maximum value near resonance. Moreover, it is observed that the irradiation energy increases the modulus of the diode current. Indeed, the increase in the irradiation energy increases the carrier losses generated.

3.1.2 Study Of The Diode Current As A Function Of The Photovoltage

In figure 04 we represent the profiles of the modulus of the diode current as a function of the photovoltage for different values of the magnetic field.

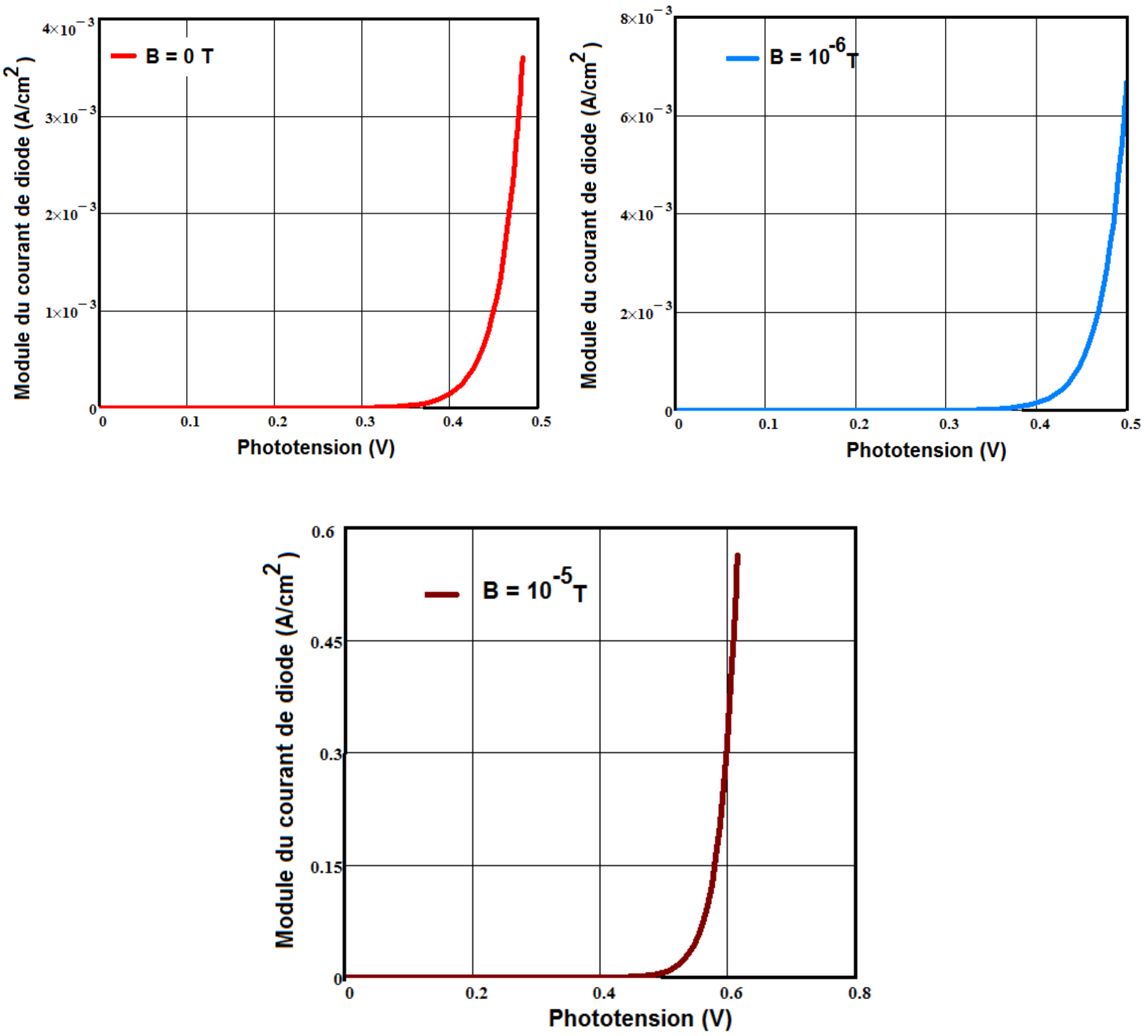

Fig. 4. ***Variation of the module of the diode current as a function of the photovoltage for different values of the magnetic field. Kl=10 MeV^{-1}.s^{-1}; λ=0,6µm; φ=100MeV***

As soon as the influence of the space charge zone loses its importance, i.e. as soon as the voltage is greater than or equal to 0.4 volts, the diode current increases with the voltage exponentially. Thus the leakage current appears as soon as there is an accumulation of charge carriers at the junction (low Sf or low gradient of the carriers) corresponding to increasing values of the voltage.

In Figure 05, we represent the profiles of the modulus of the diode current as a function of the photovoltage for different values of the irradiation energy.

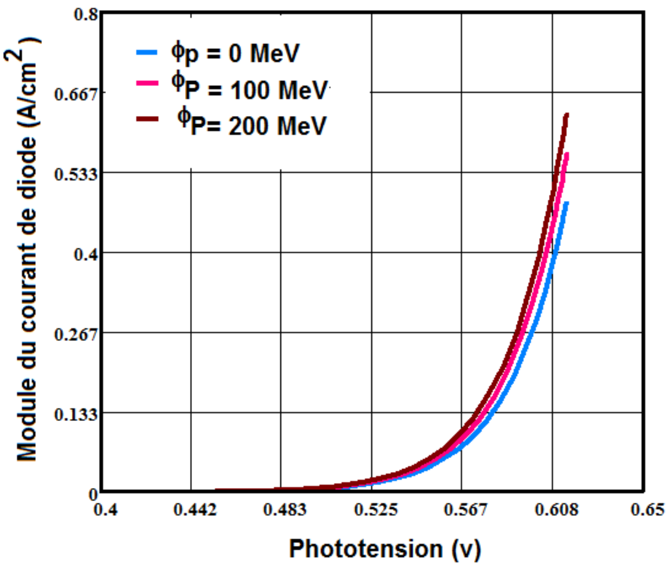

Fig. 5. Module of the diode current as a function of the photovoltage for different values of irradiation.
Kl=10 $MeV^{-1}.s^{-1}$; λ=0,6μm; B = 10^{-5} T

In this figure, we observe that the diode current is almost zero at low values of the photovoltage. Practically, we have the same looks as the previous figures. Therefore, the explanations will remain the same as to the influence of the photovoltage on the module of the diode current. Compared to the irradiation energy, we note an increase in the diode current modulus because the irradiation energy reduces the mobility of the carriers hence an increase in the accumulation of minority carriers.

Table 1. Diode current values as a function of irradiation energy and magnetic field

ϕ_p (MeV)	Id (A /cm^2)
50	0, 52512
100	0,56321
150	0,59813
200	0,63054
250	0,66093

B(T)	Id (A /cm^2)
0	0,0035
10^{-6}	0,0066
10^{-5}	0,5632

From this table, we find that when the value of the irradiation energy and the magnetic field increase, the modulus of the diode current increases which is due to the slowing down of the diffusion of the minority carriers caused by the irradiation and the accumulation of carriers at the junction by the magnetic field. Consequently, the intrinsic properties of the solar cell are damaged; this implies a drop in the conversion efficiency of the solar cell.

4 CONCLUSION

A theoretical study was carried out on the diode current of a silicon solar cell and under monochromatic illumination, in frequency modulation, under irradiation and magnetic field. This study allowed us to recall the expressions of some electrical parameters in particular that of the diode current. Indeed, this study also allowed us to show that in frequency dynamic regime, the diode current is an important electrical parameter of the solar cell. Moreover, with an irradiation energy and an applied magnetic field, the recombination of minority carriers is slowed down. Consequently, the intrinsic properties of the solar cell are damaged; this implies a drop in the conversion efficiency of the solar cell.

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