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STUDY OF THE INFLUENCE OF IRRADIATION ON PARAMETERS ELECTRICAL AND ELECTRONIC OF A MONOFACIAL SOLAR CELL CONTAINING THIN FILM CIGS UNDER ILLUMINATION MONOCHROMATIC IN DYNAMIC FREQUENCY MODE

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KEYWORDS: Irradiation, electrical parameter, electronical parameter, CIGS, damage coefficient.

ABSTRACT
The aim of this work is to show the effects of irradiation on the properties of a CIGS solar cell. The relative density of the minority carriers is presented, and shows that the depletion width depends on the effects of irradiation (irradiation energy, and the nature of the particles). We also showed in frequency dynamic regime that the following parameters: photocurrent density, open circuit voltage, the diffusion length are affected by irradiation. However, these parameters are weakened with the increase in the irradiation energy and the coefficient of damage.

INTRODUCTION
The development of thin film solar cells, particularly chalcopyrite solar cells based on Cu(In,Ga)S,Se_2 achieved considerable progress with a conversion efficiency equalizing 20% in the laboratory **[1].** Since the radiation of high energy charged particles can damage the structure of semiconductors **[2, 3,4],** the performance of the solar cell exposed to radiation is a fundamental design parameter **[5],** which pushes to know the relationship between the parameters of the solar cell (electrical parameters) and those of the radiation (radiation energy, damage coefficient).

In this work, the thickness of the transmitter is not taken into account in the calculation of electrical values, so the study will be made only in the absorber of the monofacial solar cell. The purpose of this study is, after solving the continuity equation for the density of photocreated minority carriers, to study the influence of the energy of radiation and the coefficient of damage on the electrical and electronic parameters monofacial solar cell under monochromatic illumination.

MATERIALS AND METHODS
An n+-p-p+ CIGS solar cell type is schematized on figure 1 [1]:

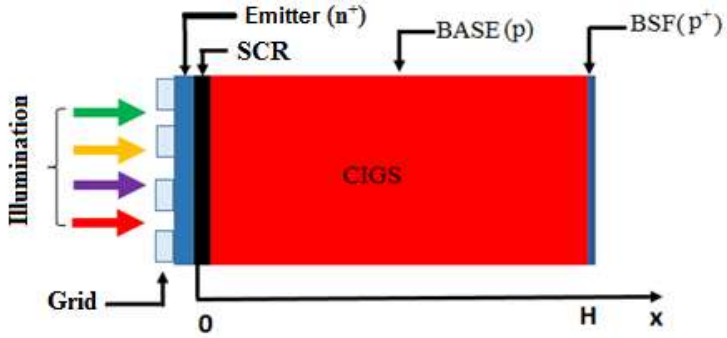

Figure 1: The CIGS (n+-p-p+) thin film solar cell under monochromatic illumination at the front surface
Density of minority charge carriers in excess

This study is based on the front side of a CIGS (n+-p-p+) thin film solar (Fig 1). Therefore, the absorber has a good contribution to the photoconversion. The following analyzes will therefore be deducted only from cell's area. When the solar cell is illuminated with a monochromatic light, the continuity equation relative to excess minority carriers (electron) density photogenerated in the absorber can be written by:

$$\frac{\partial^2 \delta(x,\lambda,Sf,Sb,Kl,\phi,\omega)}{\partial x^2} - \frac{\delta(x,\lambda,Sf,Sb,Kl,\phi,\omega)}{L^2} + \frac{G(x,\lambda,Kl)}{D} = 0 \quad \textbf{(1)}$$

In which $\delta(x,\lambda,Sf,Sb,Kl,\omega,\phi)$ is the excess minority carrier's density in the base, D is the diffusion constant, L is diffusion length, Sf and Sb are the recombination velocities at the junction and at the back surface respectively. G (x) is the generation rate of the carriers obtained from the following equation **[6]:**

$$G(x,\lambda) = g(x,\lambda)e^{-i\omega t} \quad où \quad g(x) = \alpha(\lambda)\phi(\lambda)(1-R(\lambda))e^{-\alpha(\lambda)x} \quad \textbf{(2)}$$

Where α is the absorption coefficient and R is the reflection coefficient and ϕ is the flux carriers. The study is is undertaken under the spectrum AM 1.5. The diffusion coefficient is constant and is given by equation (3): **[7]**

$$D = \frac{kT}{q} \times \mu_n \quad (3)$$

With $D = 2.584\ cm^2/s$ $L_n = \sqrt{D \times \tau_e}$

For a solar cell 300 µm **[8]:** $Ln = 5.083\ \mu m$

The general solution of the continuity equation is given by the expression (5):

$$\delta(x,\lambda,Sf,Sb,Kl,\phi) = A.\cosh\left(\frac{x}{L(\omega,Kl,\phi)}\right) + B.\sinh\left(\frac{x}{L(\omega,Kl,\phi)}\right) - \frac{\alpha(\lambda).\phi(\lambda).(1-R(\lambda)).L(\omega,Kl,\phi)}{D(\omega,Kl,\phi).[L(\omega,Kl,\phi))^2.\alpha^2-1]}.e^{-\alpha(\lambda)x} \quad \textbf{(5)}$$

In which A and B are constants determined from the boundary conditions:

- At the Junction (x=0) **[7]** :

$$D(\omega,Kl,\phi).\left.\frac{\partial\delta(x,\lambda,Sf,Sp,Kl,\omega)}{\partial x}\right|_{x=0} = Sf.\delta(x,\lambda,Sf,Sb,Kl,\omega)\Big|_{x=0} \quad \textbf{(6)}$$

- The back side (x = H) **[7]:**

$$D(\omega,Kl,\phi).\left.\frac{\partial\delta(x,\lambda,Sf,Sp,Kl,\omega)}{\partial x}\right|_{x=H} = -Sf.\delta(x,\lambda,Sf,Sb,Kl,\omega)\Big|_{x=H} \quad \textbf{(7)}$$

In which H is the total thickness of the solar cell *CIGS*, Sf and Sb are respectively junction recombination velocity and back side recombination velocity.

Relative density of the minority carriers

The relative density of the minority charge carriers is defined as the ratio of the density of minority carriers and the maximum of the density of minority carriers in excess for a given irradiation energy, according to the following expression **[9].**

$$\delta rel(x,\lambda,Sf,Sb,Kl,\phi,\omega)=\frac{\delta(x,\lambda,Sf,Sb,Kl,\phi,\omega)}{\delta \max} \quad \textbf{(8)}$$

The density profile of the excess minority carriers depending on the depth x for different values of the radiation energy is shown in Figure 2.

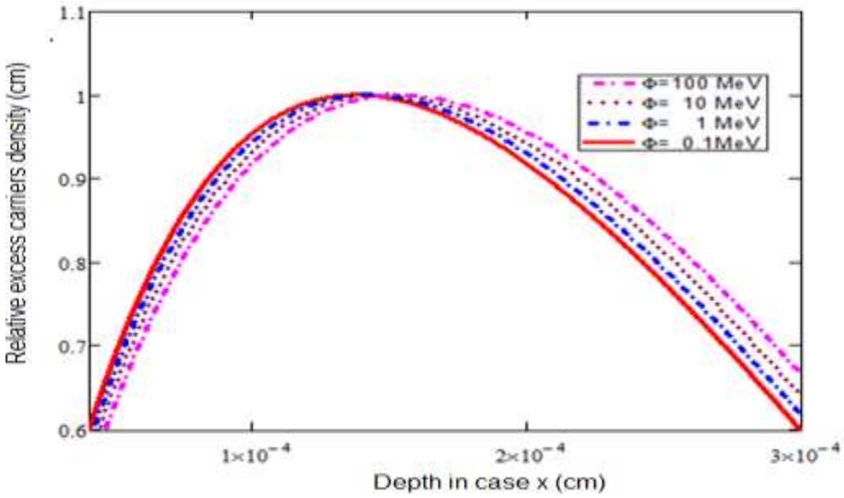

Figure 2: Relative density of minority carriers in excess depending on the depth of the absorber for different values of the irradiation energy; λ = 1020 nm; Sf = 6x10^{6} cm.s^{-1} ; Sb = 4x10^{4} cm.s^{-1}; kl = 5; ω = 5x105 Hz

We note that the relative density of the minority charge carriers increases with depth at the beginning of the absorber until reaching a maximum depth to the absorber x = 1.4719x10^{-4}cm. But at this level the density decreases with the increasing of the irradiation energy. Below this depth, density decreases to almost zero value. We see that from this point the irradiation energy no longer influences the carrier density because it no longer decreases with the irradiation energy. Indeed, the cell is illuminated only by the front face; this behavior is due to the fact that the minority carrier generation rate is maximum at the junction due to a maximum displacement of carriers towards the depletion width. For an increase in the irradiation energy, this leads to a decrease in the depletion width.

We'll discuss this result, studying the effect of irradiation on the various electrical parameters of the solar cell.

RESULTS AND DISCUSSION

Photocurrent Density

Effect of irradiation energy on the density of photocurrent

We express the photocurrent density derived from the cell based on the recombination rate Sf at the junction for different irradiation energies (Figure 3). The photocurrent of the solar cell is obtained by the gradient of minority carriers to the junction and is given by the expression (9) **[10].**

$$Jph(\lambda,Sf,Sb,Kl,\phi)=q.D(\omega,Kl,\phi).\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0} \quad \textbf{(9)}$$

In which q is the elementary charge q = 1.6x10^{-19} C. The figure 3 shows the photocurrent density as a function of the recombination velocity at the junction for different values of the irradiation energy.

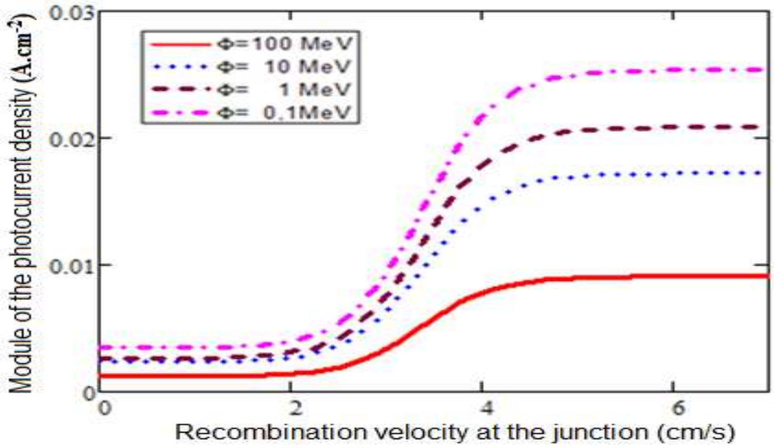

Figure 3: Module of the photocurrent density as a function of the recombination velocity at the junction for different values of the irradiation energy.
$\lambda = 400\ nm$; *Sb= 4x10^4 cm.s^{-1}; Kl= 5 ;* $\omega = 5 * 10^5\ Hz$

For a frequency modulation and a given coefficient of damage, the photocurrent density increases progressively with the rate of recombination at the junction. The photocurrent density decreases in amplitude when the irradiation energy increases. Indeed, we can say that the radiation energy has a bad effect on the photocurrent density.

We subsequently investigate the effect of the other phenomenon of radiation which is the loss coefficient on this photocurrent density.

Effect of damage coefficient on the density of the photocurrent
The Figure 4 shows the photocurrent density according to the irradiation energy for different damage coefficients.

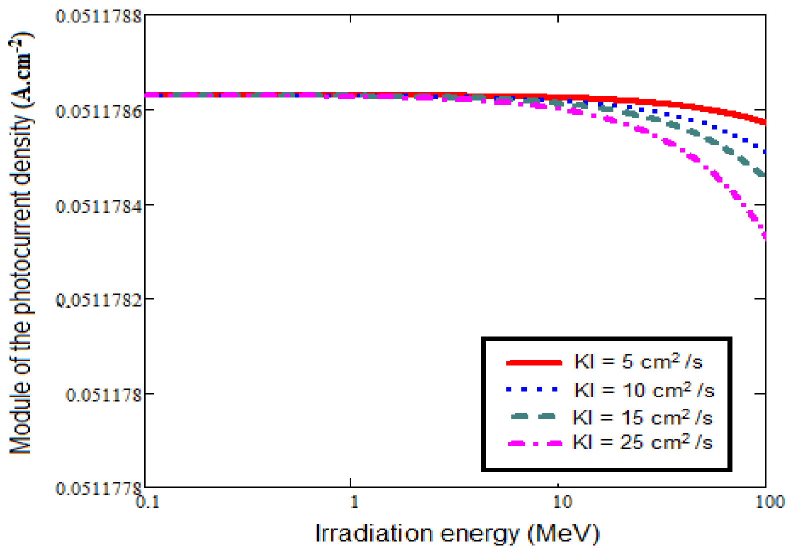

Figure 4: Module of the photocurrent density as a function of the irradiation energy, for various values of kl damage coefficient.
λ=740nm; Sf= 5x10^5 cm.s^{-1}; Sb= 2x10^2 cm.s^{-1}; ω= 5x10^{5}Hz.

The photocurrent density varies slightly with the irradiation energy for point energy below 10MeV. But beyond this point energy there is a rapid decrease of the photocurrent density with radiation energy. We note also that this decrease of photocurrent is more pronounced with strong damage coefficients. Indeed, if the coefficient of damage increases, there is a greater probability of damage caused to a given energy. So if the energy increases, the expected damage will bemore important. The energy radiation and the damage coefficient having a negative effect on the photovoltage density, it is necessary to see their behavior on the photovoltage which is also an electrical parameter.

PHOTOVOLTAGE DENSITY

The photovoltage at the junction is expressed by the relation of Boltzmann:

$$Vph(\lambda, Sf, Sb, Kl, \phi, \omega) = Vt.\ln(\frac{Nb.\delta(0)}{n_i^2}+1) \tag{10}$$

Vt is the thermal voltage, n_i is the intrinsic density of carriers at thermal equilibrium and Nb is the doping density at the absorber. Let us see the effect of the radiation energy on this photovoltage.

Effect of irradiation energy on the photovoltage

To illustrate the influence of the irradiation energy, are presented in the Figure 5 the variations of the density photovoltage according to the recombination velocity at the junction, for different values of the irradiation energy.

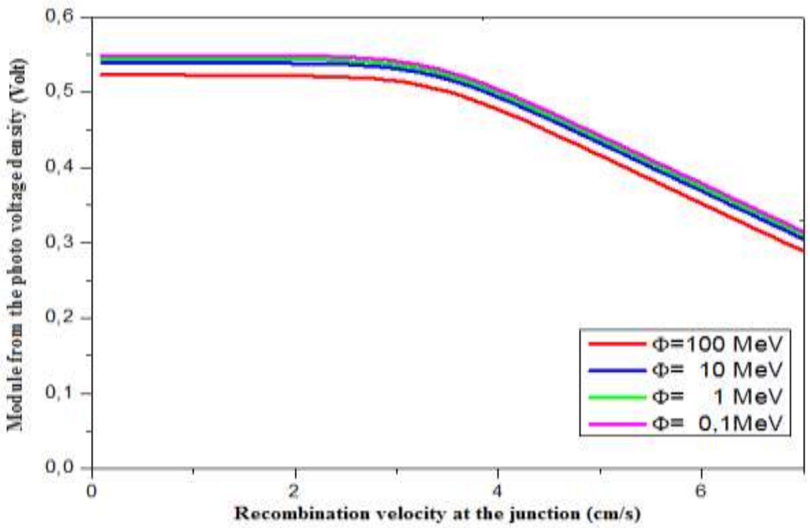

Figure 5: Module from the photovoltage density based on the recombination velocity at the junction for different values of the irradiation energy;
$\lambda = 400$ nm ; Sb= 4x10^4 cm.s^{-1}; Kl= 5 ; ω= 5x10^5 Hz

It can be noted from these curves that the photovoltage always decreases with the recombination velocity at the junction, but also with radiation energy. We note that this reduction in the photovoltage is especially pronounced when the solar cell operates in the vicinity of the short circuit. Indeed, the accumulated carriers near the junction increase the probability of interaction with the radiating particles and therefore the damage. As with the photocurrent density, we will also show the effect of the damage coefficient on the photovoltage.

Effect of damage coefficient on the photovoltage

We study now the influence of the damage coefficient on the photovoltage. In Figure 6 is represented the photovoltage density according to the irradiation energy, for different damage coefficients.

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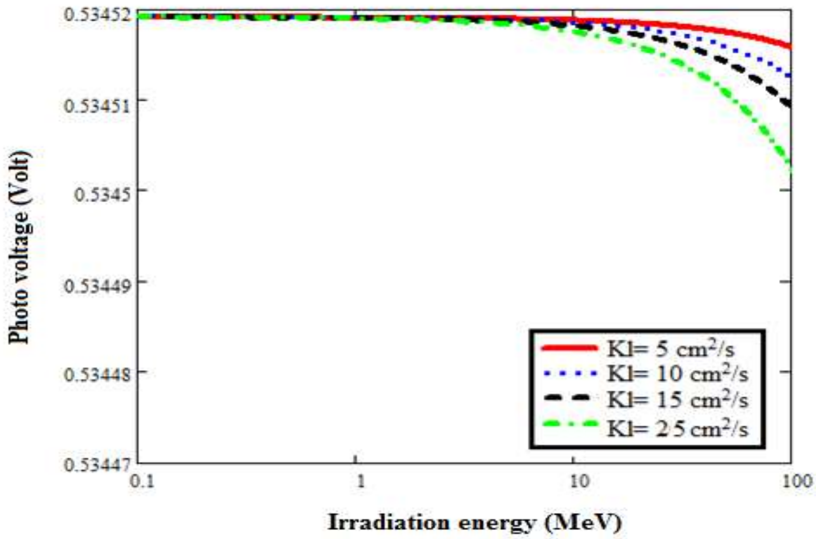

Figure 6: Module voltage photo density according to the irradiation energy for different values of coefficient of damage.
λ= 740nm ; Sf= 6x10^{6} cm.s^{-1}; Sb= 3x10^{3} cm.s^{-1}, ω= 5x10^{5}Hz

We just deduct at the (figure 5) that for low values of the recombination velocity Sf, there are not enough carriers at the junction; this is the open circuit condition, which can be obtained by the following equation: **[10].**

$$\lim_{f\to 0} V_{ph} = V_{ph_{OC}} \qquad \textbf{(11)}$$

We notice again that the photovoltage decreases with irradiation energy. By varying the damage ratio, we observe that the photovoltage decreases with the increase of the damage coefficient. Indeed, if the damage coefficient increases, it means that the material becomes more sensitive to damage caused by particles, and thus the photovoltage will be even weaker than the increase of the damage coefficient. We study now the impact of radiation on an electronic parameter of the solar cell that is the diffusion length, a very important parameter in the operation of the solar cell.

DIFFUSION LENGTH

The diffusion length L of the minority charge carriers in the absorber depends on the ϕirradiation energy and the damage coefficient Kl, from the following expression: **[10]**

$$L(Kl,\phi) = \sqrt{\frac{1}{\frac{1}{L_0^2} + Kl.\phi}} \qquad \textbf{(12)}$$

L_0 is the diffusion length without irradiation.

$$L_0 = \sqrt{D_0 \cdot \tau_e} \qquad \textbf{(13)}$$

For $\tau_e = 10^{-7}\, s$ **[11]:**

The diffusion length according to the particle energy for different values of the damage coefficient is presented in Figure 7.

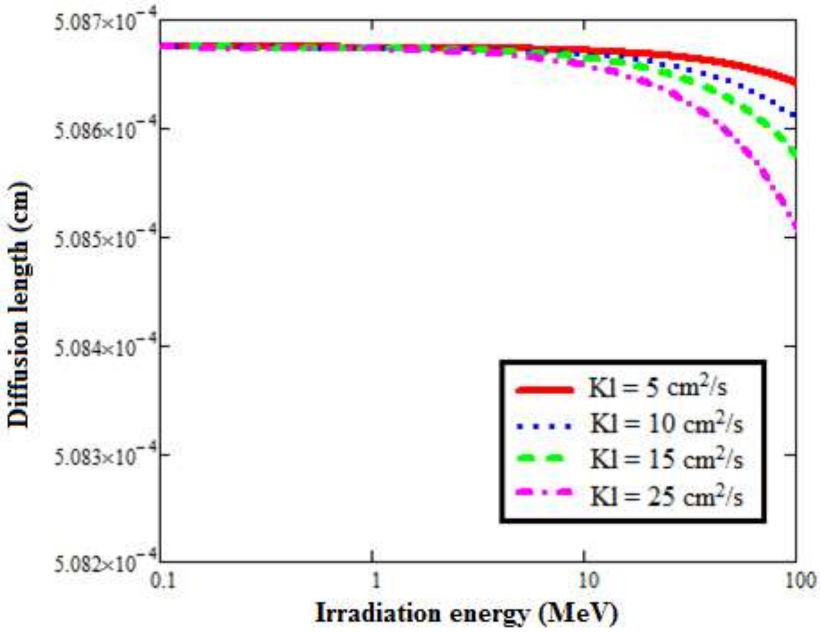

Figure 7: diffusion length depending on the radiation energy for different values of Kl damage coefficient.

The diffusion length decreases with increasing incident energy. The diffusion length also decreases the coefficient of damage, but the decline is more observable for high energy radiation. Therefore the diffusion length is strongly influenced by irradiation. Therefore the behavior of the solar cell will be influenced by irradiation.

CONCLUSION

The simulation of a Cu (In, Ga) Se_2,S_2 (CIGS) thin film solar cell under irradiation shows that electrical and electronic parameters of the cell is strongly influenced by the effects of irradiation, namely the energy of the irradiation and the type of particles. The damage caused by the particles is greater when energy increases. This radiation energy and the damage coefficient result in lower electrical and electronic parameters of the cell from which a decrease in cell performance.

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