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EFFECT OF IRRADIANT PARAMETERS ON THE MOBILITY AND DENSITY OF MINORITY CARRIERS IN FREQUENTIAL CONDITIONS OF AN n + pp + type SILICON PHOTOPILE LIT BY ITS FRONT SIDE IN MONOCHROMATIC LIGHT

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ABSTRACT
The effect of irradiation energy and damage coefficient on a monochromatic illumination type silicon solar cell in the frequency regime was investigated.

From the formalism of the diffusion coefficient and the establishment of the expression of the density of minority carriers via the continuity equation and our various curves, the choice of ideal values for the temperature; frequency and wavelength was effective. The dependence on the energy and on the nature of the irradiation (,) is indicated on the following parameters: diffusion coefficient, density of minority charge carriers, rate of recombination at the rear face.

KEYWORDS: Photocell, Irradiation energy, Damage coefficient, Diffusion coefficient, Recombination rate at the junction, Recombination rate at the rear face, Modulation frequency

1. INTRODUCTION
The sun is a huge ball of gas chemically made up of 70% hydrogen, 28% helium, the remaining 2% are most of the other atoms in the universe.
In 1977, Staebler and Wronski discovered that the electrical and optical properties of hydrogenated amorphous silicon (a-Si: H) were affected by photon irradiation. The creation of metastable defects observed has been attributed to the generation of dangling bonds due to the breaking of weak silicon-silicon bonds [1].
The term irradiation refers to the exposure of a body to a flux of radiation which may be ionizing (radiation of sufficient energy to ionize matter).
The effect of irradiation on microcrystalline silicon by photons or energetic particles is of fundamental interest because any increase in the density of defects makes it possible to study the influence of defects on transport and recombination in this semi. -driver. As a result, several scientific publications have focused on the impact of these irradiating particles on matter, in particular on the phenomenological parameters [2],[3],[4],[5],[6],[7],[8] and the electrical parameters[9],[10],[11],[12],[13],[14],[15],[16] of different solar cells (vertical junction solar cell series, solar cell vertical junction parallel, monofacial solar cell, bifacial solar cell) under different illuminations (monochromatic, polychromatic, multispectral) and under different regimes (static, dynamic, forwarder).
The aim of this article is to explore the impact of the irradiation energy and the damage coefficient on the diffusion coefficient and on the density of the minority charge carriers of a monofacial solar cell of the initially irradiated type n^+pp^+, illuminated by its front face under monochromatic light. in dynamic frequency regime and under temperature, considering that the impact of temperature and wavelength will be ignored.

2. MATERIALS AND METHODS
a- Interactions dues au rayonnements

The following table shows the type of interactions and the extent of the type of radiation damage.

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Table1 : Neutron and gamma radiation effects on Silicon components.

Radiation type	Energy range	Main type of interaction	Primary effects in Si and SiO2	Secondary effects in Si and SiO2
Photons	Low Energy	Photoelectric Effect	Ionizing phenomena	Displacement damage
	Medium Energy	Compton Effect		
	High Energy	Pair production		
Neutrons	Low Energy	Capture and nuclear reaction	Displacement damage	Ionizing phenomena
	High Energy	Elastic scattering		

b- Présentation de la photopile

The figure represents the type $n^{+}pp^{+}$ $[18]$, $[19]$ study solar cell, initially subjected to a flow of irradiation of charged particles, illuminated by its front face following a monochromatic light.

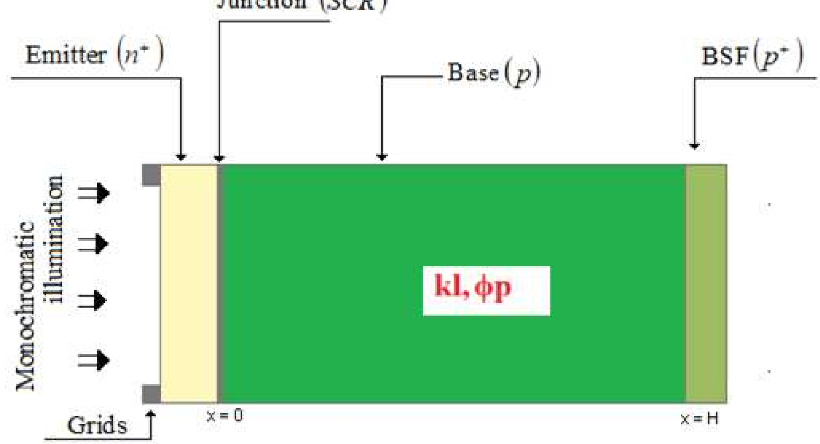

Figure 1 : An $n^{+}pp^{+}$ type of a silicon solar cell under irradiation

This type of solar cell is made up of four main parts [20]

- Emitter type (n^{+}): thin at $(0.5$ à $1\mu m)$, it is heavily doped with atoms $(10^{17}$ à $10^{19} cm^{-3})$ of cables and covered with an anti-reflection layer [21] and a metal grid which collects the photocharged charges
- the Space Charge Zone: this zone is characterized by a strong electric field that separates the electron-hole pairs that arrive at the junction.
- the Base type (p): it is large in size $(200$ à $400\mu m)$ and lightly doped with acceptor atoms in $(10^{15}$ à $10^{17} cm^{-3})$. This is the area of predominance of the phenomena of generation, diffusion and recombination.
- the BSF (Back Surface Field) [22]: it is the zone located on the rear face of the base, overdoped in acceptor atoms (p^{+}) $(10^{17}$ à $10^{19} cm^{-3})$ with respect to the base, it created a rear electric field which returns towards the junction the photocreated minority carriers near the the rear face to reduce recombinations which are harmful to the solar cell [23].

Contacts adapted in the form of a grid [24] (in Nickel –Aluminum, Silver-Aluminum, etc.) on the front and rear surfaces allow the collection of the minority charge carriers photocreated in an external circuit.

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H is the total thickness of the base.

1- RESULTS AND DISCUSSION

When the solar cell by its front face is illuminated along the emitter, electron-hole pairs are created in the base; the distribution of photocreated minority carriers (electrons) in the base is then governed by the following continuity equation:

$$D(\omega,kI,\phi p,T)\frac{\partial^2\delta(x,t)}{\partial x^2}-\frac{\delta(x,t)}{\tau}+g(x,t)=+\frac{\partial\delta(x,t)}{\partial t} \quad (1)$$

Where ,

$D(\omega,kI,\phi p,T)$ represents the complex diffusion coefficient of electrons in the base of the solar cell under irradiation and under temperature , [25], [26], [27], [28].

$$D(\omega,kI,\phi p,T)==D(kI,\phi p,T)\left[\frac{1+\omega^2\tau^2}{\left(1-\omega^2\tau^2\right)^2+\left(2\omega\tau\right)^2}+\omega\tau\frac{-1-\omega^2\tau^2}{\left(1-\omega^2\tau^2\right)^2+\left(2\omega\tau\right)^2}i\right] \quad (1)$$

$$D(kI,\phi p,T)=\frac{L(kI,\phi p,T)^2}{\tau} \quad (3)$$

$$L(kI,\phi p,T)=\frac{1}{\sqrt{\frac{1}{L(T)^2}+kI\cdot\phi p}} \quad (4)$$

$$L(T)=\sqrt{\tau\cdot D(T)} \quad (5)$$

$$D(T)=\frac{\mu(T)\cdot K_B\cdot T}{q} \quad (6)$$

Where ,

$L(kI,\phi p,T)$ is the diffusion length of excess minority carriers in the base. It is a function of the damage coefficient, the irradiation energy and the temperature.

τ is the lifespan of minority carriers after irradiation and τ_0 represents the lifespan of minority carriers before irradiation. τ and τ_0 are linked to the following expression [29]:

$$\frac{1}{\tau}=\frac{1}{\tau_0}+kI\cdot\phi p \quad (7)$$

$\mu(T)$ is the coefficient of mobility of electrons as a function of temperature [29].

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$$\mu(T) = 1.4310^{9} T^{-2.42} cm^{2} / V.s$$

K_B is Boltzmann's constant and is the elementary charge of the electron [30].

$\delta(x,t)$ et $g(x,t)$ represent respectively the density of the minority charge carriers and the rate of generation in white light of the excess charge carriers as a function of the thickness of the base and of the modulation frequency [31],[32]:

$$\delta(x,t) = \delta(x) \cdot \exp(j\omega t) \tag{10}$$

$$g(x,t) = g(x) \cdot \exp(j\omega t) \tag{11}$$

$$g(x) = \alpha_{\lambda} \cdot \phi_{\lambda} \cdot (1 - R_{\lambda}) \cdot \exp(-\alpha_{\lambda} \cdot x) \tag{12}$$

- α_{λ} is the monochromatic absorption coefficient of the material for a wavelength λ
- R_{λ} is the monochromatic reflection coefficient of the material for a wavelength λ
- φ_{λ} is the incident flux of monochromatic light λ
- x is the thickness of the base of the solar cell

Solving the equation gives the expression for the density of minority carriers written as follows:

$$\delta(x,\omega,\lambda,kI,\phi p,T) = A \cdot \cosh\left(\frac{x}{L(\omega,kI,\phi p,T)}\right) + B \cdot \sinh\left(\frac{x}{L(\omega,kI,\phi p,T)}\right) + K(\omega,kI,\phi p,T) \cdot \exp(-\alpha_{\lambda} \cdot x) \tag{13}$$

$$K(\omega,\lambda,kI,\phi p,T) = -\frac{\alpha_{\lambda} \cdot \phi_{\lambda} \cdot (1 - R_{\lambda}) \cdot \cdot L(\omega,kI,\phi p,T)^{2}}{D(\omega,kI,\phi p,T) \cdot \left[\alpha_{\lambda}^{2} L_{\omega}^{2} - 1\right]} \tag{14}$$

The coefficients and will be determined from the boundary conditions [33]

- At the base transmitter junction

$$\frac{\partial \delta(x,\omega,\lambda,kI,\phi p,T)}{\partial x} = \frac{Sf}{D(\omega,kI,\phi p,T)} \delta(0,\omega,\lambda,kI,\phi p,T) \tag{15}$$

Sf : represents the rate of recombination at the junction [34], [35], [36].

$$Sf = Sf_o + Sf_j \tag{16}$$

Sf_o : rate of intrinsic recombination induced by the shunt resistance and depending only on the intrinsic parameters of the solar cell

Sf_j : recombination rate which relates to the external load imposing the operating point of the solar cell

On the back side

$$\frac{\partial \delta(x,\omega,\lambda,kI,\phi p,T)}{\partial x}\Big|_{x=H} = -\frac{Sb}{D(\omega,kI,\phi p,T)} \delta(H,\omega,\lambda,kI,\phi p,T) \tag{17}$$

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Sb : rate of recombination of charge carriers on the rear face,. It is the consequence of the electric field created by the p / p + junction and characterizes the behavior of charge carriers at the base - rear face interface.

III. Results and discussions

1. Incident flux of light

To define the field of study, the plot of the incident light flux as a function of the wavelengths is presented in the figure knowing that the solar energy is radiated over a wide range of wavelengths (covering the whole Visible + Ultra Violet and the InfraRed domain).

From this line emanate more or less two curvatures where:

- ✓ the wavelengths are close to the ultra-violet and visible ranges $(0.2\mu m \prec \lambda \leq 0.78\mu m)$
- ✓ wavelengths emanate from the infrared frame $(0.78\mu m \leq \lambda \prec 1.2\mu m)$

Throughout this work, the chosen wavelength remains limited between the two predefined domains.

$(\lambda = 0.78\mu m)$

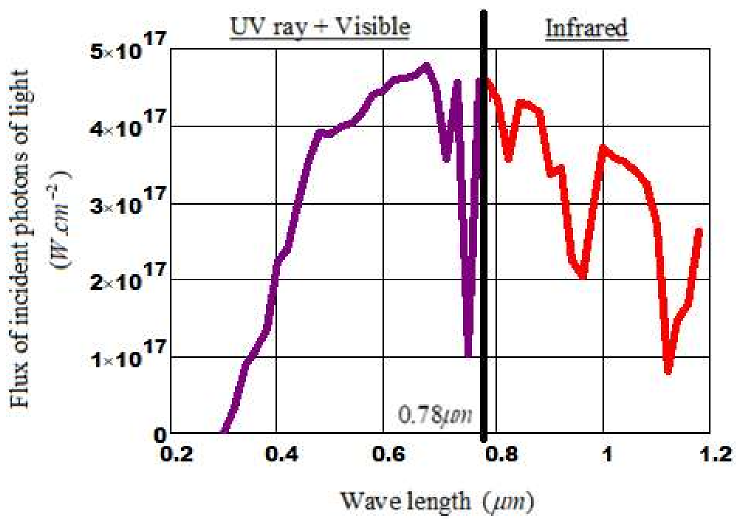

***Figure* 2 : Flux of incident photons of light versus Wavelength**

2. Coefficient de diffusion
i. En fonction de la temperature

The figure below shows the profile of the diffusion coefficient as a function of the temperature before irradiation.

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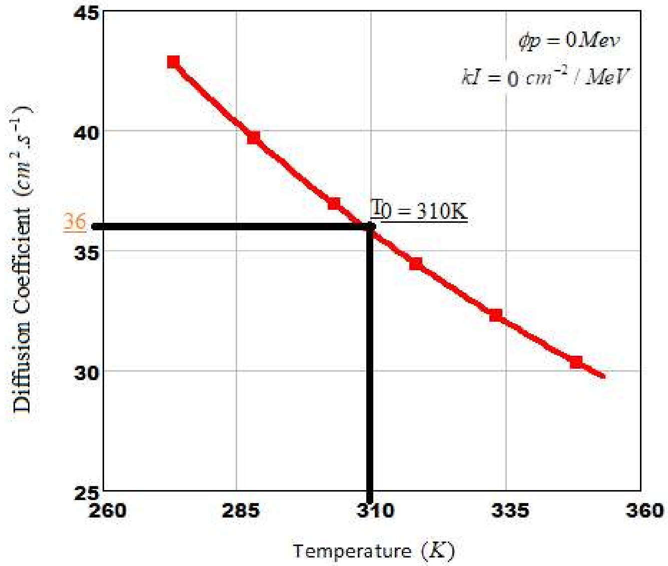
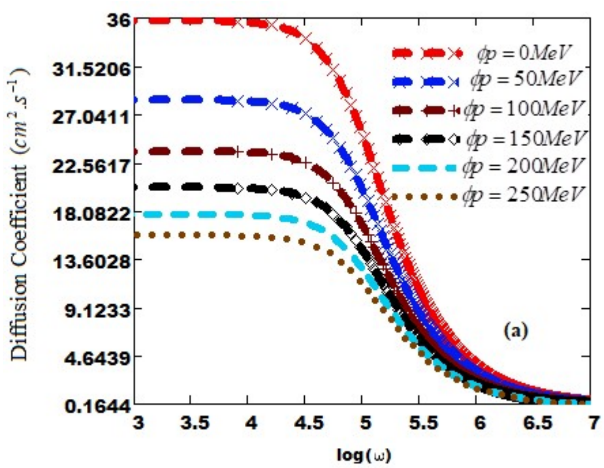


Figure 3 : Diffusion Coefficient versus temperature

The figure shows that the diffusion coefficient decreases with the increase in temperature. The rise in temperature creates a thermal disorder which increases the number of obstacles which oppose the movement of electrons. $T = 310K$ correspond to a diffusion coefficient of $36cm^2.s^{-1}$ which is specific to microcrystalline silicon.

ii. Under the effect of the modulation frequency; ionizing particle energy and damage coefficient

The figures below illustrate the respective variations of the electron scattering coefficient as a function of the logarithm of the frequency, as a function of the irradiation energy and as a function of the damage coefficient.



(figure 4a)

Under static conditions $(\omega \prec 10^{4.5} rad / s)$, the diffusion coefficient of the minority charge carriers remains constant. On the other hand, for higher frequency ranges corresponding to the dynamic frequency regime, there

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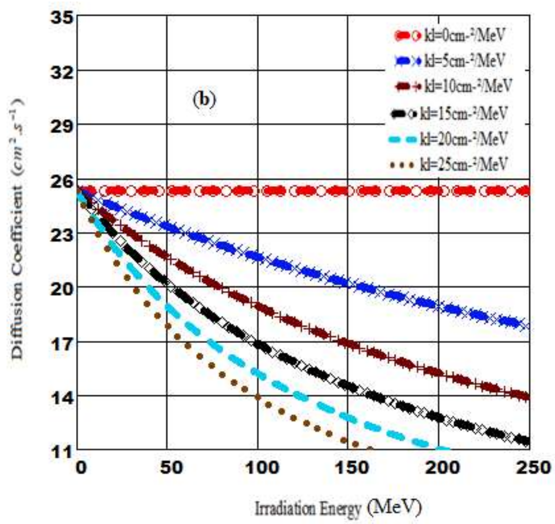
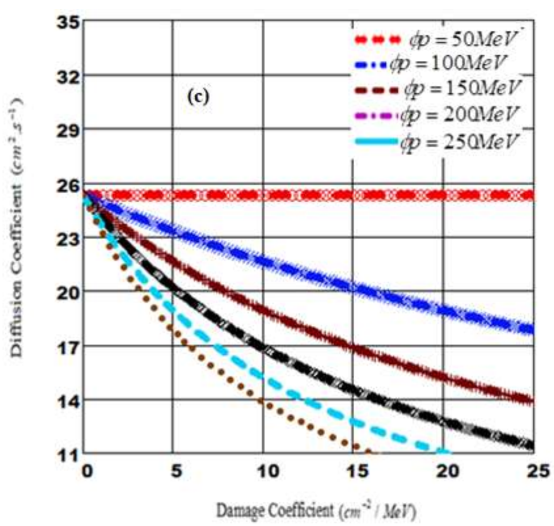
is a noticeable drop in the diffusion of minority charge carriers. Indeed, for such frequency values $(\omega \geq 10^{4.5} rad/s)$, the charge carriers cannot relax, hence their difficulty in moving correctly in the material.
We also note that under the effect of the increase in irradiation energy, the amplitude of the diffusion coefficient gradually decreases (figure $4a$)..
The curves and come from the same point which can be considered as the maximum point of the diffusion of the electrons. These curves decrease respectively according to the energy of irradiation and the coefficient of damage. So, we can now advance that both the damage coefficient and the irradiation energy have a negative impact on the mobility of electrons.



(Figure 4b)



(Figure 4c)

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Figure 4 : Respectively (a) Diffusion Coefficient versus $\log(\omega)$; (b) Diffusion Coefficient versus Irradiation Energy ; (c) Diffusion Coefficient versus Damage Coefficient : $\omega = 10^5 rad/s$, $kI = 15\ cm^{-2}/MeV$; $T = 310\ K$

The increase in the damage coefficient means a greater probability of damage caused for a given irradiation energy. So if the irradiation energy increases, the expected degradations will be more so, hence the drop noted in the electron diffusion coefficient (figure $4b$ et figure $4c$). The effect of irradiation is heavier for small values of the angular frequency. In addition, the diffusion coefficient of minority carriers is more influenced by the large frequencies than by the irradiation energy.

iii**. Density of minority charge carriers**

The figures below show the density profile of the minority charge carriers as a function of the thickness of the base in the respective vicinity of the open circuit and the short circuit for different values of the irradiation energy:

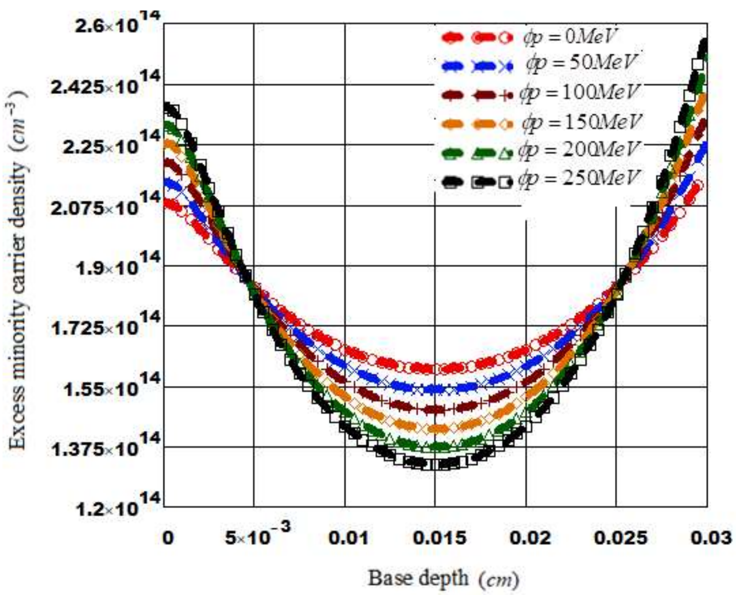

Figure 5 : Excess minority carriers density versus Base depth for different values of irradiation energy

$\lambda = 0.78\mu m$; $\omega = 10^5 rad/s$; $T = 310K$; $Sf = 2.10^2 cm/s$; $Sb(\omega,\lambda,kI,\phi p,T)$; $kI = 15cm^{-2}/MeV$

The figure suggests three levels:

- A first where the density of the minority charge carriers decreases from the junction $(x = 0cm)$ towards the middle of the thickness of the base $(x = 0.015cm)$
- First where the gradient is zero. We observe a decrease in the density of carriers as a function of the thickness of the base, because, further along the illuminated face, the incident excitatory wave attenuates two few minority carriers
- A third where the density of minority load carriers increased from the middle of the base $(x = 0.015cm)$ to the rear face $(x = 0.03cm)$

A double inversion is observed on the shape of the density of the minority carriers at respective thicknesses of $x_1 = 0.0045cm$ and $x_2 = 0.0256cm$

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The irradiation hinders the movement of the minority carriers which causes a great concentration of the photogenerated carriers in the middle of the base.

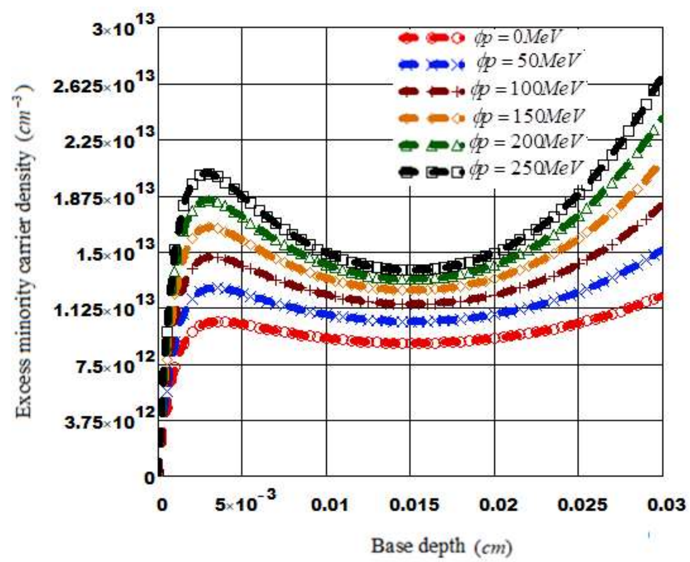

Figure 6 : Excess minority carriers density versus Base depth for different values of irradiation energy

$\lambda = 0.78\mu m$; $\omega = 10^5 rad/s$; $T = 310K$; $Sf = 6.10^6 cm/s$; $Sb(\omega,\lambda,kI,\phi p,T)$ $kI = 15cm^{-2}/MeV$

In the vicinity of the open circuit and for low values of the thickness, the effect of the irradiation energy is weakly felt on the density of the minority charge carriers.

On the other hand, in the figure, there is an absence of inversion of the pace. However, at the thickness, a decrease is noted in the amplitudes of the densities of minority carriers. Therefore, we can say with certainty that the impact of irradiation will be felt more on the photocurrent density than on the voltage.

iv. Rear face recombination speed

Expression of Sb

Starting from the equation, is expressed as follows:

$$Sb(\omega,\lambda,kI,\phi p,T) = -\frac{D(\omega,\lambda,kI,\phi p,T)}{L(\omega,\lambda,kI,\phi p,T)}\cdot\xi \tag{18}$$

With ,

$$\xi = \frac{L(\omega,\lambda,kI,\phi p,T)\cdot\alpha(\lambda) - \left[L(\omega,\lambda,kI,\phi p,T)\cdot\alpha(\lambda)\cdot\cosh\left(\frac{H}{L(\omega,\lambda,kI,\phi p,T)}\right)+\sinh\left(\frac{H}{L(\omega,\lambda,kI,\phi p,T)}\right)\right]\cdot e^{\alpha(\lambda)\cdot H}}{\left[L(\omega,\lambda,kI,\phi p,T)\cdot\alpha(\lambda)\cdot\sinh\left(\frac{H}{L(\omega,\lambda,kI,\phi p,T)}\right)-\cosh\left(\frac{H}{L(\omega,\lambda,kI,\phi p,T)}\right)\right]\cdot e^{(\alpha(\lambda)-H)}+1} \tag{19}$$

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The figure illustrates the profile of the recombination speed at the rear face as a function of the irradiation energy for different damage coefficients also called the nature of the irradiation.

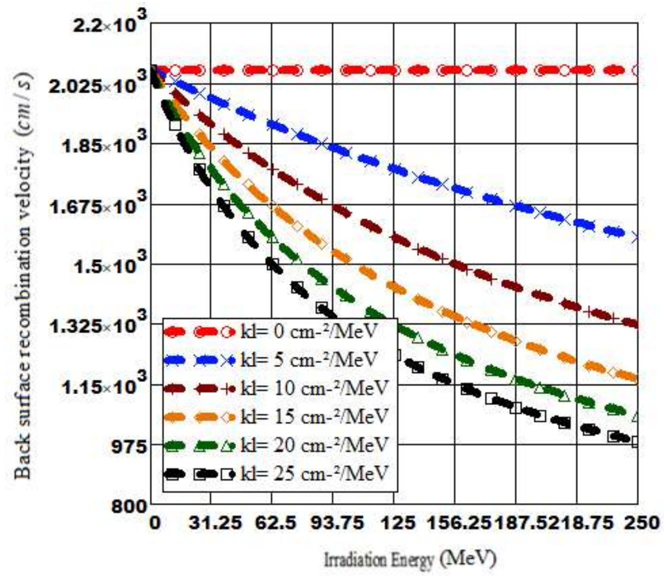

Figure 7 : Vitesse de recombinaison de la surface arrière en fonction de l'énergie d'irradiation

$$\lambda = 0.78\mu m \;;\; \omega = 10^5\, rad/s \;; T = 310K$$

Table 2 below shows the different values of the recombination speed on the rear face (Sb) depending on the irradiation parameters (energy of the particles ϕp and nature of the irradiation kI)

<u>Table2</u> : Values of Sb as a function of ϕp for different kI (with $\lambda = 0.78\mu m$; $\omega = 10^5\, rad/s$)

$kI = 0\ cm^{-2}/MeV$						
$\phi p(MeV)$	0	50	100	150	200	250
$Sb(cm/s)$	263.4	263.4	263.4	263.4	263.4	263.4
	$kI = 5\ cm^{-2}/MeV$					
$\phi p(MeV)$	0	50	100	150	200	250
$Sb(cm/s)$	263.4	1933.4	1823.2	1728.8	1647	1575.5
	$kI = 10\ cm^{-2}/MeV$					
$\phi p(MeV)$	0	50	100	150	200	250
$Sb(cm/s)$	263.4	1823.2	1647	1512.4	1406.2	1320.3
$kI = 15\ cm^{-2}/MeV$						
$\phi p(MeV)$	0	50	100	150	200	250

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$Sb(cm/s)$	263.4	1728.8	1512.4	1361.1	1249.5	1163.9
	$kI = 20\ cm^{-2}/MeV$					
$\phi p(MeV)$	0	50	100	150	200	250
$Sb(cm/s)$	263.4	1647	1406.2	1249.5	1139.6	1058.1
	$kI = 25\ cm^{-2}/MeV$					
$\phi p(MeV)$	0	50	100	150	200	250
$Sb(cm/s)$	263.4	1575.5	1320.3	1163.9	1058.1	981.89

Under the effect of the damage coefficient, a decrease was noticed in the amplitude of the density of the minority charge carriers. With the table thus left, there is also no decrease in the rate of recombination at the rear face when the coefficient of damage increased.

2- CONCLUSION

In this present article, the effect of irradiation particles on some phenomenological parameters () and on electron density has been studied.

Starting from the study solar cell and the appropriate phenomena (D, Sb), the expression of the density of minority charge carriers is established. Following the analyzes which were carried out, we can affirm that the irradiation energy and the coefficient of damage decrease the coefficient of diffusion of the minority carriers and consequently the density of the minority carriers.

The irradiation degrades the quality of the solar cell by creating defects (gaps, interstitial sites or dislocation) thus increasing the leakage current and the duration of charge collection.

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