Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/16310
DOI URL: http://dx.doi.org/10.21474/IJAR01/16310

RESEARCH ARTICLE

THE EFFECT OF IRRADIATION ENERGY ON THE ELECTRICAL POWER OF A MONOFACIAL SILICON SOLAR CELL IN THE DYNAMIC FREQUENCY REGIME UNDER MONOCHROMATIC ILLUMINATION

El Hadji Ndiaye, Seydou Faye, Fatimata Ba, Mor Ndiaye and Issa Diagne
Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal.

Manuscript Info

Manuscript History
Received: 20 December 2022
Final Accepted: 24 January 2023
Published: February 2023

Key words:-
Monofacial Silicon Solar Cell, Frequency Modulation, Irradiation Energy, Electric Power

Abstract

In this work, we studied the influence of the irradiation energy on the electric power of a monofacial solar cell in frequency dynamic regime under monochromatic illumination. After solving the minority charge carrier continuity equation in the presence of irradiation energy, we establish new expressions for the minority charge carrier density and electrical parameters such as photocurrent density, photovoltage and electrical power. Starting from these equations, we have represented the profiles of some electrical parameters such as the electrical power finally to highlight the effect of the irradiation energy on the latter.

Introduction:-

The photovoltaic conversion is provided by a solar photocell whose conversion efficiency depends on the nature and structure of the semiconductor, its manufacturing technique and operation. Given the low efficiency of these solar cells, researchers have invested in various research projects by proposing several characterization techniques for the semiconductor material and in particular on the design of solar cells. 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 speeds of recombination (at the Sf junction, on the rear face Sb) [4-5] and the electrical parameters [6-7]. Based on theoretical studies, we propose in this article, a method for determining the electrical power of a monofacial silicon solar cell under monochromatic illumination in a dynamic frequency regime and under irradiation.

Theory

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

Corresponding Author:- El Hadji Ndiaye
Address:- Laboratory of Semiconductors and Solar Energy, Physics Department,Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal.

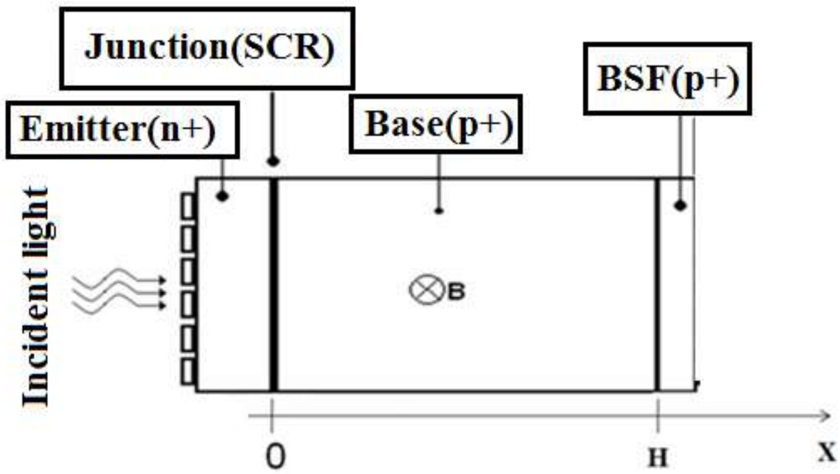


Figure. 1:- An n+-p-p+ structure of a silicon solar cell.

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:

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

Where is the density of electrons generated in the base at depth x in the base, [8] is the diffusion coefficient, G[9] the overall carrier generation rate and [10] 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.

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

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

$$g(x)=\varphi_t\alpha_t\left(1-R_t\right)\exp\left(-\alpha_t x\right) \quad \textbf{(04)}$$

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 [11]

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

Avec

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

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

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

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

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

$L\left(Kl,\varphi\right)$ 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

$L\left(Kl,\varphi,B\right)$ 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:

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

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

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

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

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

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

$$Sf=Sf_0+Sf_j\ \textbf{(14)}$$

Results and Discussions:-

Generation rate profile as a function of wavelength

The generation rate of minority carriers is given by equation (4). Its profile is shown in Figure 2 as a function of wavelength.

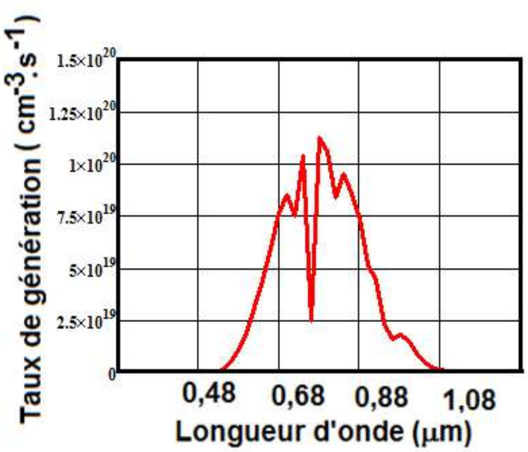


Figure 2:- Generation rate as a function of wavelength.

x=0.001cm.

On this curve, we notice that the generation rate increases with short wavelengths and gradually decreases in the case of long wavelengths. Indeed, with small wavelengths, we have a large absorption unlike with long wavelengths. This is how, for the rest of our work, we will take a wavelength located in the short wavelength zone.

Profile of the diffusion coefficient as a function of the pulsation

We represent in Figure 3 the profile of the diffusion coefficient as a function of the logarithm of the frequency for different values of the magnetic field.

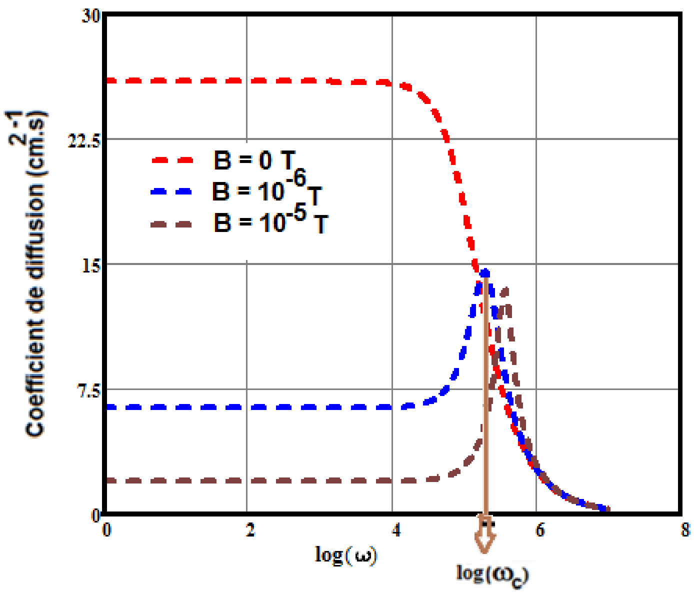


Figure 3:- Modulus of the diffusion coefficient as a function of the logarithm of the pulsation.

Kl=10 **MeV^{-1}.s^{-1} Graphically, we find that** $\omega_C = 10^{5.2}$ rad.S^{-1}

From this figure, we notice that the modulus of the diffusion coefficient is constant in quasi-static regime. However, as soon as we are in the dynamic frequency regime, we observe that the diffusion coefficient increases gradually up to a certain value of the so-called cyclotron frequency noted ωc**[9],** where we observe resonance peaks. This is how we made the choice of ωc as the value to be fixed for the frequency in the rest of the work.

Photocurrent density

The photocurrent density is the photocurrent reported at the surface of the solar cell. It is due to the diffusion of minority charge carriers across the junction. Knowing the expression for the minority carrier density, we can determine the expression for the photocurrent density using FICK's law. It is given by the following relationship:

$$J(Sf, Sb, \lambda, \omega, kl, \varphi, B) = q.D.\left.\frac{\partial \delta(x, Sf, Sb, \lambda, \omega, kl, \varphi_p, B)}{\partial x}\right|_{x=0} \quad \textbf{(15)}$$

The photocurrent density profile is shown in Figure 4 as a function of the recombination velocity at the Sf junction for different values of irradiation energy.

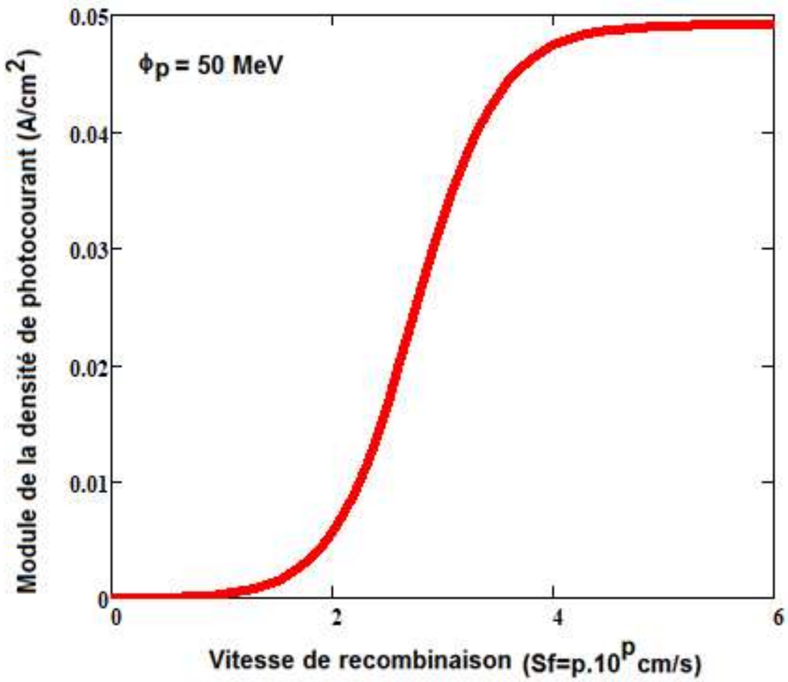


Figure 4:- Modulus of photocurrent density as a function of recombination velocity for different values of irradiation energy Kl=10 $\mathbf{MeV^{-1}.s^{-1}}$; λ=0.6µm; B= 10^{-6} T; ω =105.2 rad.S^{-1}

Note that the photocurrent increases with the recombination rate Sf and has two levels: one at low values of Sf and the other at high values of Sf. The first level reflects an open-circuit situation while the second corresponds to tothe short-circuit of the solar cell. Increasing the recombination rate at the junction allows maximum minority charge carriers to cross the junction and participate in the photocurrent. There is a remarkable decrease in the short-circuit photocurrent density when the irradiation energy increases. Indeed, the irradiation energy decreases the mobility of the carriers. Thus there will be fewer or fewer charges in the base to participate in the photocurrent.

Study of photovoltage

When the solar cell is lit, a photovoltage V appears across it, the expression of which is given by the Boltzmann relationship:

$$V = V_T \ln\left(\frac{N_b}{n_i^2}\delta(0) + 1\right) \quad \textbf{(16)}$$

Where Nb is the doping level of the base (N_b=5.10^{17} cm^{-3}) ni is the intrinsic density of the minority carriers ni=1010cm-3.

VT the thermal tension defined by the following relationship:

$$V_T = \frac{K.T}{q} \quad \textbf{(17)}$$

Knowing that :

K the Boltzmann constant.

q the charge of the electron.

T the absolute temperature at thermal equilibrium (T=300K).

The profile of the phototension as a function of the recombination speed for different values of the irradiation energy, is represented in figure 5

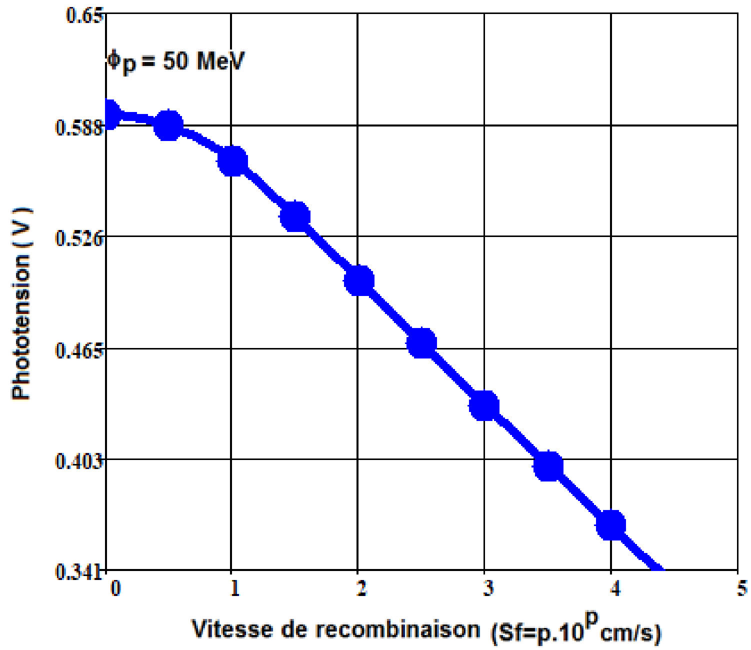


Figure 5:-Modulus of the phototension as a function of the recombination rate for different values of the irradiation energy.Kl=10 **MeV^{-1}.s^{-1}** ; λ=0.6μm; B= 10^{-6} T; ω =105.2 rad.S^{-1}

The photovoltage is maximum in open circuit. On the other hand, in short-circuit, the photovoltage is minimal and becomes asymptotic if Sf is greater than 1011 cm/s. The maximum photocurrent is obtained. This empties the base of its carriers, thus causing the phototension to drop. It is also noted that the increase in the irradiation energy leads to a decrease in the phototension due to the reduction of the minority carriers by the irradiation energy.

Study of the electric power of the solar cell.

The power supplied by the solar cell under monochromatic illumination of wavelength (λi) and for a given operating point at Sf, is expressed by the product:

P = I ·Vph(18)

We represent in figure 06 the variations of the power according to the recombination speed at the junction for different values of the irradiation energy.

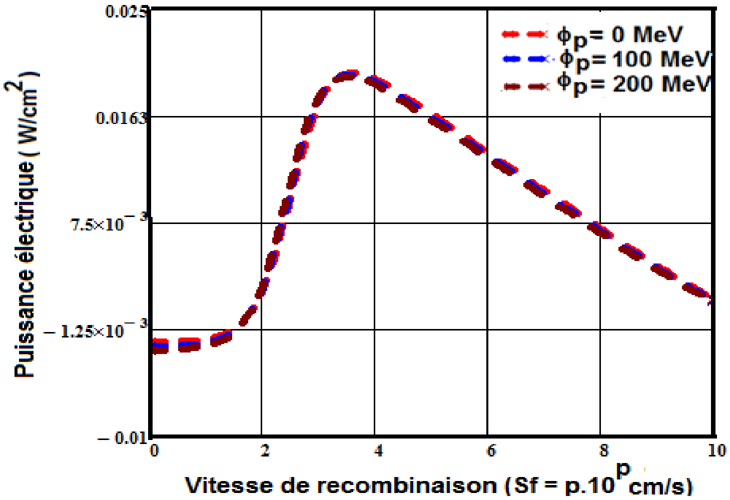
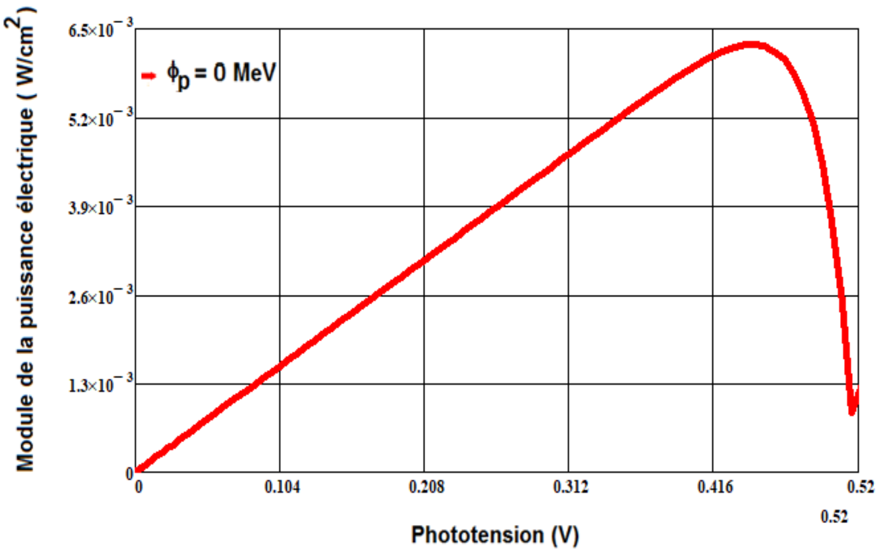


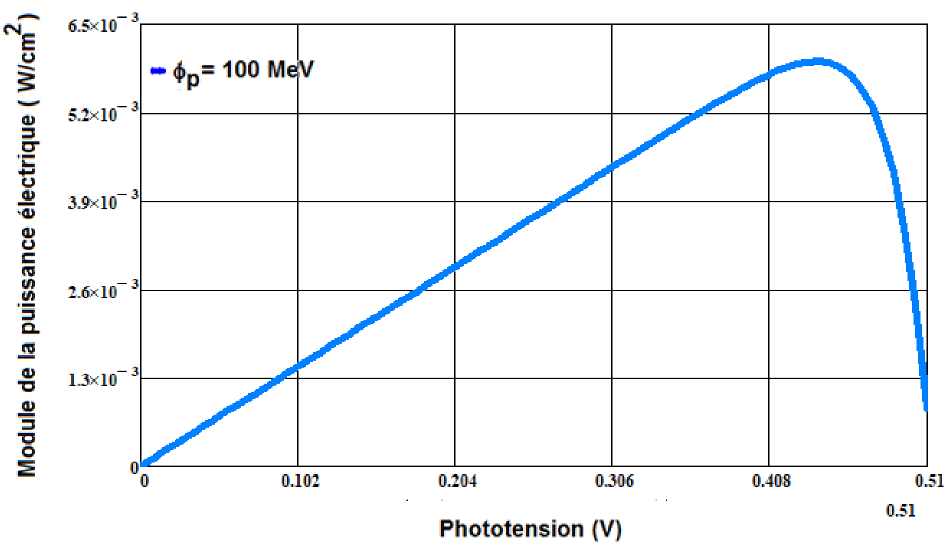
Figure 6:- Variation of power as a function of Sf for different values of irradiation energy.**Kl=10MeV^{-1}.s^{-1} ; B= 10^{-5}T;λ=0,6μm; ω=10^{5} rad.s^{-1}**

These curves essentially show two parts. In the first part, the power increases with the recombination rate at the junction up to a certain maximum, where the power decreases with the recombination rate at the junction, but it should be noted that this decrease is less marked than the increase. This maximum power is the optimum power that the solar cell can provide; it corresponds to a particular operating point (defined by a recombination speed Sf) for which there is impedance matching between the dynamic impedance of the solar cell at this point and the external load connected to the solar cell. Any difference between these two impedances (dynamic and external) causes a loss in power transfer. If we now look at the energy dependence, we observe that the power decreases with the irradiation energy; indeed, if the irradiation energy increases, the degradations will increase to a certain extent leading to a decrease (weak here) in the available power.

Study of power as a function of photovoltage.

We represent in figure 07, the variations of the power according to the tension for various values of the energy of irradiation.





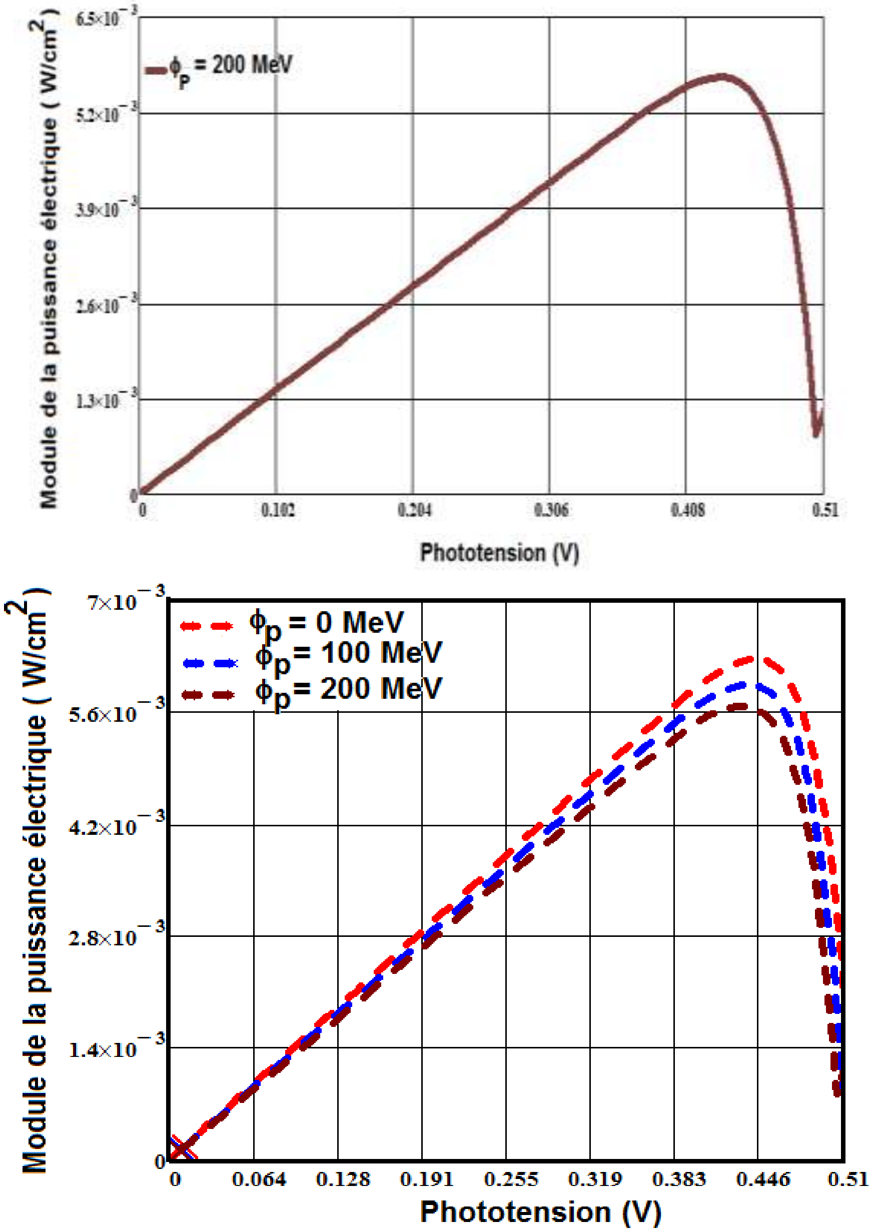


Figure 7:- Variation of electrical power as a function of photovoltage for different values of irradiation energy.**Kl=10MeV^{-1}.s^{-1}; B= 10^{-5}T; λ=0,6µm**

Table 1:- Maximum cell power as a function of irradiation energy.

□$_p$(MeV)	Pmax(W/cm^2)
0	62,67. 10^{-4}
50	60,86. 10^{-4}
100	59,49. 10^{-4}
150	58,09. 10^{-4}
200	56,78. 10^{-4}
250	55,58. 10^{-4}

The electrical power increases with the photovoltage to reach its maximum value corresponding to the maximum operating point of the solar cell. From this value, the power clearly decreases and tends towards the zero value when the voltage tends towards the value of the open circuit photovoltage. In addition, the power modulus decreases when the irradiation energy is increased, highlighting the harmful effects of irradiation on this electrical parameter of the solar cell.

Conclusion:-

In this article, we have studied the electrical parameters such as: the photocurrent density, the photovoltage and especially the electrical power. In most cases, we have highlighted the effects of phenomenological parameters such as the recombination rate at the Sf junction and then of the macroscopic parameter which is the irradiation energy. This study showed the influence of irradiation on all of these quantities considered, in particular the negative effects of the degradations caused by irradiation on electrical power. Indeed, the irradiation energy decreases the performance of the solar cell by reducing the efficiency of the solar cell.

References:-

[1]D. Sontag, G. Hahn, P. Geiger, P. Fath, E. Bucher, Two-dimensional resolution of minority carrier diffusion constants in different silicon materials, Solar Energy Materials & Solar cells, pp 533-539, 72 (2002).

[2]M. Zoungrana, I. Zerbo, A. Sere, B. Zouma, F. Zougmore 3D Study of Bifacial Silicon Solar Cell Under Intense Light Concentration and Under External Constant Magnetic Field, Global Journal of Engineering Research, vol.10, pp113-124. N.1&2, (2009).

[3]F. Ahmed and S. Garg, International Centre for Theoretical Physics (ICTP), Trieste, ITALY, Internal Report, Août 1986.

[4] I. Ly, O.H. Lemrabott, B. Dieng, I. Gaye, S. Gueye, M.S. Diouf and G. Sissoko Techniques de détermination des paramètres de recombinaison et le domaine de leur validité d'une photopile bifaciale au silicium polycristallin sous éclairement multi spectral constant en régime statique. Revue des Energies Renouvelables 187 – 206. Vol. 15 N°2 (2012).

[5] H. Ly Diallo, M. Wade, I. Ly, M. Ndiaye, B. Dieng, O.H. Lemrabott, A.S. Maïga and G. Sissoko. 1D modeling of a bifacial silicon solar cell under frequency modulation monochromatic illumination: Determination of the Equivalent Electrical circuit related to the surface recombination velocity.Research Journal of Applied Sciences, Engineering and Technology 4(12): 1672-1676, 2012.

[6] Ndiaye, M., Nouhou Bako, Z., Zerbo, I., Dieng, A., Barro, F.I. and Sissoko, G. (2008) Determination of Electrical Parameters of a Solar Cell under Monochromatic Illumination on FM, from Diagrams Bode and Nyquist. Journal des Sciences, 8, 59-69

[7] Ly Diallo, H., Dieng, B., Ly, I., Dione, M.M., Ndiaye, M., Lemrabott, O.H., Bako, Z.N., Wereme, A. and Sissoko, G. (2012) Determination of the Recombination and Electrical Parameters of a Vertical Multijunction Silicon Solar Cell. Research Journal of Applied Sciences, Engineering and Technology, 4, 2626-2631.

[8] AmadouDiao, NdeyeThiam, Martial Zoungrana, GokhanSahin, MorNdiaye, Grégoire Sissoko. (2009) Diffusion Coefficient in Silicon Solar Cell with Applied Magnetic Field and under Frequency: Electric Equivalent Circuits. World Journal of Condensed Matter Physics, 4, 2014.

[9] Sissoko, G., Museruka, C., Correa, A., Gaye, I. and Ndiaye, A.L. (1996) Spectral Light Effect on Recombination Parameters of Silicon Solar Cell. *Proceedings of World Renewable Energy Congress*, Part 3, Denver, 15-21,1487-1490.

[10] Sissoko, G., Correa, A., Nanema, E., Diarra, M.N., Ndiaye, A.L. and Adj, M. (1998) Recombination Parameters Measurement in Sijicon Double Sided Surface Field Cell. *Proceedings of the World Renewable Energy Conference*, Florence, 20-25 September 1998, 1856-1859.

[11]. **FatimataBa,PapaToutyTraore,BabouDione,MohamadouSamassaNdoye.**(2021).Effect of irradiant parameters on the mobility and density of minority carriers in frequential conditions of an n pp ++ type silicon potopile lit by its front side in monochromatic light .International Journal of Engineering Sciences & Research Technology (IJESRT), 10(7), pp: 33-46.

[12]. IbrahimaDiatta, Marcel SitorDiouf, Hameth Yoro Ba, YoussouTraore, OusmaneDiasse, Seydou Faye, Gregoire Sissoko. (2017). Temprature effect on the shunt resistance of a white biased silicon solar cell. Journal of Scientific and Engineering Research (JSAER), 4(8), pp: 11-19, ISSN: 2394-2630.

[13]. **MohamadouSamassaNdoye, BoureimaSeibou, Ibrahima Ly, Marcel SitorDiouf, Mamadou Wade, SenghaneMbodji and Gregoire Sissoko.** (2016). Irradiation effect on silicon solar cell capacitance in frequency modulation. International Journal of Innovative Technology and Exploring Engineering, 6, pp: 21-25

[14] Introduction à la Physique de L'état solide '' C. Kittel, pp. 284 – 285.