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**Research Article**

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# Impacts of irradiating particles and temperature on the photocurrent density and on the photovoltage of an n$^+$-p-n$^+$ type silicon solar cell in frequency regime under polychromatic illumination

**Fatimata Ba*, Seydou Faye, El hadji Ndiaye, Mor Ndiaye, Issa Diagne**

* Physical Department, University Cheikh Anta Diop of Dakar, 5005 Dakar, Senegal
timra654@gmail.com

**Abstract** In this work, we study the effects of irradiating particles and temperature on an n+-p-n+ type silicon solar cell. To this end, we have analyzed the responses of photocurrent density and photovoltage as a function of frequency for different irradiation energy flow $\phi p$, different damage coefficients $kI$ and different temperatures $T$ in the range $298-353K$ (knowing that test standard solar cell conditions are solar cell radiation is equal $1kW/m^2$ and temperature usually $25^{\circ}C$).

From the analysis, we can say that the temperature has a strong impact on the photovoltage and that the irradiation has a greater influence on the photocurrent density.

**Keywords** Irradiation, Irradiating particles, Damage coefficient, Irradiation Energy, Photocurrent density

## Introduction

Irradiation [1] is a phenomenon that can be natural or artificial. In space as on earth, solar cells are confronted with it and it has an impact on their normal operation. The power and efficiency of the photovoltaic module are not left out because they are impacted by other physical parameters [2] including the operating temperature.

So, starting from the following works:

- Effect of the irradiation dose on monofacial silicon solar cell parameters in static mode [3]
- Irradiation energy effect on a silicon solar cell: maximum power point determination [4]
- An investigation of temperature effects on solar photovoltaic cells and modules [5]
- Effect of irradiation on the transient response of a silicon solar cell [6]
- Theoretical study of vertical parallel junction silicon solar cell capacitance under modulated polychromatic illumination: influence of irradiation [7]
- Temperature dependence of solar cell performance – an analysis [8]
- The effect of temperature on the silicon solar cell [9]
- Effet de l'énergie d'irradiation sur la résistance série dans une photopile $(N+/P/P+)$ au silicium à jonctions verticales sériess [10]
- Temperature and $8MeV$ electron irradiation effects on GaAs solar cells [11]

we are going to conduct our investigation on the impacts of irradiation and temperature on the photocurrent density as well as on the photovoltage of a parallel vertical junction silicon solar cell previously irradiated and under temperature. The operating mode chosen is the frequency one and the illumination is polychromatic.

## Theory

The following *Figure 1* represents our $n^{+}-p-n^{+}$ [12], [13] type study solar cell:

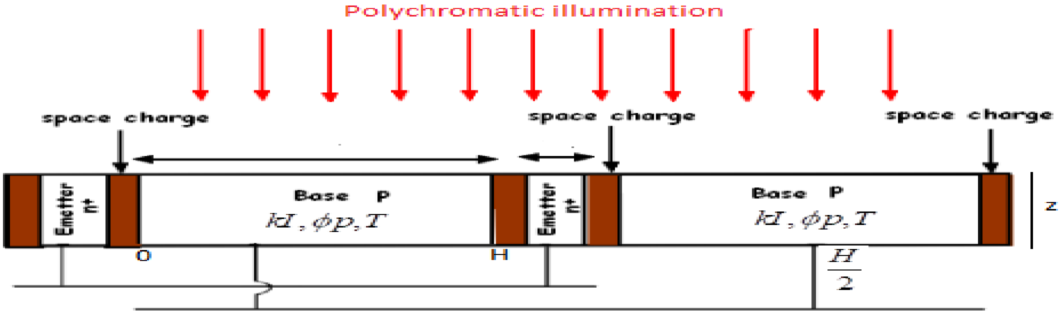

*Figure 1 : Parallel vertical junction solar cell under irradiation and under temperature*

Where **H** is the total thickness of the base and **z** is the depth of the base.

Based on the work of Ba and al [14], [15]; of Diatta and al [16]; of Ndoye and al [17] and of Diop and al [18], we can translate the physical phenomena that take place at the level of the base once our solar cell irradiated under temperature is subjected to illumination by the following continuity equation:

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

By remaining in the work of Ba and al [14], we can find the expressions of $\delta(x,t)$ and of $g(z,t)$ as a function of the temporal factor, as well as the global expressions of the diffusion coefficient $D(\omega, kI, \phi p, T)$, of the lifespan of the minority carriers after irradiation function of ($kI$ ,$\phi p$) and the recombination rate at junction $Sf$

$g(z)$ represents the charge carrier generation rate under polychromatic illumination [19]:

$$g(z) = \sum_{i=1}^{3} a_i . e^{-b_i z} \quad (2)$$

Coefficients $a_i$ and $b_i$ are deduced from modeling of the generation rate considered for the overall solar radiation spectrum $AM\ 1.5$ $[20]$ .These coefficients are given follow: $a_2 = 6.13\times10^{20} cm^{-3}/s$ ; $a_2 = 0.54\times10^{20} cm^{-3}/s$ ; $a_3 = 0.0991\times10^{20} cm^{-3}/s$ ; $b_1 = 6630 cm^{-1}$ ; $b_2 = 10^{3} cm^{-1}$ ; $b_3 = 130 cm^{-1}$.

From the resolution of the equation $(1)$ and by paying very particular attention to the expressions and the conditions of study of our previous articles, we obtain the continuity equation known as the equation of the density of the following minority charge carriers:

$$\delta(x) = A\cosh\left(\frac{x}{L(\omega, kI, \phi p, T)}\right) + B\sinh\left(\frac{x}{L(\omega, kI, \phi p, T)}\right) + \sum_{i=1}^{3} k_i . e^{-b_i z} \quad (3)$$

$$k_i = \frac{a_i}{D(\omega,kI,\phi p,T)} \cdot L^2(\omega,kI,\phi p,T) \tag{4}$$

Using the boundary conditions, the coefficients $A$ and $B$ have been determined given by [21]:

- At the junction $(x=0)$

$$D(\omega,kI,\phi p,T) \cdot \frac{\partial \delta(x)}{\partial x}\Big|_{x=0} = Sf \cdot \delta(0) \tag{5}$$

- At the middle of the base

$$D(\omega,kI,\phi p,T) \cdot \frac{\partial \delta(x)}{\partial x}\Bigg|_{x=\frac{H}{2}} = 0 \tag{6}$$

The expression of the density of the minority carriers makes it possible to access to the respective expressions of the photocurrent density and the photovoltage.

**The Photocurrent density**:

The photocurrent density is defined by Fick's relation, its expression is given as follows:

$$Jph = 2 \cdot q \cdot D(\omega,kI,\phi p,T) \cdot \frac{\partial \delta(x)}{\partial x}\Big|_{x=0} \tag{7}$$

Where :

The factor $2$ results from the two junctions around the base and the fact that they are connected in parallel manner and $q$ is the elementary charge electrons $(1.6 \times 10^{-19} Coulomb)$.

**The Photovoltage**:

The photovoltage accross the junction is expressed by means of excess minority carriers' density at the junction $(x=0)$ according to Boltzmann's relation:

$$Vph = V_T \ln\left[\frac{N_B}{n_i^2(T)} \cdot \delta(0) + 1\right] \tag{8}$$

Given that this paper investigates the impacts of temperature of the performance of some parameters of solar cell cells based on the semiconductor material Silicon, the intrinsic carrier's density varies according to the temperature [22].

$$n_i(T) = CT^{\frac{3}{2}} \cdot \exp\left(\frac{-Eg}{2 \cdot K_B \cdot T}\right)$$

(9)

$C$ is a constant equal to $3.87 \times 10^{16} cm^{-3}.K^{-\frac{3}{2}}$ ; $Eg$ is the silicon gap energy, it is a function of the temperature [23], its expression is given as follows:

$$Eg = Eg(T) = Eg(0) - \frac{\alpha T^2}{\beta + T} \tag{10}$$

$Eg(0) = 1.1557 eV$ : band gap level at atmospheric temperature; $\alpha$ and $\beta$ are constant coefficients of photovoltaic cell material of Silicon with $\alpha = 7.021 \times 10^{-4} eVK^{-1}$ ; $\beta = 1108K$

$V_T$ the thermal voltage given by: $V_T = \dfrac{K_B \cdot T}{q}$ , $N_B$ the doping density of the base $(N_B = 10^{16}cm^{-3})$ , $K_B = 1.38\times10^{-23} m^2.kg.s^{-2}.K^{-1}$ the Boltzmann constant

## Results & Discussion

### Impacts of irradiation and temperature on photocurrent density.

From equation 7 , we plot the respective profiles $2(a,b,c)$ of photocurrent density as a function of angular frequency for different irradiation energy flow, different damage coefficients and different values of temperature. To do this, we opted to work with a high value of the recombination velocity at the junction $(Sf_j = 5.10^5 cm/s)$ in order to obtain a massive crossing of the electrons at the junction and to collect a maximum of current.

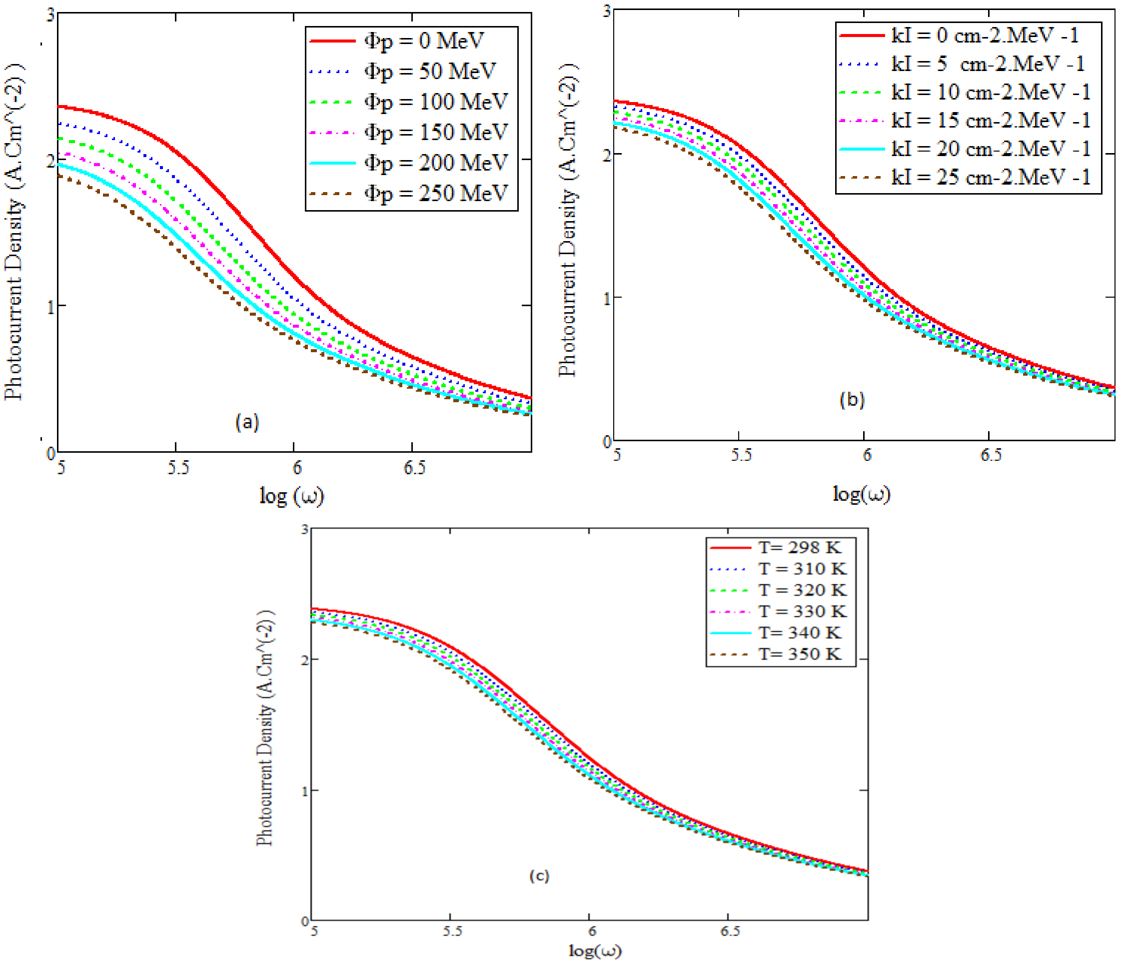

*Figure 2: Photocurrent density versus frequency*

$(a)\ \kappa I = 15cm^{-2}/MeV$ ; $(b)\ \phi p = 50MeV$ ; $(c)\ \kappa I = 0cm^{-2}/MeV$ ; $\phi p = 0MeV$ .

$Sf_j = 5.10^5 cm/s$ ; $z = 0.00002cm$ ; $T = 310K$ in $(a)$ and in $(b)$

The following tables list the values of the maximum current density according to $\phi p$ , $kI$ and $T$ .

**Table 1:** Values of the maximum current density for different irradiation energies $\phi p$

| $\phi p\ (MeV)$ | **0** | **50** | **100** | **150** | **200** | **250** |
|---|---|---|---|---|---|---|
| $\lvert Jph\rvert\ (A/cm^{-2})$ | 2.3572 | 2.2433 | 2.1401 | 2.0467 | 1.9621 | 1.8853 |

**Table 2 :** Values of the maximum current density for different damage coefficients $kI$

| $kI(cm^{-2}/MeV)$ | **0** | **5** | **10** | **15** | **20** | **25** |
|---|---|---|---|---|---|---|
| $\lvert Jph\rvert\ (A/cm^{-2})$ | 2.3572 | 2.3199 | 2.2779 | 2.2444 | 2.2052 | 2.1734 |

**Table 3 :** Values of the maximum current density for different temperatures $T$

| $T(K)$ | **298** | **310** | **320** | **330** | **340** | **350** |
|---|---|---|---|---|---|---|
| $\lvert Jph\rvert\ (A/cm^{-2})$ | 2.3819 | 2.3572 | 2.3367 | 2.3162 | 2.2948 | 2.2723 |

**Impacts of irradiation and temperature on photovoltage**

Like the plots made with the photocurrent density, we do the same for the photovoltage. We obtain the following profiles $3(a,b,c)$ :

These profiles show two levels in figures $3(a)$ and $3(b)$ . As soon as a frequency threshold is reached for each of these curvatures in these two cases, we have a reversal of the situation. The amplitude of the phototension at low flux of irradiating energy is greater than that at high flux. In these tables below, we have listed the value of the maximum amplitude of the photovoltage corresponding more or less to the open circuit voltage according to the variations of the irradiation and those of the temperature.

**Table 4 :** Values of the maximum photovoltage for different irradiation energies $\phi p$

| $\phi p\ (MeV)$ | **0** | **50** | **100** | **150** | **200** | **250** |
|---|---|---|---|---|---|---|
| $\lvert Vph\rvert\ (V)$ | 0.58379 | 0.58366 | 0.58354 | 0.58341 | 0.58327 | 0.58315 |

**Table 5 :** Values of the maximum photovoltage for different damage coefficients $kI$

| $kI(cm^{-2}/MeV)$ | **0** | **5** | **10** | **15** | **20** | **25** |
|---|---|---|---|---|---|---|
| $\lvert Vph\rvert\ (V)$ | 0.58379 | 0.58374 | 0.58370 | 0.58366 | 0.58362 | 0.58358 |

**Table 6 :** Values of the maximum photovoltage for different temperatures $T$

| $T(K)$ | **298** | **310** | **320** | **330** | **340** | **350** |
|---|---|---|---|---|---|---|
| $\lvert Vph\rvert\ (V)$ | 0.60755 | 0.58379 | 0.56391 | 0.54395 | 0.52392 | 0.50382 |

Of these profiles and apart from the impact of the large angular frequencies, the impact of the irradiation is more intense than that of the temperature with regard to the density of photocurrent. On the other hand, for the phototension it is the reverse which occurs.

The maximum amplitude of the photocurrent density corresponding approximately to the short-circuit current decreases with the increase of the irradiating particles $(\phi p, kI)$.

Indeed, the irradiation energy reduces the mobility of the carriers at the level of the junction and the more it increases, the more the degradations caused are important within the material, which implies a reduction in the photocurrent density and the photovoltage.

With the increase in the coefficient of damage, there is an increase in the probability of creation of defects by irradiation and therefore of greater leaks, hence the amplitude of the current density and of the photovoltage which decrease.

As for the increase in temperature, it is at the origin of a strong thermal agitation resulting in an unordered mobility of the carriers. Thus, a drop is noted in the amplitude of the photocurrent density at large temperature values

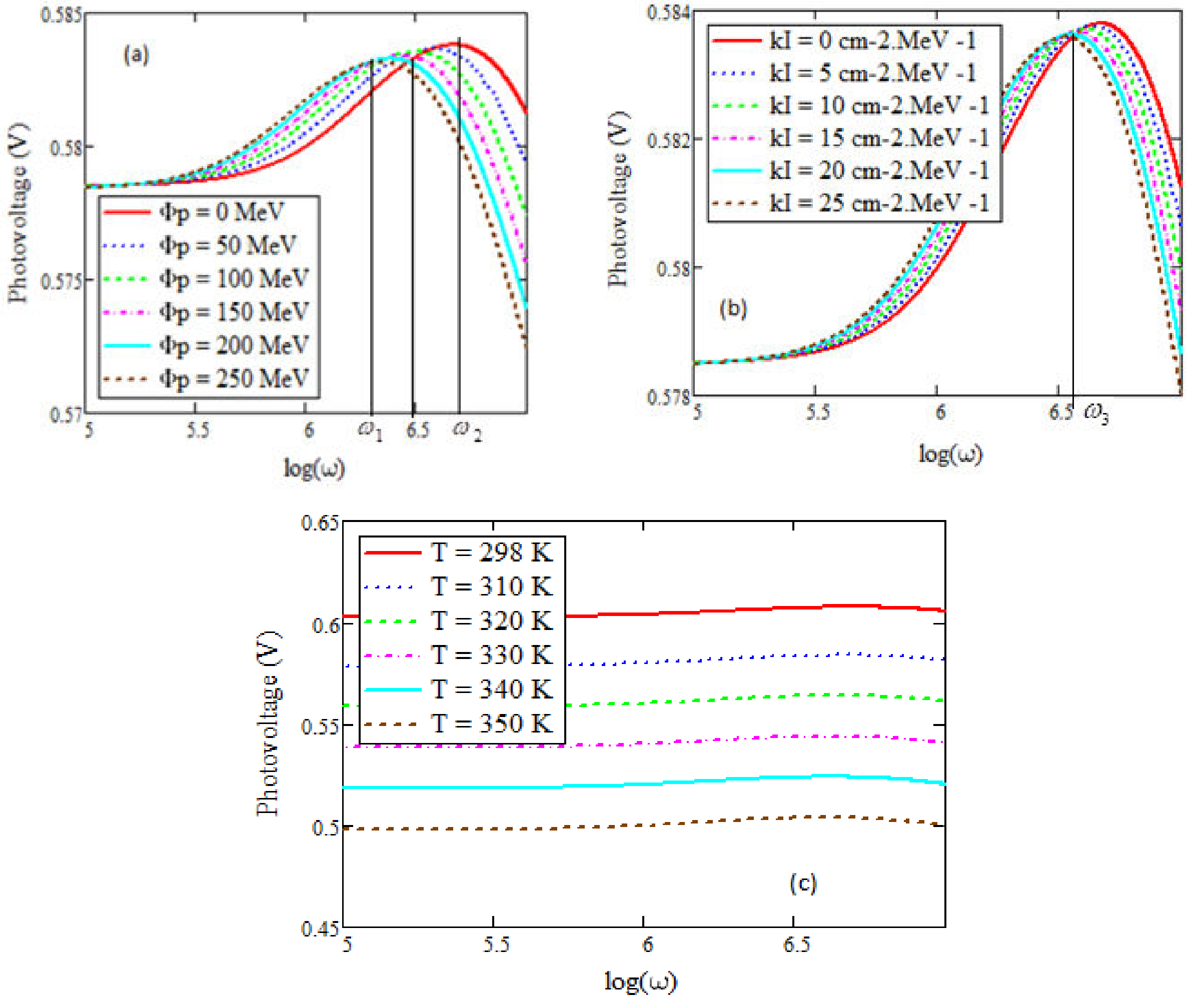

*Figure 3: Photovoltage versus frequency*

$(a)$ for $\neq \Phi p$ , $\kappa I = 15cm^{-2}/MeV$ ; $(b)$ for $\neq \kappa I$ , $\phi p = 50MeV$ ;

$(c)$ for $\neq T$ , $\kappa I = 0cm^{-2}/MeV$ ; $\phi p = 0MeV$

$Sf = 2.10^{2} cm/s$ ; $z = 0.00002cm$ ; $T = 310K$ in $(a)$ and in $(b)$

## Conclusion

In this article, the study focused on the impacts of irradiation and temperature of some performance measurement parameters of a parallel vertical junction silicon solar cell under polychromatic illumination in frequency modulation (the photocurrent density and phototension).

At the end of his research, we can say that both irradiation and temperature have a negative impact on current density and photovoltage.

However, temperature impacts photovoltage more than photocurrent density. The latter is more affected by irradiating particles than by temperature.

## References

[1]. Joseph J. Loferski. (1966). The effects of electrons and proton irradiation on thin film solar cells. Revue de Physique Appliquée, Société française de physique/EDP ,1(3), pp: 221-227.

[2]. Hassan K, Yousuf SB, Tushar MSHK, Das BK, Das P, Islam MS. Effects of different environmental and operational factors on the PV performance: A comprehensive review (2022). Energy Sci Eng, 10, pp: 656-675 .doi :10.1002/ese3.1043

[3]. Idrissa GAYE, Doudou GAYE, Abdourahmane DIALLO, Adam SAYOUDI BOUZOU, Mamadou WADE. (2022). Current Trends in Technology and Science, Volume 11, Issue 4, pp: 16–21, ISSN: 2279-0535.

[4]. Ba, M.L., Diallo, H.L., Ba, H.Y., Traore, Y., Diatta, I., Diouf, M.S., Wade, M. and Sissoko, G. (2018. Journal of Modern Physics, 9, pp: 2141-2155, ISSN: 2153-120X.

[5]. A.D. Dhass, E. Natarajan, P. Lakshmi. (2014). International Journal of Engineering (IJE), Vol. 27, No. 11, pp: 1713-1722.

[6]. I. Gaye, R. Sam, A.D. Seré, I.F. Barro, M.A. Ould El Moujtaba, R. Mané, G. Sissoko. (2012). International Journal of Emerging Trend and Technology in Computer Science (IJETTCS), Volume 1, Issue 3, pp: 210-214, ISSN: 2278-6865.

[7]. Ndeye Madeleine DIOP, Boureima SEIBOU, Mamadou WADE, Marcel Sitor DIOUF, Ibrahima LY,Hawa Ly DIALLO,Grégoire SISSOKO. (2016). International Journal of Intonative Technologie and Explorions Engineering (IJITEE),Volume 6 Issue 3, pp: 1-7, ISSN: 2278-3075.

[8]. Priyanka Singh, N.M. Ravindra. (2012). Elsevier, Solar Energy Materials & Solar Cells 10, pp: 36-45.

[9]. Asif Javed. (2014). International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS),14 -643, pp : 305-308, ISSN : 2279-0055

[10]. Oumar DIA, Mamadou Lamine BA, Gora DIOP, Ibrahima DIATTA, Mor SARR, Mamadou WADE and Grégoire SISSOKO. (2021). International Journal of Advanced Research (IJAR), 9(11), pp: 985-997, ISSN : 2320-5407.

[11]. Asha Rao, Sheeja Krishnan, Ganesh Sajeev and K Siddappa. Pramana. (2010). Journal of Physics, Vol. 74, No. 6, pp: 995-1008.

[12]. J.D. Arora, S.N. Singh and P.C. Marthur. (1981).Surface recombination effects on the performance of $n+p$ step and diffused junction silicon solar cell.Solid State Electronics, XXIV(8), pp: 739-747.

[13]. M.M. Dione, S. Mbodji, L. Samb, M. Dieng, M. Thiame, S. Ndoye, F.I. Barro, G. Sissoko. (2009). Vertical junction under constant multispectral light: Determination of recombination parameters. Proceedings of the 24th European Photovoltaic Solar Energy Conference, pp: 465-469.

[14]. Fatimata Ba, Boureima Seibou, Mamadou Wade, Marcel Sitor Diouf, Ibrahima Ly and Grégoire Sissoko (2016). Equivalent electric model of the junction recombination velocity limiting the open circuit of a vertical parallel junction solar cell under frequency modulation. IPASJ International Journal of Electronics & Communication (IIJEC), Volume 4, Issue 7, pp: 1-11 ,ISSN : 2321-5984

[15]. Fatimata Ba,Papa Touty Traore,Babou Dione,Mohamadou Samassa Ndoye.(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.

[16]. Ibrahima Diatta, Marcel Sitor Diouf, Hameth Yoro Ba, Youssou Traore, Ousmane Diasse, 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.

[17]. Mohamadou Samassa Ndoye, Boureima Seibou, Ibrahima Ly, Marcel Sitor Diouf, Mamadou Wade, Senghane Mbodji 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.

[18]. Ndeye Madeleine Diop, Boureima Seibou, Mamadou Wade, Marcel Sitor Diouf, Ibrahima Ly, Hawa Ly Diallo, Grégoire Sissoko. (2016). Theoretical study of vertical parallel junction silicon solar cell capacitance under modulated polychromatic illumination: influence of irradiation. International Journal of Intonative Technologie and Explorions Engineering (IJITEE), Volume 6 Issue 3, pp: 1-7, ISSN: 2278-3075.

[19]. J. Furlan and S. Amon. (1985). Approximation of the carrier generation rate in illuminated silicon. Solid State Electr., XVIII(12), pp: 1241-1243.

[20]. S.N. Mohammad. (1987). An alternative method for performance analysis of silicon solar cells. J. Appl. Phys. 61(2), pp: 767-772.

[21]. A. Hamidou, A. Diao, S.A. Douani, A. Moissi, M. Thiame, F.I. Barro and G. Sissoko. (2013). Determination of a vertical parallel junction solar cell under multispectral illumination steady state. International Journal of Innovative Technology Exploring Engineering (IJITEE), II(3), pp: 1-6.

[22]. C.D. Thurmond. (Aug 1975). The standard thermodynamic functions for the formation of electron and hole in Ge, Si, GaAs and GaP. Journal of Electrochemical Society, 122, 8, pp: 1133-1144.

[23]. Varshni, Y.P. (1967). Temperature dependence of the energy gap in semiconductors. Physica, Vol. 34, p. 149.