Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2021, 8(11):9-15

Research Article ISSN: 2394 - 658X

Influence of Wavelengths on the Photocurrent Density and on the Internal Quantum Efficiency of an Irradiated Monofacial Photopile of Type N + PP +

Fatimata BA, Papa Touty Traore, Seydou Faye and Babou Dione

Laboratoire des Semi-conducteursetd' Energie Solaire, Faculté des Sciences et Techniques, Université Cheikh Anta Diop, Dakar, Sénégal
badione2016@gmail.com

ABSTRACT

In this article, the influence of the wavelengths of electromagnetic radiation on the photocurrent density and on the percentage of the number of electrons created and collected relative to the number of photons absorbed from an irradiated monofacial solar cell has made the object of the study.

From the establishment of the scattering coefficient and the density of the minority carriers, the expressions of the photocurrent density and the internal quantum efficiency are established and studied as a function of the wavelength for different: angular frequencies, energies of irradiations and damage coefficients.

Key words: Irradiating particles, Photocell, wavelength, Internal Quantum Efficiency, UV, Infrared

INTRODUCTION

The solar spectrum used as a reference in the photovoltaic industry corresponds to an illumination of at a temperature of with a crossing (Air Mass where G means global because taking into account both direct and diffuse radiation) called the standard test conditions (STC) [1]. This definition of the spectrum is all the more important as it will impact the performance of photovoltaic devices. The limited performance of solar cells has been studied by several groups of researchers including the famous work of Shockley and Queisser [2].There is also the work of M. Green [3], H. Kiess [4] and F. Meillaud et al [5]. The various loss factors are due to purely physical restrictions related to the material, or to technological limitations induced by the manufacturing process.

1) Physical losses
i. Losses by long wavelength photons
ii. Losses due to excess photon energy
iii. Voltage factor
iv. Fillfactor
2) Technological losses
I. Reflectivity
ii. Shading rate
iii. Absorption efficiency
iv. Collection efficiency

In addition to these limitations, there is also the influence of the series resistance and the shunt resistance.

The fill factor (ff) and the efficiency (η) provide information on the overall performance of the structure. To detail these characteristics as a function of the wavelength used, the parameters $IQE; EQE$ (respectively internal quantum efficiency and external quantum efficiency) are introduced.

In this article, the variation of the photocurrent density and the internal quantum efficiency (IQE) of an irradiated monofacial solar cell, under monochromatic illumination and under frequency condition is highlighted.

STUDYMODEL

Study device

The following figure represents the single-face silicon-based study solar cell of the type n^+pp^+ [6],[7], initially irradiated with charged particles and subjected to monochromatic illumination.

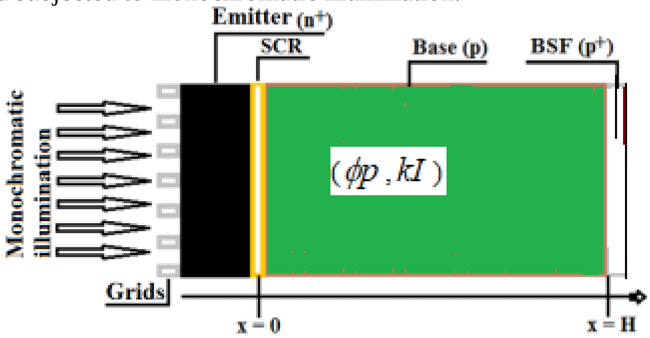

Fig. 1 An n^+pp^+ type of a silicon solar cell under irradiation

The continuity equation that governs the phenomena that take place there after illumination is:

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

Where,

i- $D(\omega,kI,\phi p,T)$ represents the complex diffusion coefficient of electrons in the base of the solar cell under irradiation and under temperature [8], [9], [10],[11]. F. Ba et al establish its full expression with an explicit determination of the parameters in the article [12] where the temperature 310 K corresponds to a diffusion coefficient of which is specific to microcrystalline silicon.

ii- $\delta(x,t)$ and $g(x,t)$ respectively represent 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 [13], [14]:

$$\delta(x,t)=\delta(x)\cdot\exp(j\omega t) \quad (2)$$

$$g(x,t)=g(x)\cdot\exp(j\omega t) \quad (3)$$

$$g(x)=\alpha_\lambda\cdot\phi_\lambda\cdot(1-R_\lambda)\cdot\exp(-\alpha_\lambda\cdot x) \quad (4)$$

α_λ represents the monochromatic absorption coefficient of the material , R_λ : the monochromatic reflection coefficient of the material for a wavelength λ ; φ_λ : the incident flux of monochromatic light,: the thickness of the base of the solar cell or the depth of penetration of the incident flux of light.

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

$$\delta(x,\omega,\lambda,kI,\phi p,T)=A\cdot\cosh\left(\frac{x}{L(\omega,kI,\phi p,T)}\right)+B\cdot\sinh\left(\frac{x}{L(\omega,kI,\phi p,T)}\right)+K(\omega,kI,\phi p,T)\cdot\exp(-\alpha_\lambda\cdot x) \quad (5)$$

With,

$$K(\omega,\lambda,kI,\phi p,T)=-\frac{\alpha_\lambda\cdot\phi_\lambda\cdot(1-R_\lambda)\cdot\cdot L(\omega,kI,\phi p,T)^2}{D(\omega,kI,\phi p,T)\cdot\left[\alpha_\lambda{}^2L_\omega{}^2-1\right]} \quad (6)$$

The coefficients A and B will be determined from the boundary conditions [15]:

- At the base transmitter junction

$$\frac{\partial\delta(x,\omega,\lambda,kI,\phi p,T)}{\partial x}\Big|_{x=0}=\frac{Sf}{D(\omega,kI,\phi p,T)}\delta(0,\omega,\lambda,kI,\phi p,T) \quad (7)$$

Sf : represents the rate of recombination at the junction [16], [17], [18]

$$Sf = Sf_o + Sf_m \tag{8}$$

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

$Sf_m = m.10^m$: Recombination rate which relates to the external load imposing the operating point of the solar cell

- On the back side

$$\frac{\partial \delta(x,\omega,\lambda,kI,\phi p,T)}{\partial x}\Big|_{x=H} = -\frac{Sb}{D(\omega,kI,\phi p,T)}\delta(H,\omega,\lambda,kI,\phi p,T) \tag{9}$$

Sb : Recombination rate of charge carriers on the rear face [19], [20].

The internal quantum efficiency (IQE) is the number of electrons created and collected for each absorbed photon. It is obtained by taking into account the specific characteristics of the cell (diffusion length, surface and volume recombination); its expression is given as follows:

$$IQE(\omega, j, p,\lambda,kI,\phi p,T) = \frac{EQE(\omega, j, p,\lambda,kI,\phi p,T)}{(1-R_\lambda)} \tag{10}$$

$(1-R_\lambda)$: is the transmitted part of the incident photon flux in the material.

$$EQE(\omega, j, p,\lambda,kI,\phi p,T) = \frac{Jph(\omega, j, p,\lambda,kI,\phi p,T)}{q\cdot\phi_\lambda} \tag{11}$$

$$IQE(\omega, j, p,\lambda,kI,\phi p,T) = \frac{Jph(\omega, j, p,\lambda,kI,\phi p,T)}{q\cdot(1-R_\lambda)\cdot\phi_\lambda} \tag{12}$$

q : Elementary charge of the electron; $Jph(\omega, j, p,\lambda,kI,\phi p,T)$: photocurrent density, its expression is given by the relation called Fick relation.

$$Jph(\omega, j, p,\lambda,kI,\phi p,T) = q\cdot D(\omega,kI,\phi p,T)\cdot\frac{\partial \delta(x,\omega,\lambda,kI,\phi p,T)}{\partial x}\Big|_{x=0} \tag{13}$$

The figure below illustrates the variation of the photocurrent density as a function of the wavelength for different values of the rate of recombination at the junction.

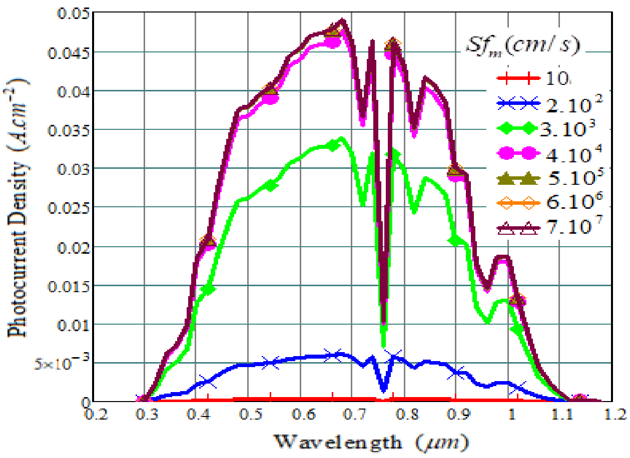

Fig. 2 Photocurrent Density versus Wavelength for different values of the recombination velocity at the junction.

$\omega = 10^5 rad/s$; $kI = 15cm^{-2}/MeV$; $\phi p = 50MeV$; $T = 310K$

From this plot, we have a small variation in the photocurrent density for low and long wavelengths. The absorption peak is obtained at $\lambda = 0.68\mu m$ where the photocurrent density is at its maximum. Beyond that, there is a decrease in the latter as a function of the wavelength.

Only energy photons $E = \frac{h \cdot c}{\lambda} \succ Eg = \frac{h.c}{\lambda g}$ ($h = 6{,}62 \times 10^{-34} J.s$: Planckconstant; $c = 3 \times 10^{8} m.s^{-1}$: speed of light ; Eg : silicon gap energy) can be called. The absorbed energy allows electrons to pass from the valence band to the conduction band, hence the positive gradient observed for the photocurrent density at low wavelengths (part of the visible + UV).

In the infrared range, increasing the wavelength decreases the photocurrent density.And this decrease is more marked for the high recombination speeds at the junction. The following table shows a distribution of the wavelengths and the gap energy of silicon at a temperature $T = 300K$

Table-1 Wavelength of electromagnetic radiation

Ray	**Wavelength**	**Photon Energy**
UV	$100 - 380\ nm$	$3.26 - 124\ eV$
VISIBLE	$380 - 750\ nm$	$1.65 - 3.26\ eV$
INFRARED	$750 - 1200\ nm$	$0.0012 - 1.65\ eV$

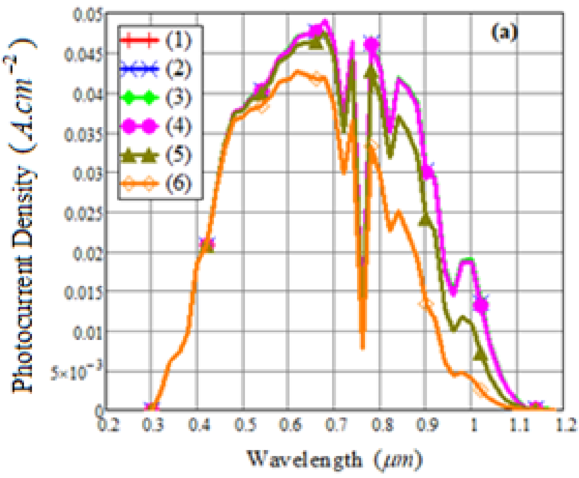

Figure 3a

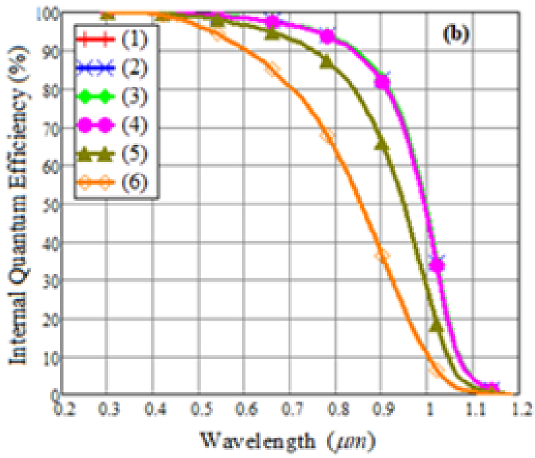

Figure 3b

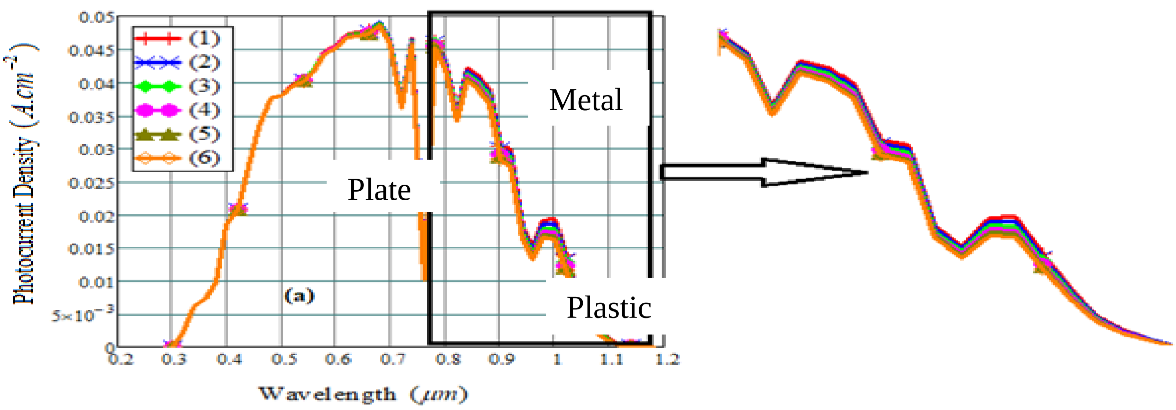

Figure 4a

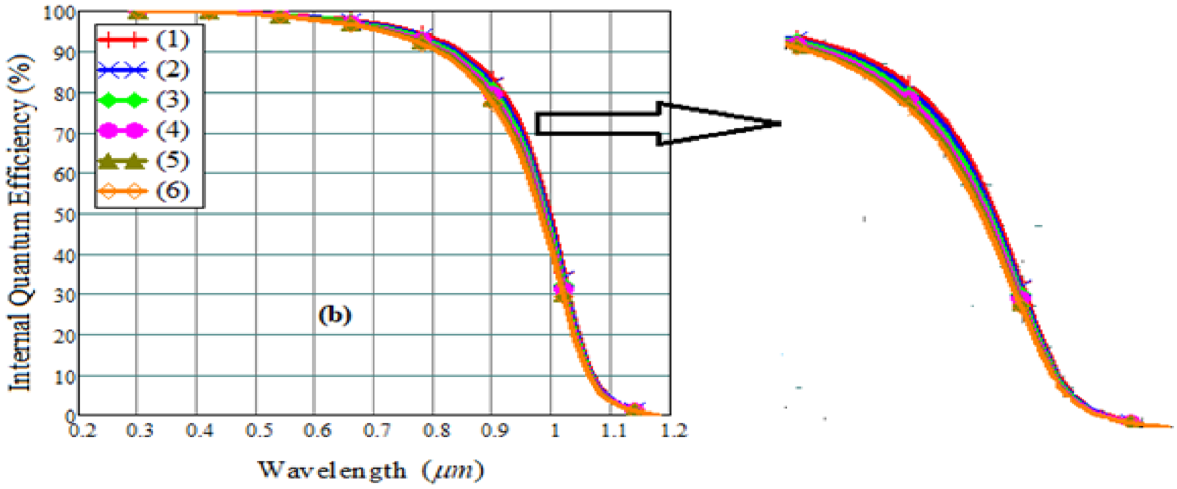

Figure 4b

Fig. 3,4,5 : (a) Photocourant Density and (b) Internal Quantum Efficiency versus Wavelength

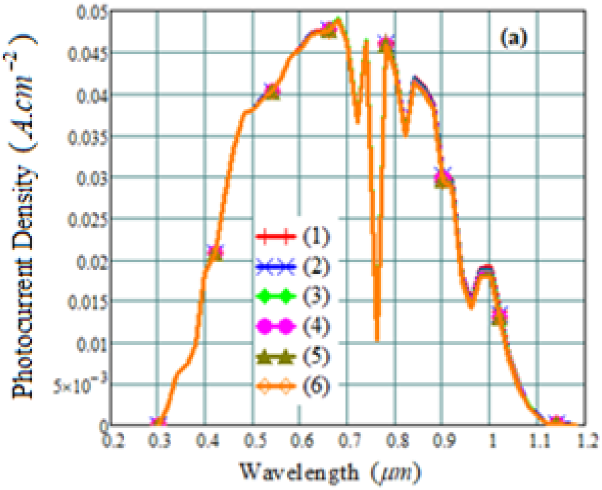

Figure 5a

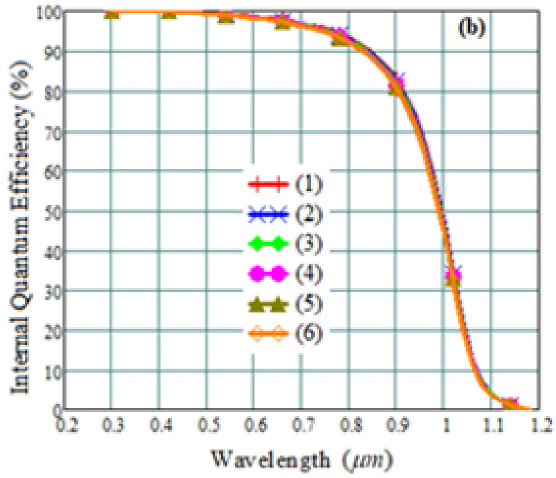

Figure 5b

Fig. 3,4,5 : (a) Photocourant Density and (b) Internal Quantum Efficiency versus Wavelength

Table -2 List of different data taken to plot the figures above:

Figures $3(a,b)$	For $\neq \omega(rad/s)$ $(1):10^2 rad/s$; $(2):10^3 rad/s$; $(3):10^4 rad/s$; $(4):10^5 rad/s$; $(5):10^6 rad/s$; $(6):10^7 rad/s$; $\phi p = 50MeV$; $kI = 15cm^{-2}/MeV$;
Figures $4(a,b)$	For $\neq \phi p(MeV)$ $(1):0MeV$; $(2):50MeV$; $(3):100MeV$; $(4):150MeV$; $(5):200MeV$; $(6):250MeV$; $\omega = 10^5 rad/s$
Figures $5(a,b)$	For $\neq kI(cm^{-2}/MeV)$ $(1):5cm^{-2}/MeV$; $(2):10cm^{-2}/MeV$; $(3):15cm^{-2}/MeV$; $(4):20cm^{-2}/MeV$; $(5):25cm^{-2}/MeV$; $Sf_m = 6.10^6 cm/s$; $\omega = 10^5 rad/s$
$T = 310K$; $Sf_m = 6.10^6 cm/s$; $Sb(\omega, \lambda, kI, \phi p, T)$	

The various quantum efficiency profiles as a function of the wavelength have generallyobtained a constancy and then a progressive decrease as a function of the wavelength.

- For $0.3\mu m \le \lambda \le 0.68\mu m$, the internal quantum efficiencyleaves an absolute maximum and thendecreases as the wavelengthincreases (from 99% to 97%). There is a strong absorption of veryenergetic incident photons.
- For $0.68\mu m \prec \lambda \le 1.12\mu m$, the internal quantum efficiencygraduallydecreases (from 97% to 2%). At thesewavelengths, the absorption coefficient of siliconbecomeslower and lower, resulting in low absorption of lessenergetic incident photons.

Under the effect of the angularfrequency and of the irradiatingparticles (irradiation energy and damage coefficient kI)), the amplitude of the photocurrentdensity and of the internal quantum efficiencydecreases. We have :

- under the effect of the angularfrequency (ω) : a break in the generation of excessminority carriers thusleading to a decrease in the photocreated carriers participating in the photocurrent.
- under the effect of the irradiation energy (ϕp) and the damage coefficient (kI) : a decrease in the diffusion coefficient of the minority carriers and consequently in the photocurrentdensity.

The diminutive because the energy of photons in the infrareddomainismuchlowerthan the energy of the band gap or gap energy. In addition, variations in internal quantum efficiency are related to the effects of back surface recombination and the short diffusion length of carriers. As the wavelengthincreases, theseeffectsincrease and the internal quantum efficiencydecreases.

CONCLUSION

In this article, the effect of wavelength on photocurrent density and on internal quantum efficiency has been investigated. Short wavelengths (part of Ultra Violet $+$ Visible) are designated on the front panel, while long wavelengths (Infrared) can be designated on the rear panel. The different variations of the internal quantum efficiency are explained by the variation of the photocurrent. In addition, the internal quantum is a function of the photocurrent density.

Thus, the study of internal quantum efficiency provides information on the quality of the front and rear of our solar cell.

REFERENCES

[1]. Measurement of Photovoltaic Current-Voltage Characteristics, 2nd ed., IEC Standard 60904-3, 1989.

[2]. W. Shockley and H.J.Queisser,'' Detailed Balance Limit of Efficiency of p-n Junction Solar Cells'', J. App. Phys., Vol. 32, p. 510, juin 1961.

[3]. M.A.Green,'' Solar cells : Operating principles, technology , and system applications '', Englewood Cliffs, 1982

[4]. H.Kiess, ''On the ultimate efficiency of solar cells'', Sol. Energy Mater. Sol. Cells, vol. 38, n° 1-4 , pp. 45-55 , 1995.

[5]. F. Meillaud , A. Shah , C. Droz , E. Vallat – Sauvain , and C. Miazza , ''Efficiency limits for single-junction and tandem solar cells'', Sol. Energy Mater. Sol. Cells, vol. 90, n°. 18-19, pp. 2952-2959, 2006.

[6]. Chenidhya, D., Kirtikara, K. and Jivacata, C. (2005) PV Module Dynamic Impedance and its Voltage Frequency Dependencies. Solar Energy Materials and Solar Cells, 89, pp. 243-251.

[7]. Hubner, A., Aberle, A.G and Hezel, R. (2001) 20% Efficient Silicon Solar Cells Bifacial. 14th European PVSEC, Munich, pp. 1796- 1798

[8]. Mor Ndiaye, Zeinabou Nouhou Bako, Alfred Dieng, Fabé Idrissa Barro, G. Sissoko,'' Détermination des paramétres électriques d'une photopile sous éclairement monochromatique en modulation de fréquence à partir des diagrammes de Bode et de Nyquist'', J. Scie., VIII(3), pp. 56-68, 2008.

[9]. N. Thiam, A. Diao, M. Wade, M. Ndiaye, I. Zerbo, M. Sarr, A.S. Maiga and G.Sissoko, ''Study of the photothermal response of a monofacial solar cell in dynamique regime under a multispectral illumination'', Research Journal of Applied Sciences, Engineering and Technology, pp. 1-8, 2012.

[10]. A. Dieng, L. Ould Habiboulahy, A.S. Maiga, A. Diao, G. Sissoko. Impedance spectroscopy method applied to electrcal parameters determination on bifacial silicon solar cell under magnetic field. J. Scie. Vol. 7, N°3 (2007), pp. 48-52.

[11]. Ibrahima TALL, Boureima SEIBOU, Mohamed Abderahim Ould El Moujtaba, Amadou DIAO, Mamadou WADE, Gregoire SISSOKO (2015) Diffusion Coefficient Modeling of a Silon Solar Cell under Irradiation Effect in Frequency : Electric Equivalent Circuit.International Journal of Engineering and Technology Trends (IJETT), 19, pp. 56-61.

[12]. Fatimata Ba, Papa Touty Traore,Babou Dione,Mohamadou Samassa Ndoye, ''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''.International Journal of Engineering Sciences & Research Technology (IJESRT), 10(7), July ,2021, pp. 33-46

[13]. J.N. Hollenhort and G. Hasnain,'' Frequency dependent whole diffusion in InGaAs double heterostrucutures'', Appl. Phys. Lett., LXIV(15), pp. 2203-2205, 1995.

[14]. A.Mandelis,'' Coupled ac photocurrent and photothermal reflectance response theory of semiconducting p-n junctions'', Journal of Applied Physics, LXVI(11), pp. 5572-5583, 1989.
[15]. G. Sissoko, C. Musereuka, A. Corréa, I. Gaye, A.L. Ndiaye. ''Light spectral effect on recombination parameters of silicon solar cell '', World Renewable Energy Congress, part III, pp.1487 – 1490, (1996).
[16]. G. Sissoko, E. Nanema, A. Correa, P.M. Biteye, M. Adji, A. L. Niaye, ''Silicon solar cell recombination parameters determination using the illumination I-V Characteristic'', Proceedings of the World Renewable Energy Conference Florence-Italy, pp. 848-1851, 1998.
[17]. H.L. Diallo, A.S. Maiga, A. Wereme and G. Sissoko, ''New approach of both junction and back surface recombination velocities in a 3D modeling study of a polycrystalline silicon solar cell'', Eur. Phys. J. Appl. Phys., XLII, pp. 193-211, 2008.
[18]. S. Mbodji, I. Ly, H.L. Diallo, M.M. Dione, O. Diasse and G. Sissoko, ''Modeling Study of N+/P Solar Cell Resistances from Single I-V Characteristic Curve Considering the Junction Recombination Velocity (Sf)'', Res. J. Appl. Sci. Eng. Technol., IV(1), pp. 1-7, 2012.
[19]. Fossum, J.G. (1977) Physical Operation of Back – Surface – Field Silicon Solar Cells. IEEE Transactions on Electron Devices, 2, pp. 322-325.
[20]. Joardar, K., Dondero, R.C. and Schroda, D.K. (1989) A Critical Analysis of the Small – Signal Voltage – Decay Technique for Minority – Carrier Lifetime Measurement in Solar Cells.Solid – State Electronis, 32, pp. 479-483.