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(Research Article)

Influence of the magnetic field on the shunt resistance of an n+p-p+ silicon solar cell in the frequency modulation

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Abstract

A photovoltaic cell is a device that generates electricity directly from visible light. Several factors affect the conversion efficiency of solar cells. Parasitic resistances such as the shunt resistance is a fundamental parameter of the equivalent electrical model of the solar cell, which induces the leakage current of electrical charges when its value is low. It represents all leakage currents within the solar cell. It is also an indicator of good or poor quality of a solar cell, since a high value indicates low leakage current through the cell, and vice versa. A number of measurement techniques are used to determine the leakage current, in particular electrical current and voltage.

Keywords: Solar Cell; Magnetic Field; Shunt Resistance; Series Vertical Junction

1. Introduction

Problems of energy supply and use are pollution, acid precipitation, ozone depletion, forest destruction and emissions of radioactive linked not only to global warming, but also to environmental concerns such as air substances. To prevent these effects, some potential solutions have evolved, including energy conservation through proven energy efficiency, reduced fossil fuel consumption and increased environmentally-friendly energy supplies.

Among them, electricity generation with the solar cell system has received a great deal of research attention because it appears to be one of the possible solutions to the environmental problem [1] solar energy is the energy that comes from the sun. The energy is used by solar cells, which convert sunlight into direct electrical current.

Solar cells are composed of various semiconductor materials. Semiconductors are materials that become conductors of electricity when exposed to light or heat.

Authors [4, 5, 6, 7] have highlighted the effects of shunt resistors on solar cell performance. They show conclusively that shunt resistors can adversely affect the performance of solar cells and PV modules. Previous work has been carried out on shunt resistors Rsh in static [8, 9, 10] transient [11,12], and frequency modulation [13,14,15] regimes. In this paper, we study the influence of the magnetic field on the shunt resistance of a series vertical junction silicon n+p-p+ type solar cell in frequency modulation.

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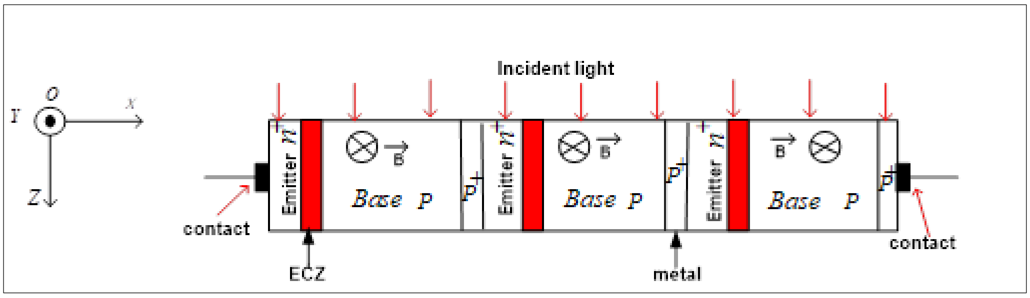
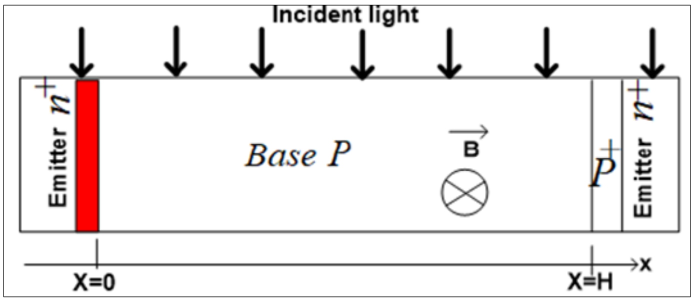
2. Study model and mathematical problem solving

2.1. Study model

This study is based on a vertical junction silicon solar cell, with the following assumptions: the thicknesses of the space charge region and the emitter are very small compared to that of the base, so their contributions are neglected so that only the contribution of the base is taken into account. Figure 1 shows an n+-p-p+ series vertical junction silicon solar cell from [16] under monochromatic illumination and applied magnetic field and a single cell. The magnetic field vector $\vec{B}$is perpendicular to the plane (xoz).



a)



b)

Figure 1 (a) A series vertical junction solar cell with an applied magnetic field, (b) A single structure of a vertical junction solar cell with an applied magnetic field.

2.2. Mathematical problem solving

When the solar cell is under light excitation, generation, recombination and diffusion phenomena occur in the base. The minority carriers photogenerated in the base are governed by the continuity equation in the frequency-dynamic regime [17, 18].

$$D^{*}.\frac{\partial^{2}\delta(x,z,t)}{\partial x^{2}}-\frac{\delta(x,z,t)}{\tau}=-G(z,t).+\frac{\partial\delta(x,z,t)}{\partial t} \quad (1)$$

Where x and z represent the horizontal and vertical depths respectively. D^* is the complex electron diffusion coefficient as a function of magnetic field and modulation frequency. τ is the average charge carrier lifetime and t is the time. Its expression in the frequency dynamic regime under the effect of the magnetic field is given by the following equation.

$$\boldsymbol{D_n^*}=\frac{D_n\left[\left(1+\tau_n^2(\omega_c^2+\omega^2)\right)+i.\omega.\tau_n\left(\tau_n^2(\omega_c^2-\omega^2)-1\right)\right]}{\left(1+\tau_n^2(\omega_c^2+\omega^2)\right)^2+4.\omega^2.\tau_n^2} \quad (2)$$

$\boldsymbol{D_n^*}$ the complex diffusion coefficient of electrons as a function of magnetic field and modulation frequency, and $\boldsymbol{D_n}$ the intrinsic diffusion coefficient of electrons without an applied magnetic field [19, 20].

Where ω is the angular modulation frequency (ω=2πf with f the frequency); $\boldsymbol{\tau_n}$ the average lifetime of minority carriers; with q and m_e being the electron's elementary charge and mass respectively, B the intensity of the applied magnetic field.

The overall generation rate is given by [21]:

$$G(z,t) = g(z).e^{i\omega t} \tag{3}$$

where g (z) the spatial component and $e^{i\omega t}$ the temporal component, ω the angular frequency and i the pure imaginary. The expression for the generation rate g (z) is:

$$g(z) = \phi.\alpha.(1-R)e^{-\alpha.z} \tag{4}$$

Where ϕ is the monochromatic incident flux of light, α is the monochromatic absorption coefficient of the material, and R is the monochromatic reflection coefficient of the material.

The density of minority charge carriers can be expressed as [22]:

$$\delta(x,z,t) = \delta(x,z).e^{i\omega t} \tag{5}$$

δ(x, z): is the spatial part. Replacing equations (3) and (5) in equation (1) gives:

$$\frac{\partial^2\delta(x,z,\lambda,\omega,B)}{\partial x^2} - \frac{\delta(x,z,\lambda,\omega,B)}{L^2(\omega,B)} = -\frac{g(z)}{D(\omega,B)} \tag{6}$$

We pose:

$$L^2(\omega,B) = \tau.D(\omega,B) \tag{7}$$

The general solution to equation (6) is:

$$\delta(x,z,\lambda,\omega,B) = K_1.e^{\frac{x}{L(\omega,B)}} + K_2.e^{-\frac{x}{L(\omega,B)}} + \frac{L^2(\omega,B)}{D(\omega,B)}.\phi.\alpha.(1-R)e^{-\alpha.z} \tag{8}$$

Coefficients K_1 and K_2 are determined by boundary conditions [23].

- at the transmitter-base junction (x=0):

$$D^*.\left.\frac{\partial\delta(x,z)}{\partial x}\right|_{x=0} = Sf.\delta(x,z)|_{x=0} \tag{9}$$

- in the middle of the base in x=H/2:

$$\left.\frac{\partial\delta(x,z)}{\partial x}\right|_{x=\frac{H}{2}} = 0 \tag{10}$$

With H the depth of the solar cell base along the horizontal, Sf the recombination rate at the junction [24, 25]. Photocurrent density is due to the diffusion of minority charge carriers across the emitter-base junction. The photocurrent density of the solar cell is obtained by grading the density of minority carriers at the junction; its expression is given by [26]:

$$J_{ph}(x,\ z,\omega,\lambda,B,\ Sf) = q.D(\omega,B)\left.\frac{\partial\delta(x,z,\omega,\lambda,B,Sf)}{\partial x}\right|_{x=0} \tag{11}$$

Where q is the electron's elementary charge.

3. Results and discussion

3.1. Photocurrent versus photovoltage characteristic Jph-Vph.

The Jph-Vph characteristic explains the evolution of photocurrent as a function of photovoltage for different operating points of the solar cell. The profile of the Jph-Vph characteristic for different magnetic field values is shown in Figure 2.

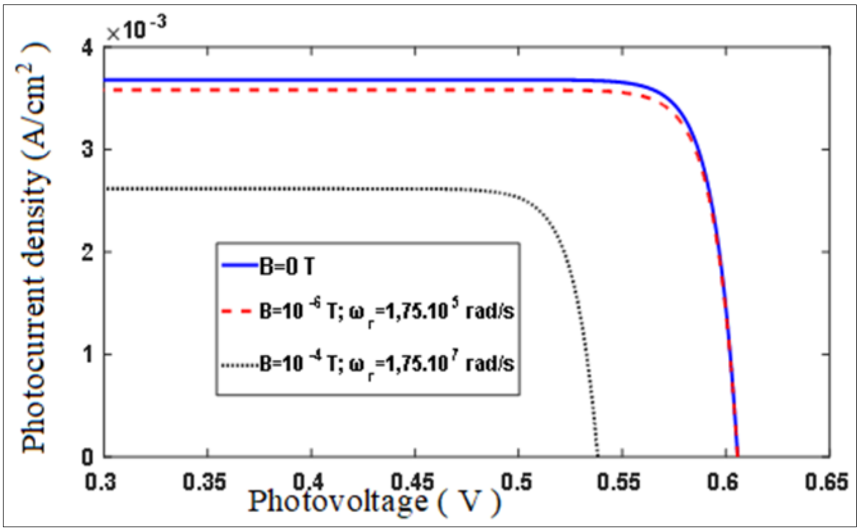


Figure 2 Jph-Vph characteristic for different magnetic field values. z=0.002 cm; λ=0.86 µm

In figure 2, all three curves show the same pattern. It can be seen that photocurrent density is at its highest, and virtually constant, at low photovoltage levels: in this range, the solar cell is operating in a short-circuit condition. As the solar cell's photovoltage tends towards higher values, photocurrent decreases: the solar cell operates in open-circuit mode.

Moreover, the application of a magnetic field reduces the amplitude of the short-circuit photocurrent and the open-circuit photovoltage for a given wavelength.

3.2. Shunt resistance in the vicinity of the short circuit

3.2.1. Theoretical approach to determining shunt resistance

Shunt resistance, also known as parallel resistance, is due to impurities, surface conditions, dangling bonds and imperfections in the p-n junction (or p-i-n for amorphous silicon), which cause leakage currents through the solar cell. The higher the Rsh, the better the cell [27].

It has almost no effect on open-circuit photovoltage, but has a considerable influence on short-circuit photocurrent. It can be determined from the current-voltage characteristic. The current-voltage characteristic is shown in figure 3.

In Figure 3, for given values of applied magnetic field and angular frequency, the curve shows a zone where the photocurrent corresponds to the short-circuit photocurrent. This zone lies within the range [5.10^5cm/s ; 8.10^8 cm/s] of the recombination speed at the junction. The solar cell operates in a short-circuit situation; it can be assimilated to a current generator.

In this zone, the short-circuit photocurrent decreases slightly as the photovoltage rises from a value close to zero to a higher value: there is then an electrical quantity linked to this variation in short-circuit photocurrent, which can be called "leakage resistance" or "shunt (or parallel) resistance". In the vicinity of short-circuit operation, we can propose an equivalent electrical circuit shown in figure 4.

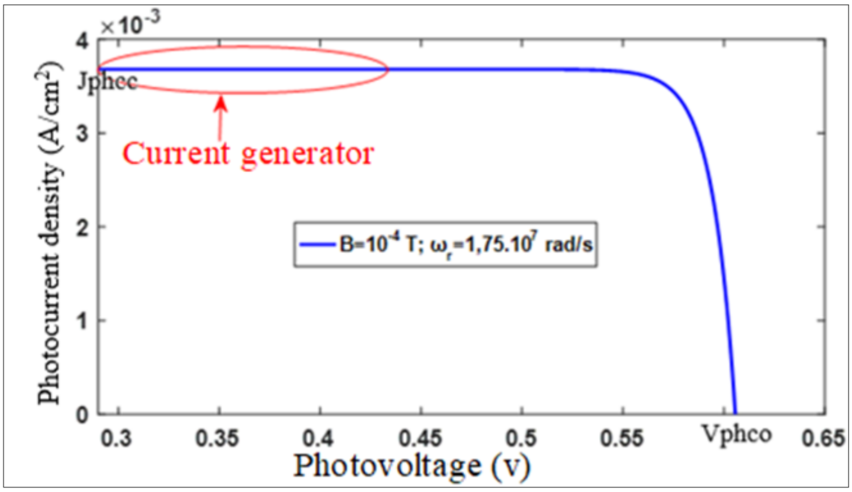


Figure 3 Current-voltage characteristic

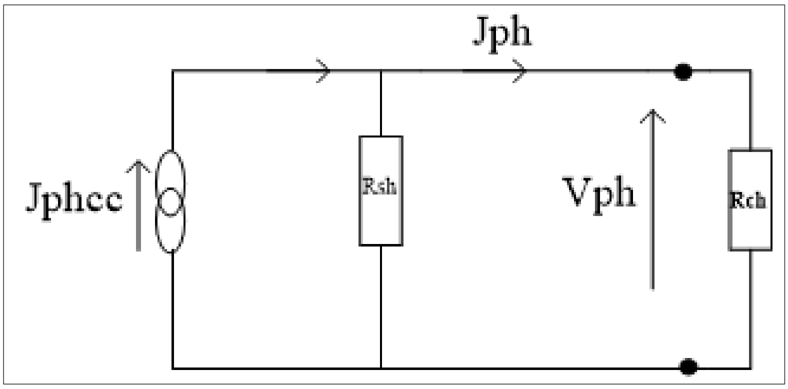


Figure 4 Equivalent electrical circuit of the solar cell in a short-circuit situation

Where Jphcc is the short-circuit photocurrent; Jph the photovoltage as a function of the recombination rate at the junction; Rsh the shunt (or parallel) resistance; Rch the load resistance and Vph the photovoltage across Rch.

Applying the law of meshes to this circuit, we obtain:

$$V_{ph}(\omega, B, \lambda, z, Sf) = Rsh(\omega, B, \lambda, z, Sf) \times [J_{phcc}(\omega, B, \lambda, z, Sf) - J_{ph}(\omega, B, \lambda, z, Sf)] \quad (12)$$

The shunt resistance is therefore:

$$\mathrm{Rsh}(\omega, \mathrm{B}, \lambda, \mathrm{z}, \mathrm{Sf}) = \frac{\mathrm{V_{ph}}(\omega,\mathrm{B},\lambda,\mathrm{z},\mathrm{Sf})}{\mathrm{Jphcc}(\omega,\mathrm{B},\lambda,\mathrm{z}) - \mathrm{Jph}(\omega,\mathrm{B},\lambda,\mathrm{z},\mathrm{Sf})} \quad (13)$$

3.2.2g Influence of the magnetic field on the shunt resistors

The influence of the magnetic field on the shunt resistor is shown in Figure 5:

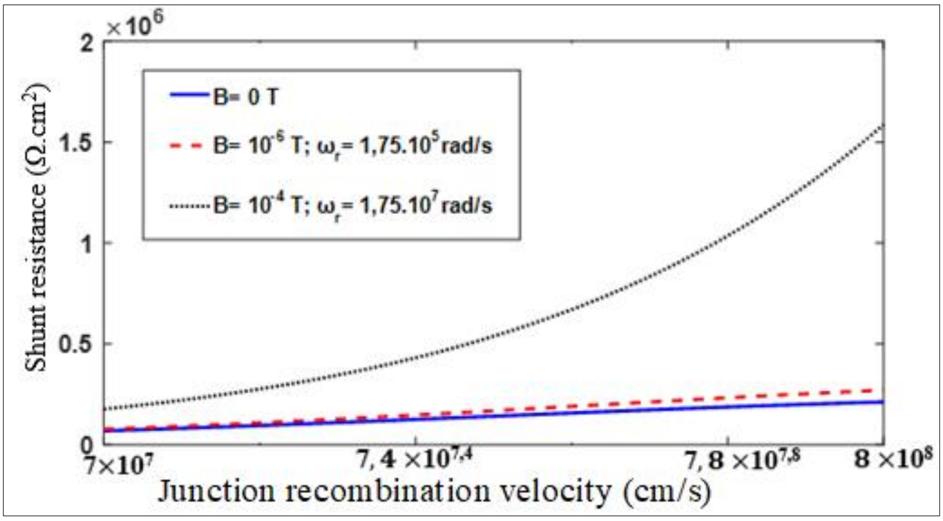


Figure 5 Shunt resistance profile as a function of junction recombination rate for different magnetic field values. z=0.002 cm; λ=0.86 µm

Figure 5 shows the same curves for resistance calibration. For a given curve, the shunt resistance increases with the junction recombination velocity. As the recombination rate increases, the number of photogenerated minority carriers crossing the junction also increases: there is a likely decrease in recombined minority carriers, consequently, this leads to a low leakage current, resulting in an increasing shunt resistance.

In such cases, we can say that the increase in shunt resistance corresponds to a good quality solar cell. When a magnetic field is applied to the solar cell at a given angular frequency, the amplitude of the shunt resistance calibration curve increases.

In fact, the applied magnetic field slows down the diffusion of photogenerated minority carriers, or diverts them from their initial trajectories towards the solar cell's lateral surfaces. This leads to a decrease in leakage currents, which in turn leads to an increase in shunt resistance, but no statement can be made about the quality of the solar cell.

The cut-off frequency ω_c as a function of the magnetic field is given by the following relationship:

$$\omega_c = \frac{q.B}{m_e} \quad (14)$$

Where ω_c is the cyclotron frequency, i.e. the frequency of the electron on its orbit in the presence of the magnetic field. This relationship enabled us to obtain a dependence between magnetic field intensity and resonance frequency ω_r. The following table shows the correlation between magnetic field intensity, resonant frequency and shunt resistance for a recombination speed at the junction Sf= 8.10^8 cm/s. The following table shows the correlation between the magnetic field (resonance frequency) and the shunt resistance.

Table 1 Some values of magnetic field and shunt resistance for Sf=8.108 cm/s

Resonance frequency ω_r (rad/s)	Magnetic Field B (T)	Shunt Resistance Rsh $(10^6\Omega.cm^2)$
0	0	0.20
1.75×10^5	10^{-6}	0.31
1.75×10^7	10^{-4}	1.54

This table highlights some values of magnetic field and shunt resistance for Sf= 8.10^8 cm/s. It shows conclusively that as the magnetic field increases, the shunt resistance becomes considerable. Indeed, when the magnetic field is applied, almost all minority carriers are deflected towards the sides of the solar cell before reaching the junction, thus reducing the number of minority carriers lost through the junction and increasing the shunt resistance.

4. Conclusion

The shunt resistance is determined using the current-voltage characteristic. This study shows conclusively that the applied magnetic field tends to slow down or deflect photogenerated minority carriers towards the junction: their diffusion is slowed down and their trajectories are modified. Applying the magnetic field and resonant frequency to the base of the solar cell increases the amplitude of the shunt resistance. When the magnetic field (for a given resonant frequency) is applied, almost all minority carriers are deflected towards the sides of the solar cell before reaching the junction, thus reducing the number of minority carriers lost through the junction, lowering the leakage current and increasing the shunt resistance.

Compliance with ethical standards

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Disclosure of conflict of interest

The author has no conflict of interest in this study.

References

[1] F. Dincer and M. Meral, "Critical Factors that Affecting Efficiency of Solar Cells," Smart Grid and Renewable Energy, Vol. 1 No. 1, 2010, pp. 47-50. doi: 10.4236/sgre.2010.11007.

[2] V. Hung and L. Thanh, "Thermodynamic Properties of Semiconductors with Defects," Materials Sciences and Applications, Vol. 2 No. 9, 2011, pp. 1225-1232. doi: 10.4236/msa.2011.29166.

[3] Van Dyk, E. E., & Meyer, E. L.(204) "Analysis of the effect of parasitic resistances on the performance of photovoltaic modules. Renewable Energy". Vol 29(3) , pp.333–344.

[4] Sharma, A. K., Agarwal, S. K., & Singh, S. N.(2007) "Determination of front surface recombination velocity of silicon solar cells using the short-wavelength spectral response. Solar Energy Materials and Solar Cells", vol 91(15-16), pp.1515–1520 https://doi:10.1016/j.solmat.2007.04.018

[5] Mohammad, S.N. (1987) "An Alternative Method for the Performance Analysis of Silicon Solar Cells". Journal of Applied Physics, vol 61(2), pp:767-772 https://doi.org/10.1063/1.338230

[6] Yadav, P., Pandey, K., Tripathi, B., Kumar, C.M., Srivastava, S.K., Singh, P.K. and Kumar, M. (2015) " An Effective Way to Analyze the Performance Limiting Parameters of a Poly-Crystalline Silicon Solar Cell Fabricated in the Production Line''. Solar Energy, vol 122, pp:1-10.https://doi.org/10.1016/j.solener.2015.08.005

[7] Green, M.A. (1995) '' Silicon Solar Cells Advanced Principles & Practice Printed by Bridge Printer Pty. Ltd. pp: 29-35 Dunning Avenue, Roseberry, Centre for Photovoltaic Devices and Systems

[8] ly, I., Ndiaye, M., Wade, M., Thiam, N., Gueye, S., & Sissoko, G.(2013) " Concept of Recombination Velocity Sfcc at the Junction of a Bifacial Silicon Solar Cell, in Steady State, Initiating the Short-Circuit Condition", Research Journal of Applied Sciences, Engineering and Technology, vol 5(1), pp: 203–208

[9] S. Mbodji, I. Ly, H. L. Diallo, M.M. Dione, O. Diassé and G. Sissoko(2012) "Modeling Study of N+/P Solar Cell Resistances from Single I-V Characteristic Curve Considering the Junction Recombination Velocity (Sf)" Research Journal of Applied Sciences, Engineering and Technology,vol 4(1), pp: 1-7

[10] J.J. Liou, F.A. Lindholm, and D.C. Malocha,(1998)"Forward-voltage capacitance of heterojunction space charge regions", J.Appl.Phys.vol 63 (10), pp: 5015-5022

[11] Zondervan, A., Verhoef, L. A., & Lindholm, F. A., (1998) "Measurement circuits for silicon-diode and solar-cell lifetime and surface recombination velocity by electrical short-circuit current decay", IEEE Transactions on Electron Devices, vol 35(1), pp.85–88

[12] Zouma, B., Barro, F. and Aziz Honadia, P. (2021) " Silicon Solar Cell Space Charge Region and Capacitance Behavior under Electric Field''. Energy and Power Engineering, vol 13, pp: 41-50. doi: 10.4236/epe.2021.131003.

[13] Ba, F., Seibou, B., Wade, M., Diouf, M.S., Ly, B., & Sissoko, G.,(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"vol 4 (7) , pp.1-11.

[14] J. H. Scofield,(1995) "effets of series resistance and inductance on solar cell admittance measurements", Solar Energy Materials and Solar Cells, vol 37 (2) , pp:217-233

[15] Mohamadou Samassa NDOYE, Boureima SEIBOU, Ibrahima LY, Marcel Sitor DIOUF, Mamadou WADE, Senghane MBODJI, Grégoire SISSOKO (2016) ''Irradiation Effect on Silicon Solar Cell capacitance in Frequency Modulation'' International Journal of Innovative Technology and Exploring Engineering (IJITEE) Vol 6(3), pp: 21-25

[16] Sourabié, I. , Zerbo, I. , Zoungrana, M. , Combari, D. and Bathiebo, D. (2017) '' Effect of Incidence Angle of Magnetic Field on the Performance of a Polycrystalline Silicon Solar Cell under Multispectral Illumination'' Smart Grid and Renewable Energy, vol8, pp:325-335. Doi: 10.4236/sgre.2017.810021.

[17] Ba, M. , Thiam, N. , Thiame, M. , Traore, Y. , Diop, M. , Ba, M. , Sarr, C. , Wade, M. and Sissoko, G. (2019) '' Base Thickness Optimization of a (n+-p-p+) Silicon Solar Cell in Static Mode under Irradiation of Charged Particles'' Journal of Electromagnetic Analysis and Applications,vol11, pp:173-185. doi: 10.4236/jemaa.2019.1110012

[18] Mamadou Yacine BA, Mame Faty MBAYE FALL, Mbi KABORE,Gora DIOP, Ibrahima DIATTA, Mor SARR,Mamadou SALL,Mamadou WADE and Gregoire SISSOKO (2021) ''ETUDE DE LA CAPACITE D'UNE PHOTOPILE AU SILICIUM A JONCTIONS VERTICALES SERIES SOUS ECLAIREMENT MONOCHROMATIQUE'' Int. J. Adv. Res. Vol 9(12), pp : 126-135 D OI:10.21474/IJAR01/13884

[19] A. Diao, N. Thiam, M. Zoungrana, M. Ndiaye, G. Sahin and G. Sissoko (2014) "Diffusion coefficient in silicon solar cell with applied magnetic field and under frequency: Electric equivalent circuits", World Journal of Condensed Matter Physics, vol 4, pp 1-9, http://dx.doi.org/10.4236/wjcmp.2014

[20] Diatta, I., Ly, I. , Wade, M. , Diouf, M. , Mbodji, S. and Sissoko, G. (2016) '' Temperature Effect on Capacitance of a Silicon Solar Cell under Constant White Biased Light'' World Journal of Condensed Matter Physics,vol 6, pp:261-268.Doi: 10.4236/wjcmp.2016.63024.

[21] Shaban, S. (2020) ''The Solar Cell Parameters as a Function of Its Temperature in Relation to Its Diurnal Efficiency'' Optics and Photonics Journal, vol10, pp: 1-12. Doi: 0.4236/opj.2020.101001.

[22] Sada Traore, Idrissa Gaye, Oulimata Mballo, Ibrahima Diatta, Richard Mane, Mor Ndiaye, Mohamed Abderahim El Moujtaba and Gregoire Sissoko(2021) ''MINORITY CARRIER'S MOBILITY DETERMINATION IN THE BASE REGION OF N+-P-P+SILICON SOLAR CELL UNDER EFFECTS OF IRRADIATION FLUX, TEMPERATURE AND MAGNETIC FIELD''Int. J. Adv. Res.vol 9(08), pp:694-703 DOI:10.21474/IJAR01/1331

[23] Adhikari, S. , Kayastha, M. , Ghimire, D. , Aryal, H. , Adhikary, S. , Takeuchi, T. , Murakami, K. , Kawashimo, Y. , Uchida, H. , Wakita, K. and Umeno, M. (2013) '' Improved Photovoltaic Properties of Heterojunction Carbon Based Solar Cell''. Journal of Surface Engineered Materials and Advanced Technology,vol 3, pp:178-183. Doi: 10.4236/jsemat.2013.33024.

[24] Samoura, A, Sakho, O , Faye, O. and Beye, A. (2017) ''Base Doping Effects on the Efficiency of Vertical Parallel Junction Solar Cells''. Open Journal of Applied Sciences, vol7, pp: 282-290. Doi: 10.4236/ojapps.2017.76023.

[25] Gora Diop, hamet yoro ba, ndeye thiam, youssou traoré, Babou Dione, mamour Amadou ba, Pape Diop, Masse Samba DIOP, Oulimata MBALLO and Grégoire SISSOKO (2019) ''Base thickness Optimization of a vertical series junction silicon solar cell under magnetic field by the concept of back surface recombination velocity of minority carrier'' ARPN Journal of Engineering and Applied Sciences vol.14(23) pp: 1-8

[26] Fossum, J. G.(1977) '' Physical operation of back-surface-field silicon solar cells. IEEE Transactions on Electron Devices, vol. 24(4), pp: 322–325. Doi : 10.1109/t-ed.1977.18735

[27] Thomas Mambrini. Thèse de doctorat ''Caractérisation de panneaux solaires photovoltaïques en conditions réelles d'implantation et en fonction des différentes technologies''. Météorologie. Université Paris Sud - Paris XI, 2014. Français.pp.47-75