ijar
ISSN NO. 2320-5407

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/15158
DOI URL: http://dx.doi.org/10.21474/IJAR01/15158

RESEARCH ARTICLE

OPTIMIZATION OF SILICON SOLAR CELL BASE THICKNESS, WHILE ILLUMINATED BY A LONG WAVELENGTHMONOCHROMATIC LIGTH: INFLUENCE OF BOTH LORENTZ LAW AND UMKLAPP PROCESS

Sega Diagne[1], Ousmane Sow[1], Gora Diop[2,4], Richard Mane[2], Ibrahima Diatta[2], Djiby Ndiongue[1], Youssou Traore[1], Lemrabott Habiboullah[3], Mamadou Wade[4] and Gregoire Sissoko[2]

1. Institut Universitaire de Technologie. Université Iba Der THIAM de Thiès-Sénégal.
2. Groupe International de Recherche en Energie Renouvelable(GIRER). BP. 15003, Dakar, Sénégal.
3. Ecole Supérieure Multinationale de Télécommunication, Dakar, Sénégal.
4. Ecole Polytechnique de Thiès, BP A10, Thiès, Sénégal.

……

Manuscript Info

……

Manuscript History
Received: 05 June 2022
Final Accepted: 09 July 2022
Published: August 2022

Key words:-
Silicon Solar Cell, Diffusion Coefficient, Absorption coefficient, Surface Recombination Velocity, Optimum Base Thickness, Lorentz and Umklapp Processes

Abstract

……

The optimum thickness of a silicon solar cell base is determined using phenomelogic parameters, which are the minority carriers' diffusion coefficient and the recombination velocity at the back side, influenced by Lorentz's law and the Umklapp process.The results obtained are consistent with the generation of minority charge carriers deep in the base by a monochromatic light of long wavelength.

……

Introduction:-

The optimization of the dimensions of the different regions of the solar cell, allows a saving of material in the final elaboration. Mechanical cutting [1, 2, 3] cannot lead to results that can be justified from physical mechanisms point of view.

Modeling work [4, 5, 6, 7, 8, 9, 10, 11, 12] taking into account physical mechanisms is an interesting way for the search for geometric dimensions leading to a better efficiency of the solar cell [13].

The study that is presented aims to determine the optimum thickness of the base of the solar cell, placed under the conditions of both temperature[14, 15] and magnetic field[16, 17], starting from the physical mechanisms [18, 19] of absorption-generation-diffusion and recombination in volume and surfaces, of the minority charge carriers photogenerated in the base.

Then the steady state magneto-transport equation [16] relating to the density of excess minority carriers generated by a monochromatic light with constant flux ($\alpha(\lambda)$) in the base of a (n+/p/p+) silicon solar cell [20, 21] under applied magnetic field (B) and imposed temperature (T), is solved.

Corresponding Author:- Grégoire SISSOKO, gsissoko@yahoo.com
Address:- Groupe International de Recherche en Energie Renouvelable(GIRER). BP. 15003, Dakar, Sénégal.

The surface recombination rates [22], such as, (Sf) at the junction (n^+/p) [23, 24] and (Sb) on the back side (p/p+) [25, 26, 27, 28, 29, 30] intervene for the boundary conditions, and make it possible to define a complete solution $\delta(x, Sf, Sb, D(B,T), (\alpha(\lambda)))$ of the density of the minority charge carriers in the base.

The photocurrent density $J_{ph}(H, Sf, Sb, D(B,T), (\alpha(\lambda)))$ is then deduced and represented as a function of (Sf) the recombination velocity of the minority charge carriers at the junction, which at its large values makes it possible to extract the expressions of the recombination velocity (Sb) on the back side [23]

The representation of both (Sb) expressions in curves as a function of (**H**) the thickness of the base of the solar cell, for different values of (**Dmax**), makes it possible to obtain (**Hopt**) the optimum thickness.

Consequentially (**Hopt**) is represented as a function of the optimum diffusion coefficient (**Dmax (B, Topt)**) and then (**Topt**) and (**B**). The results are analyzed and interpreted to show the (Si) material saving conditions. Thus the base optimum thickness (**Hopt**) increases with Dmax coefficient, but decreases with both (**Topt**) and (**B**), giving rise to mathematical relationships modeling which are proposed.

Theory

The structure of the **n^+-p-p^+**monofaciale silicon solar cell [20, 21] under constant monochromatic illumination, under magnetic field (**B**) at temperature (**T**), is given by **figure 1.**

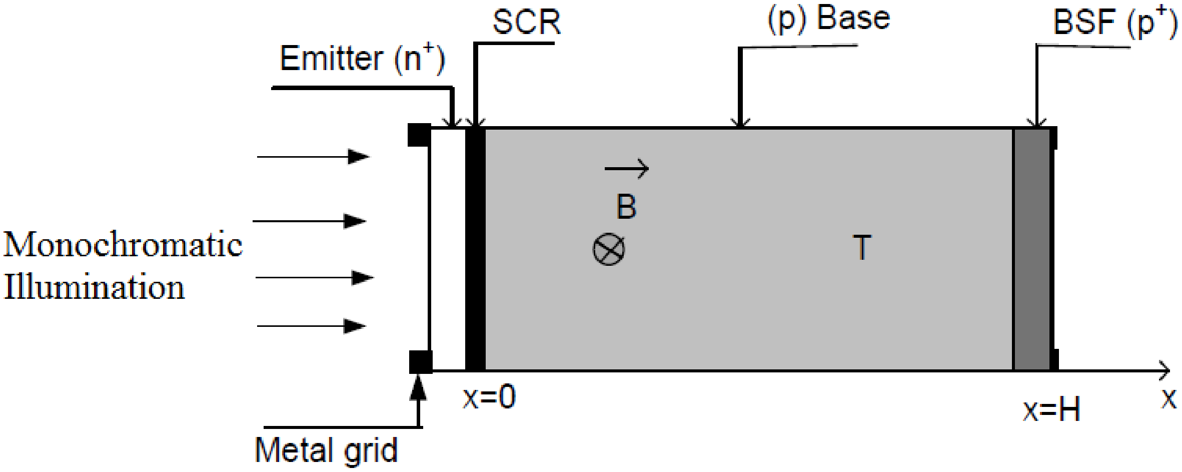

Figure 1:- Structure of (**$n^+/p/p^+$**) silicon solar cell.

Monochromatic illumination flux is strongly absorbed in the base, because of low absorption coefficient $\alpha(\lambda) = 6.2\,cm^{-1}$for $\lambda = 1.08\ \mu m$that corresponds to long wavelengthfor silicon material [31, 32, 33, 34]. The excess minority carriers are photogenerated deeply in the base and therefore submitted strongly to the magnetic field effect [16, 18, 35].

Then excess minority carriers' density $\delta(x,B,T)$ generated with monochromatic illumination in the base of the solar cell, under magnetic field (**B**) at temperature (**T**), is then governed by the following magneto transport equation in steady state [16, 17].

$$D(B,T)\times\frac{\partial^2\delta(x,B,T)}{\partial x^2}-\frac{\delta(x,B,T)}{\tau}=-G(x) \quad (1)$$

τ and $D(B,T)$ are respectively the lifetime and the diffusion coefficient of the excess minority carriers in the base under magnetic field and under temperature.

Under magnetic field, the diffusion coefficient is given by the following relation [16]:

- $$D(B,T)=\frac{D(T)}{1+(\mu B)^2} \quad (2)$$

With: $D(T)=\dfrac{\mu(T)\cdot K\cdot T}{q}$ (3)

And the mobility coefficient [36] is given as:

$\mu(T)=1{,}43.10^{19}.T^{-2{,}42}$ (4)

- L represents the diffusion length of excess minority carriers in the base:

  $L^2(B,T)=D(B,T)\cdot\tau$ (5)

- Carrier generation rate $G(x,t)$ is given by the relationship :

  $G(x)=\alpha(\lambda)\cdot I_0(\lambda)\cdot(1-R(\lambda))\cdot e^{-\alpha\cdot(\lambda).x}$ (6)

- x is the depth in the base.

  1) The solution of equation (1) is:

$$\delta(x,B,T,\alpha)=A\cdot\cosh\left[\frac{x}{L(B,T)}\right]+E\cdot\sinh\left[\frac{x}{L(B,T)}\right]+K\cdot e^{-\alpha\cdot x} \quad (7)$$

With $K=\dfrac{\alpha\cdot I_0\cdot(1-R)\cdot[L(B,T)]^2}{D(B,T)\left[L(B,T)^2\cdot\alpha^2-1\right]}$ (8)

and $\left(L(B,T)^2\cdot\alpha^2\neq 1\right)$ (9)

Coefficients A and E are determined through the boundary conditions:

- At the junction (x = 0)

$$\left.\frac{\partial\delta(x,\alpha,B,T)}{\partial x}\right|_{x=0}=Sf\cdot\left.\frac{\delta(x,\alpha,B,T)}{D(B,T)}\right|_{x=0} \quad (10)$$

- On the back side in the base (x = H)

$$\left.\frac{\partial\delta(x,\alpha,B,T)}{\partial x}\right|_{x=H}=-Sb\cdot\left.\frac{\delta(x,\alpha,B,T)}{D(B,T)}\right|_{x=H} \quad (11)$$

Sf and Sb are respectively the recombination velocities of the excess minority carriers at the junction[37, 38, 39, 40, 41] and at the back surface[23, 24, 42].

Results and Discussions:-

Diffusion coefficientunder both magnetic field and temperature

Plot of expression (2) with help of equations (3, 3 and 4), allows to extract (Dmax) the maximum diffusion coefficient [43] which is related to optimum temperature (Topt) for a given magnetic value, by following relation:

$D_{\max}(B,T_{opt})=\alpha'\cdot\left[T_{opt}(B)\right]^{\beta'}$ (12)

With $\alpha'=-1.51\ cm^2/s.K$, and $\beta'=11.87$

The optimal **Topt(B)** temperature separates two physical processes (normal process and Umklapp process) for a given magnetic field (**B**) where the diffusion of the minority charge carriers is maximum leading then, to **table. 1**.

Table 1:- Logarithm of the maxima of the diffusion coefficient and the optimal temperature.

Magnetic field B(T)	0.0003	0.0004	0,0005	0,0006	0.0007	0.0008	0.0009	0.001
$\mathrm{LnT_{opt}(B)}$	5.54	5.65	5.73	5.81	5.87	5.94	5.99	6.01
$\mathrm{lnD_{max}(B)}$	3.507	3.337	3.206	3.1	3.009	2.931	2.866	1.893

Photocurrent

The photocurrent density at the junction is obtained from the density of minority carriers in the base and is given by the following expression:

$$J_{ph}(Sf, Sb, \alpha, H, B, T) = qD(B,T)\left.\frac{\partial\delta(x, \alpha, H, Sf, Sb, B, T)}{\partial x}\right|_{x=0} \quad (13)$$

Where q is the elementary electron charge.

Figure 2:- shows the profile of photocurrent density versus the junction surface recombination velocity for different (**Dmax**) diffusion coefficient values impose by (**Topt**), for a given (**B**) value.

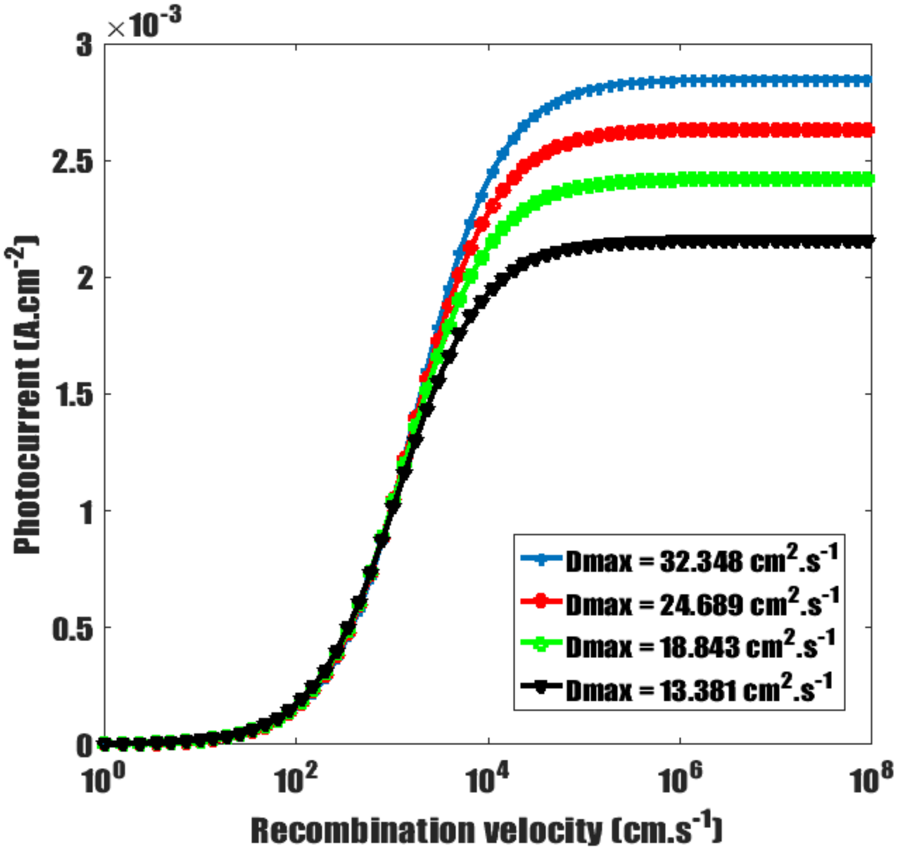

Figure 2:- Photocurrent density versus recombination velocity for different Dmax diffusion coefficient values ($\alpha = 6.2\ cm^{-1}$).

Base thickness Optimization through back surface recombination velocity representation

The representation of photocurrent density according to the junction recombination velocity of minority carriers, shows that, for very large (**Sf**), short-circuit current density (Jphsc) is obtained by a bearing. Then, in this junction recombination velocity interval, it comes:

$$\left.\frac{\partial J_{ph}(Sf, Sb, H, \alpha, B, T)}{\partial Sf}\right|_{Sf \geq 10^5 cm.s^{-1}} = 0 \quad (14)$$

The solution of equation (14) leads to both expressions of excess minority carrier's recombination velocity in the back surface [23, 24, 27, 39, 40], is given through equations (15) and (16):

$$Sb1(B, T, H) = -\frac{D(B,T)}{L(B,T)}.\tanh\left(\frac{H}{L(B,T)}\right) \quad (15)$$

Sb1 is related to the diffusion process of excess minority carriers [23, 24, 25, 39, 40]

$$Sb2(B,T,H,\alpha(\lambda))=\frac{D(B,T)}{L(B,T)}\cdot\left[\frac{\alpha(\lambda)\cdot L(B,T)\cdot\left(\exp(-\alpha(\lambda)\cdot H)-\cosh\left(\frac{H}{L(B,T)}\right)+\sinh\left(\frac{H}{L(B,T)}\right)\right)}{\exp(-\alpha(\lambda)\cdot H)-\cosh\left(\frac{H}{L(B,T)}\right)+\alpha(\lambda)\cdot L(B,T)\cdot\sinh\left(\frac{H}{L(B,T)}\right)}\right]$$

(16)

Sb2 is associated to both velocity processes [23, 32], the generation (αD) and the diffusion $(\frac{D}{L})$.

The **figure. 3** gives the representation of both back surface recombination velocity's expressions versus thickness of the base of the solar cell for different (Dmax) diffusion coefficient. The technique of the intercept point of the two curves (**Sb1** and **Sb2**) leads to the base optimum thickness [44, 45, 46, 47, 48, 49, 50].

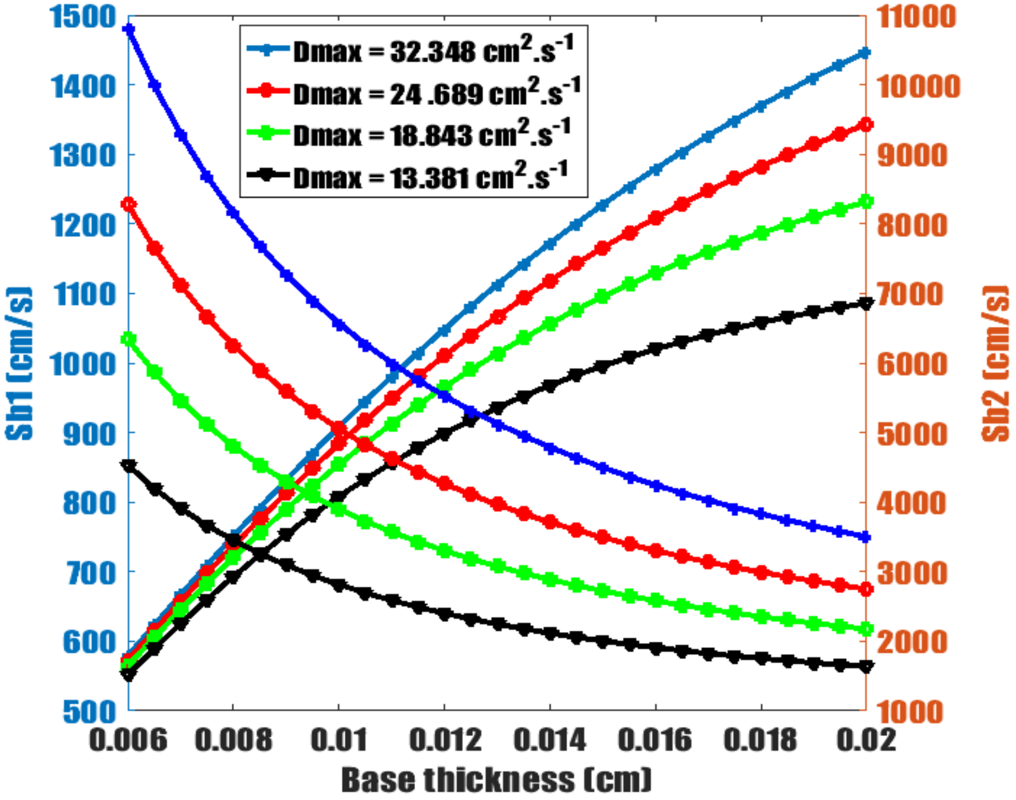

Figure 3:- **Sb1** and **Sb2** versus depth in the base for given diffusion coefficient ($\alpha = 6.2$ cm^{-1}).

Table 2, gives the results obtained of the base optimum thickness of the (**n$^+$/p/p$^+$**) silicon solar cell, front illuminated with long wave length light (weak absorption), and under magnetic field and temperature.

Table2:-Base Optimum thickness.

B (Tesla)	$10^{-3.5}$	$10^{-3.3}$	$10^{-3.1}$	$10^{-2.9}$
Topt(K)	261	315	381	461
Dmax (cm^2/s)	32.348	24.689	18.843	13.381
Hopt (cm)	0.0111	0.0102	0.0094	0.0085

Figure. 4, shows the base optimum thickness versus (**Dmax**) the maximum diffusion coefficient of minority carrier. The diffusion coefficient (**Dmax**) is obtained at the boundary (**Topt**) of two physical phenomena, deflection (Lorentz's law) and the Umklapp process, due respectively to the magnetic field and temperature variation. This boundary led to the choice of optimization variables. Then the optimum thickness increases with the minority carrier diffusion coefficient [5, 6, 7, 11, 30, 44, 46, 47].

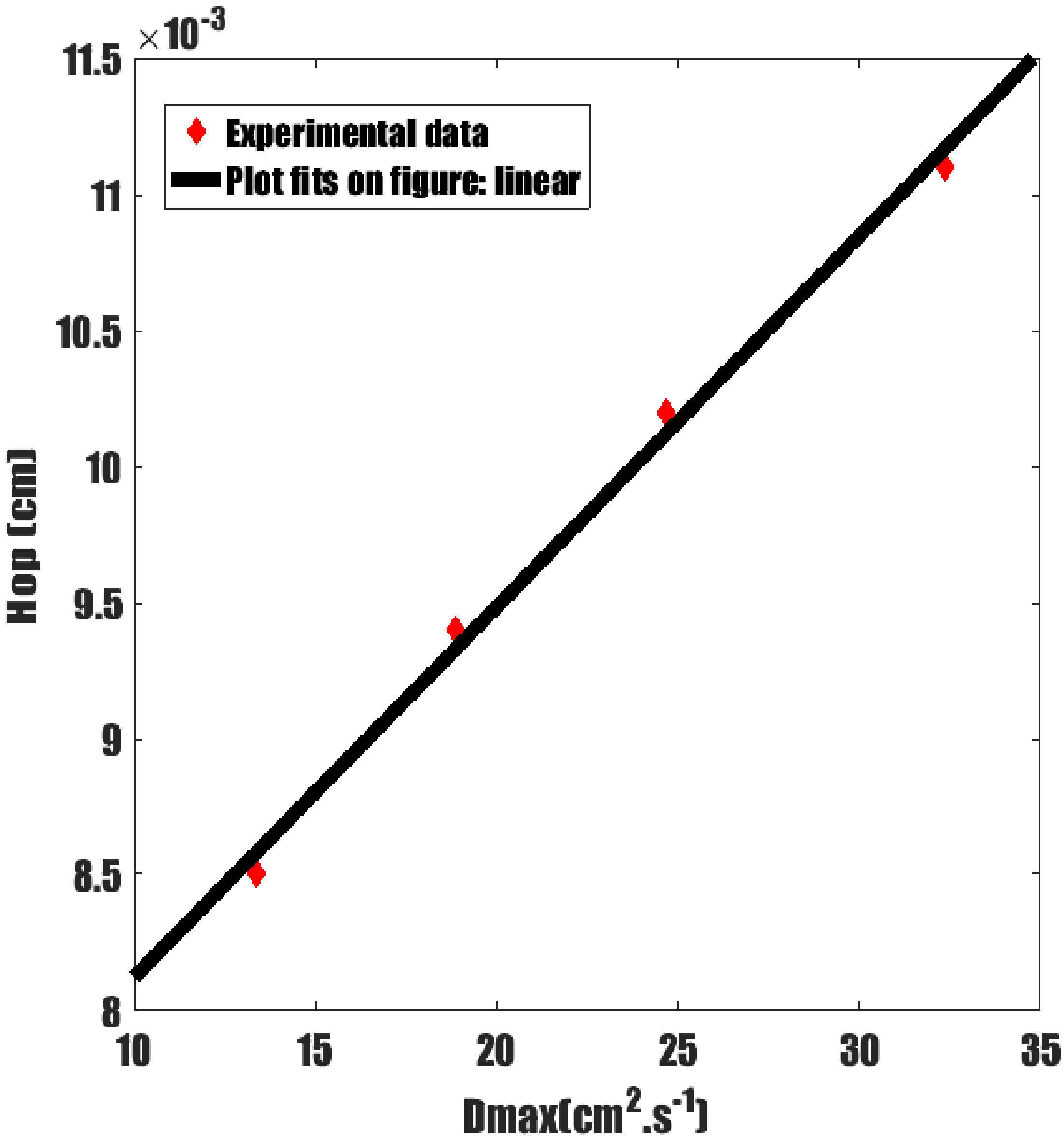

Figure 4:- Optimum thickness versus Dmax.

The optimum thickness of the base (**Figure 4**) increases linearly **(Eq. 17)** with the diffusion coefficient of the minority carriers, which is limited only by the doping rate of the material[5]. The relationship is given as:

$$Hopt(cm) = -1.4 \cdot 10^{-4} \times D\max + 0.0068 \qquad (17)$$

The optimum thickness of the base (Figures 5 and 6) decreases linearly respectively with the optimal temperature Topt(B) and the magnetic field(B). This decrease in the optimum thickness indicates the possible choice of reducing the amount of material to be used for the development of the solar cell, when it is to operate under the conditions indicated.

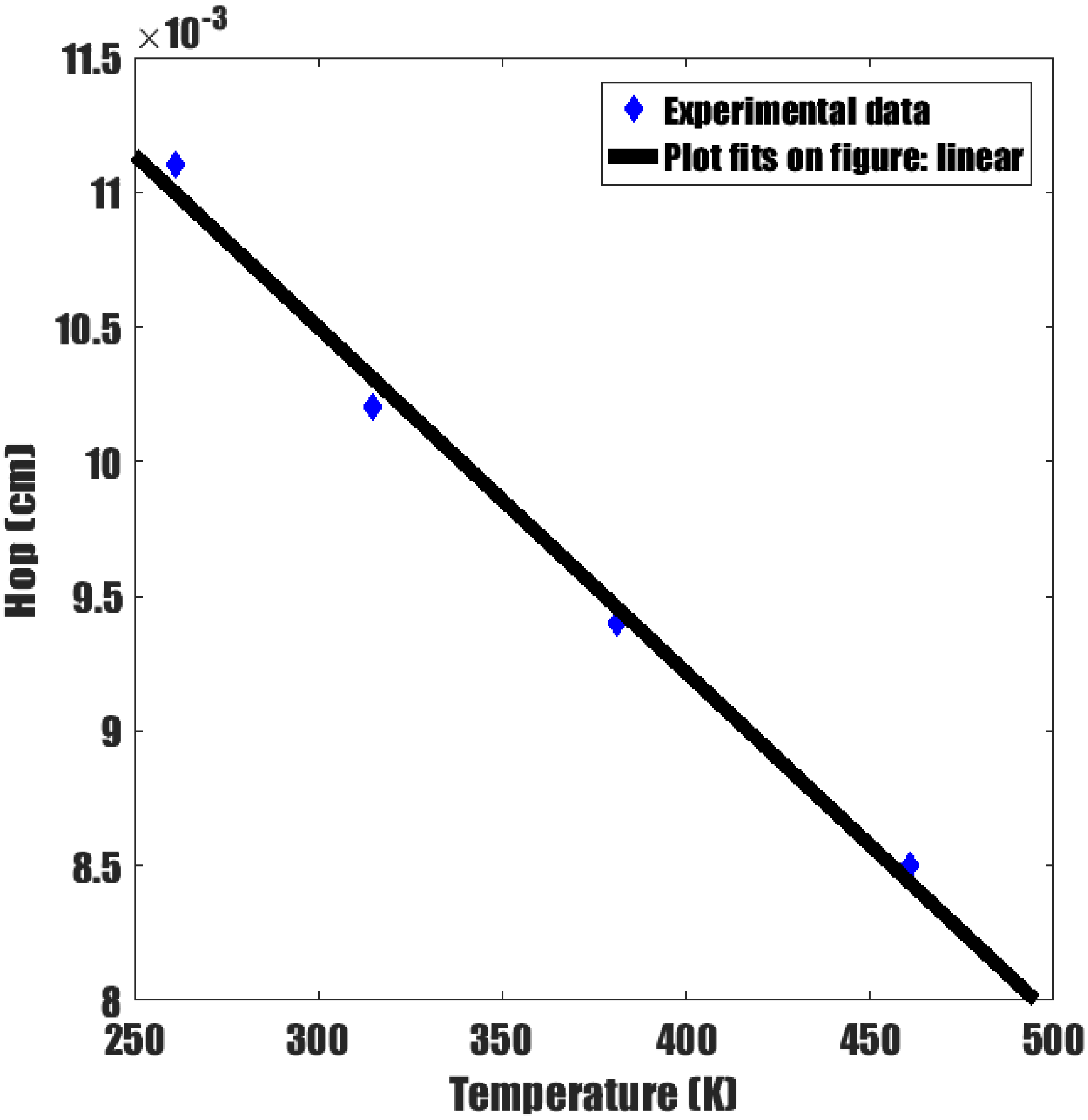

Figure 5:- Optimum thickness versus temperature.

The modelling expression of the optimum base thickness versus temperature is given as:

$$Hop(cm) = -1.3 \cdot 10^{-5} \times T(K) + 0.014 \qquad (18)$$

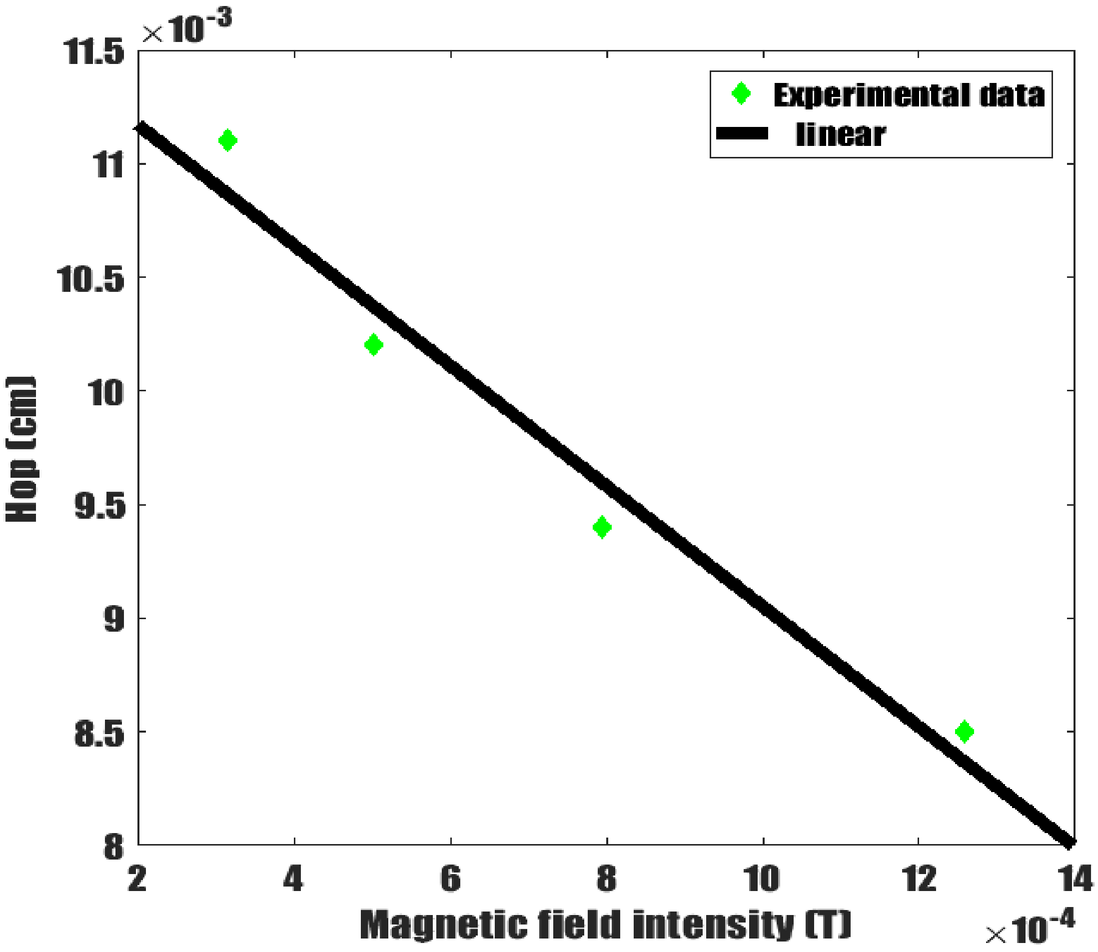

Figure 6:- Optimum thickness versus magnetic field.

The modelling expression of the optimum base thickness versus magnetic field is given as:

$$Hop(cm) = -1.3 \cdot 10^{-5} \times B(Tesla) + 0.014 \quad (19)$$

The **figure. 2** shows that the magnetic field applied parallel to the surface of the junction (**n^+/p**) causes a decrease in the photocurrent produced by the solar cell, because the Lorentz force deflects the electric charges, which consequently lengthens the path traveled to reach the junction [16, 18, 35]. Thus to increase the collection of photogenerated minority charge carriers and thus obtain an optimal photocurrent from the solar cell under the action of a magnetic field, the reduction of the thickness (**Eq. 19**) then is necessary [6, 7, 11, 12]. Improving the efficiency of solar cells necessarily involves controlling recombination parameters and controlling dimensions during their development.

Conclusion:-

This work made it possible to extract the optimum thickness of the base of the silicon solar cell under monochromatic illumination of weak absorption and to establish the mathematical co-relationships with the maximum diffusion coefficient of excess minority carriers obtained at the optimum temperature point, the boundary between the physical phenomena of deflection due to the magnetic field and Umklapp due to temperature.

For this, the magneto-transport equation relating to the density of the minority carriers in the base of the solar cell was solved, provided with the boundary conditions, which made it possible to introduce the recombination velocity in front and rear face.

The study of the expressions of the recombination velocity of the minority carriers on the back side, deduced from the density of the photocurrent, made it possible to extract the optimum thickness of the base of the solar cell.

References:-

[1] Van Steenwinkel, R., Carotta, M.C., Martinelli, G., Mercli, M., Passari, L. and Palmeri, D. (1990) Lifetime Measurement in Solar Cell of Various Thickness and Related Silicon Wafer. Solar Cells, 28, 287-292. https://doi.org/10.1016/0379-6787(90)90063-B

[2] J. Dugas, (1994). 3D modelling of a reverse cell Made with improved multicrystalline silicon wafers. Solar Energy Materials and Solar Cells 32, pp71-88.

[3] Demesmaeker, E., Symons, J., Nijs, J. and Mertens, R. (1991) The Influence of Surface Recombination on the Limiting Efficiency and Optimum Thickness of Silicon Solar Cells. 10th European Photovoltaic Solar Energy Conference, Lisbon, 8-12 April 1991, 66-67. https://doi.org/10.1007/978-94-011-3622-8_174

[4] Meimouna Mint SidiDede, MamadouLamine Ba, MamourAmadou Ba, MorNdiaye, Sega Gueye, El Hadj Sow, IbrahimaDiatta, Masse Samba Diop, Mamadou Wade, GregoireSissoko, (2020). Back Surface Recombination Velocity Dependent of Absorption Coefficient as Applied to Determine Base Optimum Thickness of an n+/p/p+ Silicon Solar Cell. Energy and Power Engineering, 12, 445-458 https://www.scirp.org/journal/epe

[5] Masse Samba Diop, Hamet Yoro Ba, NdeyeThiam, IbrahimaDiatta, YoussouTraore, MamadouLamine Ba, El Hadji Sow, OulymataMballo, GrégoireSissoko (2019).
Surface Recombination Concept as Applied to Determinate Silicon Solar Cell Base Optimum Thickness with Doping Level Effect. World Journal of Condensed Matter Physics, 9, pp.102-111. https://www.scirp.org/journal/wjcmp

[6] Gora Diop, Hamet Yoro Ba, NdeyeThiam, YoussouTraore, BabouDione, MamourAmadou Ba, PapeDiop, Masse Samba Diop, OulimataMballo and GregoireSissoko (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, No. 23, pp.4078-4085.

[7] Dibor Faye, Sega Gueye, Mor Ndiaye, Mamadou Lamine Ba, Ibrahima Diatta, Youssou Traore, Masse Samba Diop, Gora Diop, Amadou Diao, Gregoire Sissoko, (2020). Lamella Silicon Solar Cell under Both Temperature and Magnetic Field: Width Optimum Determination. Journal of Electromagnetic Analysis and Applications, 12, 43-55. https://www.scirp.org/journal/paperinformation.aspx?paperid=99976

[8] Caleb Dhanasekaran, P. and Gopalam, B.S.V. (1981). Effect of Junction Depth on the Performance of a Diffused n^+p Silicon Solar Cell. Solid State Electrons, 24, 1077-1080. https://doi.org/10.1016/0038-1101

[9] MassambaDieng, BoureimaSeibou, Ibrahima LY, Marcel SitorDiouf, Mamadou Wade, GrégoireSissoko (2017). Silicon Solar Cell Emitter Extended Space Charge Region Determination under Modulated Monochromatic Illumination by using Gauss's Law. International Journal of Innovative Technology and Exploring Engineering Vol. 6, issue 2, pp.17-20.

[10] Arora, J.D, S.N. Singh and P.C. Mathur (1981). Surface Recombination effects on the performance of n+-p step and diffused junction silicon solar cells. Solid State Electronics, 24(8), pp.739–747

[11] Maimouna Mint Ely , NdeyeThiam , MorNdiaye , YoussouTraore , Richard Mane , El hadji Sow , Oulimatamballo , Masse Samba Dieng , CheikhTidianeSarr , Ibrahima Ly , GregoireSissoko, (2020). Surface recombination velocity concept as applied to determinate back surface illuminated silicon solar cell base optimum thickness, under temperature and external magnetic field effects. Journal of Scientific and Engineering Research, 7(2):69-77

[12] Nouh Mohamed MoctarOuld Mohamed, Ousmane Sow, Sega Gueye, YoussouTraore, IbrahimaDiatta, AmaryThiam, MamourAmadou Ba, Richard Mane, Ibrahima Ly, GregoireSissoko (2019). Influence of Both Magnetic Field and Temperature on Silicon Solar Cell Base Optimum Thickness Determination. Journal of Modern Physics, 10, 1596-1605 https://www.scirp.org/journal/jmp

[13] Martin A. Green, Keith Emey, Yoshihiro Hishikawa and Wilhelm Warta(2011). Solar cell efficiency tables (version 37).Prog. Photovolt: Res. Appl. N0 19, pp 84-92.(Willey). DOI: 10. 1002/pip. 1088

[14] A. A. Maznev, O. B. Wright (2014). Demystifying umklappvs normal scattering in lattice thermal conductivity American Journal of Physics, vol: 82 (11), pp: 1062-1066.

[15] IbrahimaDiatta, IssaDiagne, CheikhSarr, Khady Faye, MorNdiaye, and Grégoire SISSOKO (2015). Silicon solar cell capacitance: influence of both temperature and wavelength. IPASJ International Journal of Computer Science (IIJCS). Volume 3, Issue 12, December, pp 1-8.

[16] Y. Betser, D. Ritter, G. Bahir, S. Cohen and J.Serling. (1995). Measurement of the minority carrier mobility in the base of heterojunction bipolar transistors using a magneto transport method. Appl. Phys. Let. 67(13): 1883-1884.
[17] Th. Flohr and R. Helbig (1989). Determination of minority-carrier lifetime and surface recombination velocity by Optical-Beam-Induced- Current measurements at different light wavelengths. J. Appl. Phys. Vol.66 (7), pp 3060 – 3065.
[18] Vardanyan, R.R., Kerst, U., Wawer, P., Nell, M.E. and Wagemann, H.G (1998). Method for Measurement of All Recombination Parameters in the Base Region of Solar Cells. 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, Vienna, 6-10 July 1998, 191-193.
[19] Sudha Gupta, Feroz Ahmed and Suresh Garg, (1988). A method for the determination of the material parameters τ, D, L_o, S and α from measured A.C. short-circuit photocurrent. Solar Cells, Vol. 25, pp 61-72.
[20] Fossum, J.G. (1977) Physical Operation of Back-Surface-Field Silicon Solar Cells. IEEE Transactions on Electron Devices, 2, 322-325. https://doi.org/10.1109/T-ED.1977.18735
[21] Le Quang Nam, M. Rodot, M. Ghannam, J. Cppye, P. de Schepper, J. Nijs, (1992). Solar Cells with 15.6% efficiency on multicristalline silicone, using impurity gettering, back surface field and emitter passivation. Int. J. Solar Energy. Vol. 11, pp.273-279.
[22] De Vischere, P. (1986). Comment on G. J. Rees. Surface Recombination Velocity-A Useful Concept. Solid State Electronics, 29, 1161-1164. https://doi.org/10.1016/0038-1101(86)90059-6
[23] Sissoko, G., Museruka, C., Corréa, A., Gaye, I. and Ndiaye, A.L. (1996). Light Spectral Effect on Recombination Parameters of Silicon Solar Cell. World Renewable Energy Congress, Pergamon, 15-21 June 1996, 1487-1490.
[24] Diallo. H.L, Maiga, S.A., Wereme, A. and Sissoko, G. (2008). New Approach of Both Junction and Back Surface Recombination Velocities in a 3D Modelling Study of a Polycrystalline Silicon Solar Cell. The European Physical Journal Applied Physics, 42, 203-211. https://doi.org/10.1051/epjap:2008085
[25] YoussouTraore, NdeyeThiam, MoustaphaThiame, AmaryThiam, MamadouLamine Ba, Marcel SitorDiouf, IbrahimaDiatta, OulymataMballo, El Hadji Sow, Mamadou Wade, GrégoireSissoko (2019). AC Recombination Velocity in the Back Surface of a Lamella Silicon Solar Cell under Temperature. Journal of Modern Physics, 10, pp.1235-1246 https://www.scirp.org/journal/jmp
[26] Gueye, M., Diallo, H.L., Kosso, A., Moustapha, M., Traore, Y., Diatta I. and Sissoko, G. (2018). AC Recombination Velocity in a Lamella Silicon Solar Cell. World Journal of Condensed Matter Physics, 8, 185-196, http://www.scirp.org/journal/wjcmp.
[27]Zerbo, I., Barro, F.I., Mbow, B., Diao, A., Madougou, S., Zougmore, F. and Sissoko, G. (2004). Theoretical Study of Bifacial Silicon Solar Cell under Frequency Modulate white Light: Determination of Recombination Parameters. Proceedings of the 19th European Photovoltaic Solar Energy Conference, Paris, 7-11 June 2004, 258-261.
[28] Mint Sidihanena Selma, NdeyeThiam, MorNdiaye, YoussouTraore, IbrahimaDiatta, Marcel SitorDiouf, OulimataMballo, Masse Samba Diop and GregoireSissoko (2019).Temperature and magnetic field effect on back surface recombination velocity ina silicon solar cell under white modulated illumination. ARPN Journal of Engineering and Applied Sciences, Vol. 14, N^O. 24, pp. 4141-4147
[29] Joardar. K., Dondero. R.C. and Schroda. D.K (1989). Critical Analysis of the Small-Signal Voltage-Decay Technique for Minority-Carrier Lifetime Measurement in Solar Cells. Solid State Electronics, 32, pp.479-483. https://doi.org/10.1016/0038-1101(89)90030-0
[30] Ndiaye, F.M., Ba, M.L., Ba, M.A., Diop, G., Diatta, I., Sow, E.H., Mballo, O. and Sissoko, G. (2020) Lamella Silicon Optimum Width Determination under Temperature. International Journal of Advanced Research, 8, 1409-1419. https://doi.org/10.21474/IJAR01/11228
[31]Stokes, E.D. and Chu, T.L. (1977) Diffusion Lengths in Solar Cells from Short-Circuit Current Measurements. Applied Physics Letters, 30, 425-426. https://doi.org/10.1063/1.89433
[32]Antilla, O.J. and Hahn, S.K. (1993) Study on Surface Photovoltage Measurement of Long Diffusion Length Silicon: Simulation Results. Journal of Applied Physics, 74, 558-569 https://doi.org/10.1063/1.355343
[33] U. C. Ray And S. K. Agarwal, (1988). Wavelength Dependence of Short-Circuit Current Decay in Solar Cells. J. Appl. Phys. 63 (2), pp.547-549.
[34]K.Rajkanan, R. Singh and J. Schewchun, Absorption coefficient of silicon for solar cell calculations. Solid-State Electronics,1979,22,793-795.https://doi.org/10.1016/0038-1101(79)90128-X
[35]S. Erel, (2002) .The effect of electric and magnetic fields on the operation of a photovoltaic cell. Solar Energy Materials & Solar Cells 71, pp. 273-280.

[36] Kunst, M., Muller, G., Schmidt, R. and Wetzel, H. (1988). Surface and Volume Decay Processes in Semiconductors Studied by Contactless Transient Photoconductivity Measurements. Applied Physics A, 46, 77-85. https://doi.org/10.1007/BF00615912

[37] Sissoko, G., Sivoththanam, S., Rodot, M. and Mialhe, P. (1992). Constant Illumination-Induced Open Circuit Voltage Decay (CIOCVD) Method, as Applied to High Efficiency Si Solar Cells for Bulk and Back Surface Characterization. 11th European Photovoltaic Solar Energy Conference and Exhibition, Montreux, 12-16 October 1992, 352-354.

[38]G. Sissoko, S. Mbodji (2011). A Method to Determine the Solar Cell Resistances from Single I-V Characteristic Curve Considering the Junction Recombination Velocity (Sf). International Journal of Pure Applied Sciences and Technology, Vol: **6**, pp: 103-114.

[39] G. Sissoko, E. Nanema, A. Correa, M. Adj, A.L. Ndiaye, M.N. Diarra (1998). Recombination parameters measurement in double sided surface field solar cell. Proceedings of World Renewable Energy Conference, Florence–Italy, pp. 1856–1859

[40] Y. L. B. Bocande, A. Correa, I. Gaye, M. L. Sow and G. Sissoko (1994). Bulk and surfaces parameters determination in high efficiency Si solar cells. Renewable Energy, vol 5, part III, pp. 1698-1700, Pergamon, 0960-1481 / 94$ 700 +0.00.

[41] El Hadji Ndiaye, GokhanSahin, Amary Thiam, MoustaphaDieng, Hawa Ly Diallo, MorNdiaye, GrégoireSissoko (January 2015). Study Of The Intrinsic Recombination Velocity At The Junction Of Silicon Solar Under Frequency Modulation And Irradiation.
Journal of Applied Mathematics and Physics 03(11):1522-1535

[42] Diasse, O., Diao, A., Ly, I., Diouf, M.S., Diatta, I., Mane, R., Traore, Y. and Sissoko, G. (2018) Back Surface Recombination Velocity Modeling in White Biased Silicon Solar Cell under Steady State. Journal of Modern Physics, 9, 189-201. https://doi.org/10.4236/jmp.2018.92012

[43] Richard Mane, Ibrahima Ly, Mamadou Wade, IbrahimaDatta, Marcel S. Douf, YoussouTraore, MorNdiaye, SeniTamba, GrégoireSissoko (2017). Minority Carrier Diffusion Coefficient D*(B, T): Study in Temperature on a Silicon Solar Cell under Magnetic Field. Energy and Power Engineering, 9, pp.1-10 http://www.scirp.org/journal/epe

[44] Thiaw, C. , Ba, M. , Amadou Ba, M. , Diop, G. , Diatta, I. , Ndiaye, M. and Sissoko, G. (2020) n^+-p-p^+ Silicon Solar Cell Base Optimum Thickness Determination under Magnetic Field. Journal of Electromagnetic Analysis and Applications, **12**, 103-113. doi: 10.4236/jemaa.2020.127009.

[45] Meimouna Mint SidiDede, MorNdiaye, Sega Gueye, MamadouLamine Ba, IbrahimaDiatta, Marcel SitorDiouf, El Hadj Sow, AmadouMamour Ba, MassambaDiop, And GregoireSissoko (2020). Optimum base thickness determination technique as applied to n/p/p+ silicon solar cell under short wavelengths monochromatic illumination International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 29 No. 3 Jun. 2020, pp. 576-586 © 2020 Innovative Space of Scientific Research Journals http://www.ijias.issr-journals.org

[46] M. Sall, M. F. MB. Fall, O. Diasse, G. Diop, I, Diatta, O. Dia, K. Loum, M. Wade and Sissoko, G. Determination of the optimum thickness of the base of the n+/p/p+ silicon solar cell, illuminated by the rear face by a monochromatic light of long wavelength in frequency modulation. Journal of Chemical, Biological and Physical Sciences. JCBPS; Section C; November 2021 –January 2022, Vol. 12, No. 1; 064-077.DOI :10.24214/jcbps.C.11.4.07891.]

[47] Ndiaye, A. , Gueye, S. , Sow, O. , Diop, G. , Ba, A. , Ba, M. , Diatta, I. , Habiboullah, L. and Sissoko, G. (2020) A.C. Recombination Velocity as Applied to Determine n^+/p/p^+ Silicon Solar Cell Base Optimum Thickness. Energy and Power Engineering, **12**, 543-554. doi: 10.4236/epe.2020.1210033

[48] Ndiaye, A. ,Gueye, S. , Mbaye Fall, M. , Diop, G. , Ba, A. , Ba, M. , Diatta, I. , Habiboullah, L. and Sissoko, G. (2020). Diffusion Coefficient at Resonance Frequency as Applied to n+/p/p+ Silicon Solar Cell Optimum Base Thickness Determination. Journal of Electromagnetic Analysis and Applications, **12**, 145-158. doi: 10.4236/jemaa.2020.1210012. [49] Ba, M.L., Thiam, N., Thiame, M., Traore, Y., Diop, M.S., Ba, M., Sarr, C.T., 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, 11, 173-185. https://doi.org/10.4236/jemaa.2019.1110012

[50] AmadouSarrGning, MamadouLamine Ba, MamourAmadou Ba, Gora Diop, IbrahimaDiatta, El Hadji Sow, OulimataMballo and GregoireSissoko (2020). Optimum basethickness determination of a back illuminated silicon solar cell: irradiation effect. International Journal of Advanced Research, 8(07), 100-109. http://dx.doi.org/10-21474/IJAR01/11268.