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Research Article

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Optimization of the base thickness of a silicon solar cell with multi-vertical junctions connected in series, through dynamic expressions of the recombination velocity on the back side

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Abstract The minority carrier's diffusion equation, is solved in the base of a vertical Multi- junction's silicon solar cell connected in series (VMJS), under illumination in frequency modulation. The AC photocurrent is studied as a function of the recombination velocity at the junction, and allow us to establish the expressions of the AC recombination velocity of minority carriers on the back side. The profile of AC recombination velocity of minority carriers leads to the determination of the optimum thickness of the base, allowing the production of a maximum of electric current. The optimum thickness is thus expressed by mathematical relations as a function of both, the dynamic diffusion coefficient and the frequency of modulation of the incident light.

Keywords VMJ Silicon Solar Cell – AC Recombination Velocity - Base Thickness – modulation frequency

1. Introduction

The silicon solar cell (n+/p/p+) is produced under several architectures [1, 2, 3], according to both the intensity and the orientation of the incident illumination relative to the plane of the surface of the space charge region (n+/p) [4]. For incident illumination perpendicular to the plane of the junction, the solar cell may be monofacial [5] or bifacial for illumination carried out by the back side (p+) [4, 6, 7].

When the incident light arrives parallel to the plane of the junctions (n+/p) and (p/p+), the structure can be vertical multi-junctions connected in series (n+/p/p+) [8] or (n/p) connected in parallel [9]. It is therefore designed using electronically poor (Si) material under concentrated illumination intensity [10, 11], so that photogenereted charge carriers everywhere in the different regions can be easily collected, because of the proximity of the junctions (n/p) [12]. This constitutes an economic advantage.

This raises the problem of the distance to be covered by the minority carriers, in other words, it is therefore a second advantage to optimize, the thickness of the base that would produce a maximum photocurrent, by collecting more carriers.

The proposed work aims to determine the optimum thickness [13, 14, 15] of the base of the vertical multi-junctions silicon solar cell (n+/p/p+), connected in series, when it is under monochromatic illumination in frequency modulation.

For this, the diffusion equation in dynamic regime relative to the minority carriers in the base [16, 17] is solved, taking into account the recombination velocity (Sf) at the junction and (Sb) on the rear side (p/ p+) [18, 19, 20, 21, 22, 23].

The expression of the dynamic photocurrent Jph is established. It is represented graphically as a function of (Sf). From this representation, the expressions of the dynamic recombination velocity (Sb) on the back side (p/p+) are deduced [24] dependent on base depth

The analysis of these expressions in graphic mode, makes it possible to determine the optimum thickness (Hopt) of the base, necessary for the production of an optimal photocurrent for given frequency. The mathematical modeling of this thickness as a function of both, the diffusion coefficient and the frequency of modulation of the illumination is established.

2. Theory

The structure of the n^+-p-p^+ vertical junction silicon solar cell [1, 7, 8] under monochromatic illumination, in frequency modulation is given by figure 1.

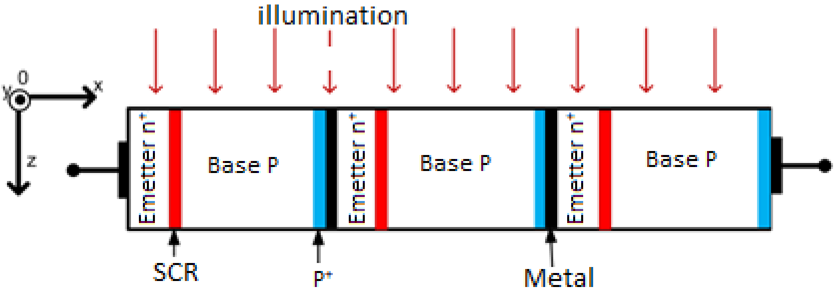

Figure 1: Structure of vertical junction solar cell under modulated monochromatic light

The series vertical junction solar cell, being a series combination of photovoltaic solar cells connected to each other by a metal, is designed in such a way that the incident illumination is parallel to the plane of the space charge region (SCR). The structure of this solar cell is shown in Figure 2:

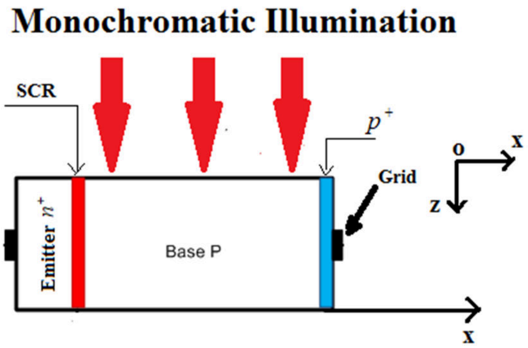

Figure 2: One unit of the series vertical junction solar cell

The excess minority carriers' density $\delta(x,t)$ generated in the base of the solar cell obeying to the (2D) continuity equation [8, 25, 26, 27] is given as:

$$D(\omega)\times\frac{\partial^2\delta(x,z,t)}{\partial x^2}-\frac{\delta(x,z,t)}{\tau}=-G(z,\omega,t,\alpha)+\frac{\partial\delta(x,z,t)}{\partial t} \qquad (1)$$

The expression of the excess minority carriers' density is written, according to the space coordinates (x,z) and the time t, as:

$$\delta(x,z,t)=\delta(x,z)\cdot e^{-j\omega t} \tag{2}$$

Carrier generation rate $G(z,\omega,t,\alpha)$ is given by the following relationship:

$$G(z,\omega,t,\alpha)=g(z,\alpha)\cdot e^{-j\omega t} \tag{3}$$

With:

$$g(z,\alpha)=\alpha(\lambda)\cdot I_0(\lambda)\cdot(1-R(\lambda))\cdot e^{-\alpha\cdot(\lambda).z} \tag{4}$$

- z is the depth in the base. Io is the intensity of monochromatic illumination. The quantities α(λ) and R(λ) are the monochromatic absorption and reflection coefficients of the silicon material with wavelength (λ) [28].
- $D(\omega)$ is the complex diffusion coefficient of excess minority carrier in the base. Its expression is given by the relationship [25, 27]:

$$D(\omega)=D_0\times\left(\frac{1-j.\omega^2.\tau^2}{1+(\omega\tau)^2}\right) \tag{5}$$

By replacing equations (2) and (3) in equation (1), the continuity equation for the excess minority carriers' density in the base is reduced to the following relationship:

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

$L(\omega)$ is the complex diffusion length of excess minority carriers in the base given by:

$$L(\omega)=\sqrt{\frac{D(\omega)\tau}{1+j\omega\tau}} \tag{7}$$

τ is the excess minority carriers lifetime in the base.

The solution of equation (6) is:

$$\delta(x,z,\omega,\alpha(\lambda))=A\cdot\cosh\left[\frac{x}{L(\omega)}\right]+B\cdot\sinh\left[\frac{x}{L(\omega)}\right]+K\cdot e^{-\alpha\cdot z} \tag{8}$$

With $K=\frac{\alpha\cdot I_0\cdot(1-R)\cdot[L(\omega)]^2}{D(\omega)\left[L(\omega)^2\cdot\alpha^2-1\right]}$ (9)

and $\left(L(\omega)^2\cdot\alpha^2\neq 1\right)$ (10)

Coefficients A and B are determined through the boundary conditions expressed as:

- At the junction (x = 0)

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

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

$$\left.\frac{\partial\delta(x,z,\omega,\alpha(\lambda))}{\partial x}\right|_{x=H}=-Sb\cdot\left.\frac{\delta(x,z,\omega,\alpha(\lambda))}{D(\omega)}\right|_{x=H} \tag{12}$$

Sf and Sb are the re excess minority carriers recombination at the junction [17, 19, 29] and the rear [20, 21, 23] of the base.

3. Results and Discussions

3. 1 Photocurrent density

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

$$J_{ph}\left(Sf, z, H, \omega, \alpha(\lambda)\right) = qD(\omega)\left.\frac{\partial\delta\left(x, z, H, Sf, \omega, \alpha(\lambda)\right)}{\partial x}\right|_{x=0} \qquad (13)$$

Where q is the elementary electron charge.

Influence of modulation frequency on photocurrent density

Figure 3 shows the influence of frequency on the photocurrent density, which is very marked at large (Sf) values corresponding to the solar cell in short circuit condition illuminated with strong penetration absorption coefficient ($\alpha = 6.2$ cm^{-1}).

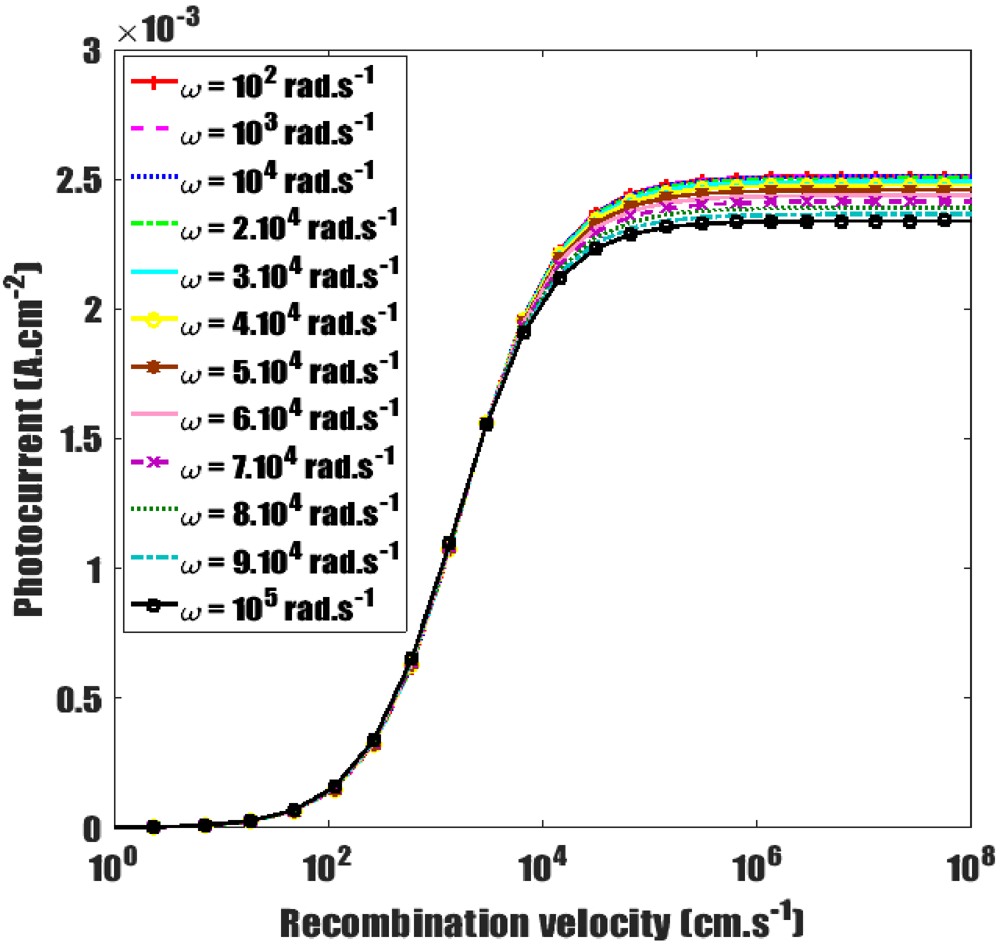

Figure 3: Profile of the photocurrent module density as a function of the recombination velocity at the junction, for different frequency values ($D_0 = 35$cm; $\alpha = 6.2$ cm^{-1} ; z = 0,017 cm ; H=0,02 cm)

3.2 Base thickness optimization

The representation of photocurrent density (Figure. 3) according to the junction recombination velocity of minority carriers shows that, for very large Sf, a bearing sets up and corresponds to the short-circuit current density (Jphsc). So, in this junction recombination velocity interval [16, 30], we can write:

$$\left.\frac{\partial J_{ph}(Sf,z,H,\lambda,\omega)}{\partial Sf}\right|_{Sf\geq 10^{5}\,cm.s^{-1}}=0 \tag{14}$$

The solution of equation (14) leads to the expressions of ac recombination velocity in the back surface, given by equations (15) and (16):

$$Sb1(\omega,H)=-\frac{D(\omega)}{L(\omega)}\cdot th\left(\frac{H}{L(\omega)}\right) \tag{15}$$

$$Sb2(\omega,H)=-\frac{D(\omega)sh\left(\dfrac{H}{L(\omega)}\right)}{L(\omega)\left(ch(\dfrac{H}{L(\omega)})-1\right)} \tag{16}$$

Figure 4 representation is the profile of the two expressions of back surface recombination velocity versus thickness of the base of the solar cell, in order to determine the optimum thickness of the base, abscissa of the intercept point, for given frequency.

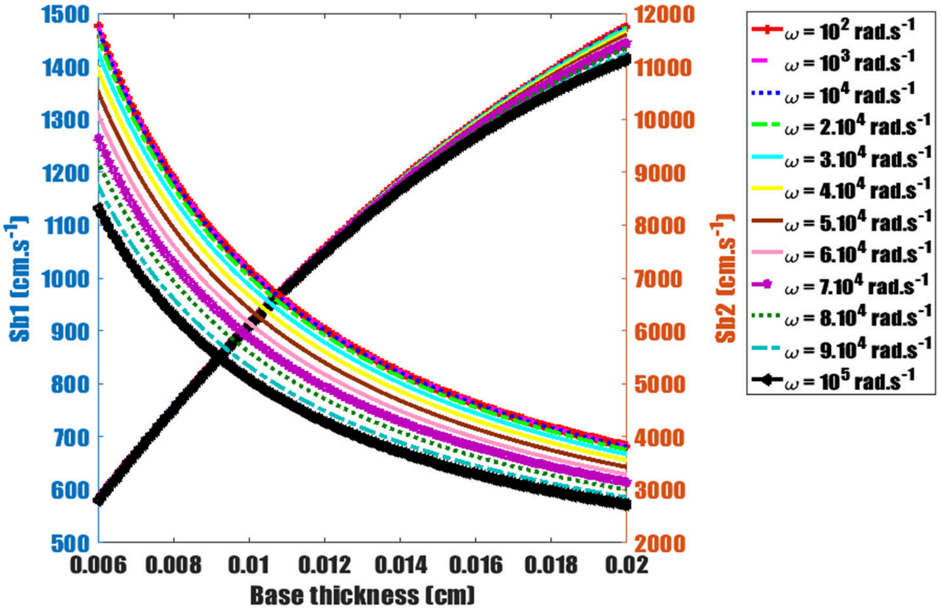

Figure 4: Sb1 and Sb2 versus depth in the base for different frequency

The intercept point of the two curves leads to the optimum thickness of the base for each modulation frequency. Table 1 shows the results obtained. **Figures 4** and **5** produce the (Hopt) representation as a function of the modulation frequency and the dynamic diffusion coefficient respectively.

ω(rad.s^{-1})	10^2	10^3	10^4	2.10^4	3.10^4	4.10^4	5.10^4	6.10^4	7.10^4	8.10^4	9.10^4	10^5
D (cm^2/s)	35	34.9965	34.6535	33.6538	32.1101	30.1724	28.0000	25.7353	23.4899	21.3415	19.3370	17.5000
H_{opt} (cm)	0.0107	0.0107	0.0107	0.0106	0.0105	0.0104	0.0102	0.01	0.0098	0.0096	0.0094	0.0092

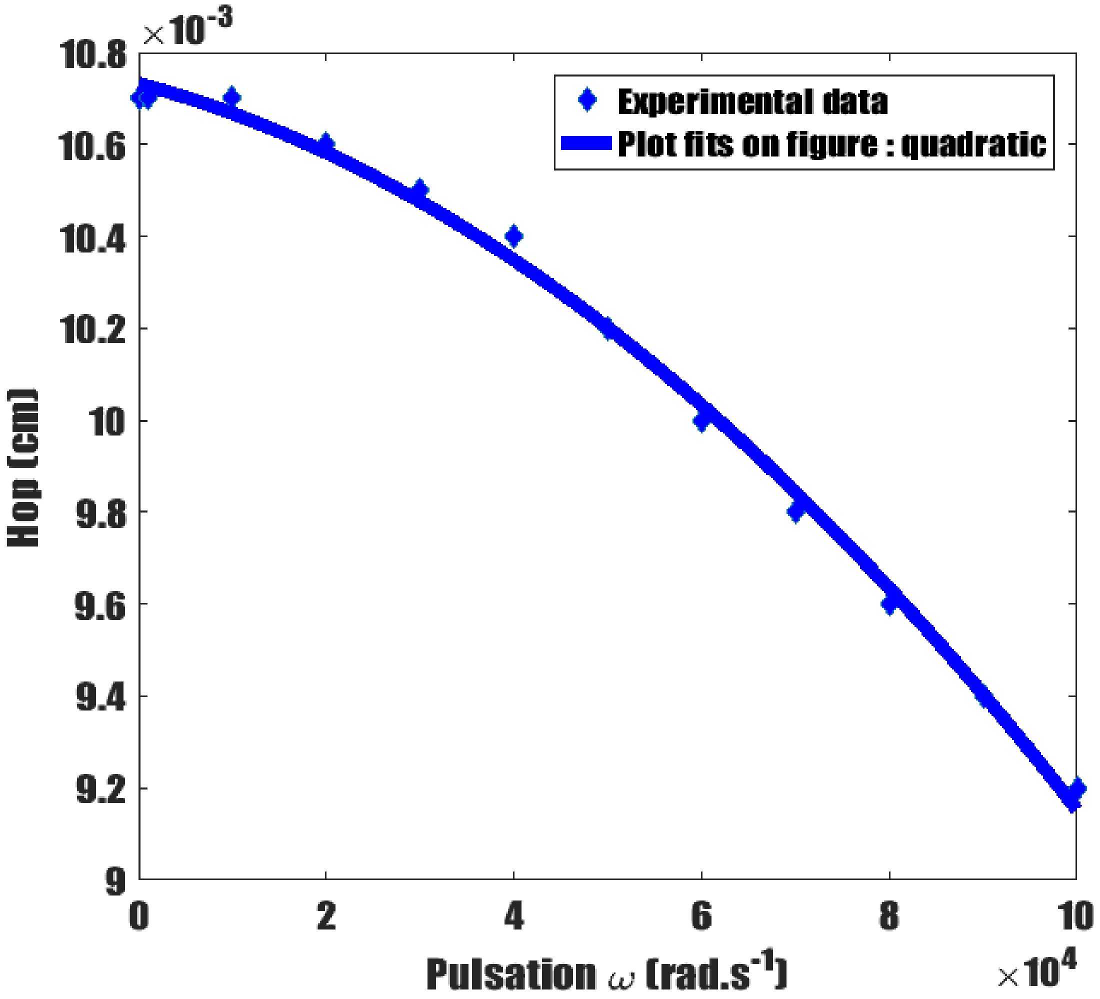

Figure 5: Optimum thickness versus frequency

Equation (17) gives the mathematical correlation of the optimum thickness with the modulation frequency. Hopt is a decreasing function of the modulation frequency, expressed as:

$$Hopt(cm) = -10^{-13} \times \omega^2 - 5.5 \cdot 10^{-9} \times \omega + 0.011 \qquad (17)$$

Thus, it appears that low frequencies require significant base thicknesses, while at high frequencies, the optimum thickness remains thin [31, 32, 33; 34].

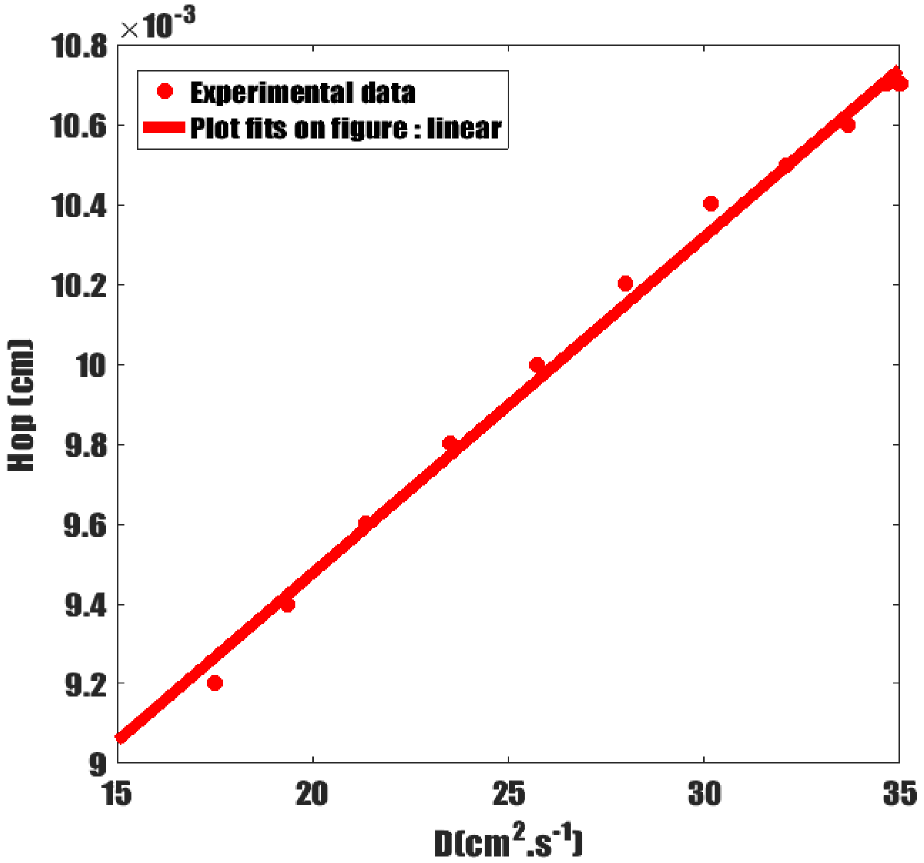

Figure 6: Optimum thickness versus diffusion coefficient

The equation (18) is an increasing Hopt function with the dynamic diffusion coefficient. These latter (Eq.5) is decreasing with the modulation frequency.

$$Hopt(cm) = 8.4 \cdot 10^{-5} \times D + 0.0078 \tag{18}$$

Various research works have produced results on the optimum thickness of the base of the silicon solar cell, which actually increases with the diffusion coefficient of the minority carriers in the base subjected to physical conditions, such as, monochromatic illumination [35], magnetic field [36, 37], temperature [38], irradiation flux by charged particles [39], variation in doping rate [34, 40], as well as the possible combination of these different factors [41, 42, 43].

The optimum thickness, on the other hand, decreases with these factors and makes it possible to model the conditions allowing the saving of matter in the development of the solar cell [44, 45, 46].

4 Conclusion

The technique of intersecting the curves of the recombination rates of the minority carriers in the base was applied on silicon solar cell, with multi vertical junctions connected in series and placed under illumination in frequency modulation.

The optimum thickness of the base decreases with the modulated frequency, while it increases with minority carriers' dynamic diffusion coefficient.

The modeling equations of the optimum thickness of the base indicate how to achieve the saving of silicon material in the development of the solar cell.

References

[1]. Green, M.A. (1995) Silicon Solar Cells Advanced Principles & Practice. Bridge Printer Pty. Ltd., Clayton North, 29-35.

[2]. Lago-Aurrekoetxea, R.M., del Can Izo, C., Pou, I. and Luque, A. (2001) Fabrication Process for Thin Silicon Solar Cells. 17th European PVSEC, Munich, 1519-1522.

[3]. Schneider, A., Gerhards, C., Huster, F., Neu, W., Spiegel, M., Fath, P., Bucher, E., Young, R.J.S., Prince, A.G., Raby, J.A. and Carollal, A.F. (2001) BSF for Thin Screen-Printed Multicrystalline Si Solar Cells. 17th European PVSEC, Munich, 1768-1771.

[4]. Luque, A., Ruiz, J.M., Cuevas, A., Eguren, J. and Agost, M.G. (1997) Double Side Solar Cells to Improve Static Concentrator. Proceedings of the 1st European Photovoltaic Solar Energy Conference, Luxembourg, 269-277. https://doi.org/10.1007/978-94-009-9840-7_25

[5]. Rodot, L.Q.N.M. (1992) Solar Cells with 15.6% Efficiency on Multicrystalline Silicon, Using Impurity Gettering Back Surface Field and Emitter Passivation. International Journal of Solar Energy, 11, 273-279. https://doi.org/10.1080/01425919208909745

[6]. Ohtsuka, H., Sakamoto, M., Tsutsui, K. and Yazawa, Y. (2000) Bifacial Silicon Solar Cells with 21.3% Front Efficiency and 19.8% Rear Efficiency. Progress in Photovoltaics: Research and Applications, 8, 385-390.
https://doi.org/10.1002/1099-159X(200007/08)8:4<385::AID-PIP340>3.0.CO;2-B

[7]. Wise, J.F. (1970) Vertical Junction Hardened Solar Cell. U.S. Patent 3, 690-953.

[8]. Gover, A. and Stella, P. (1974) Vertical Multijunction Solar-Cell One-Dimensional Analysis. IEEE Transactions on Electron Devices, ED-21, 351-356. https://doi.org/10.1109/T-ED.1974.17927

[9]. Mazhari, B. and Morkoç, H. (1993) Theoretical Study of a Parallel Vertical Multi-Junction Silicon. Journal of Applied Physics, 73, 7509-7514. https://doi.org/10.1063/1.353998

[10]. Sarfaty, R., Cherkun, A., Pozner, R., Segev, G., Zeierman, E., Flitsanov, Y., Kribus, A. and Rosenwaks, Y. (2011) Vertical Junction Si Micro-Cells for Concentrating Photovoltaics. Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, 5-6 September 2011, 145-147.

[11]. Paternoster, G., et al. (2013) Back-Contact Vertical Junction Silicon Solar Cells for Concentrating Photovoltaics. 28th European Photovoltaic Solar Energy Conference and Exhibition, Paris, 672-675.

[12]. Gaubas, E. and Vanhellemont, J. (1996) A Simple Technique for the Separation of Bulk and Surface Recombination Parameters in Silicon. Journal of Applied Physics, 80, 6293-6297. https://doi.org/10.1063/1.363705

[13]. 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_17

[14]. Noriaki, H. and Chusuke, M. (1987) Sample Thickness Dependence of Minority Carrier Lifetimes Measured Using an AC Photovoltaic Method. Japanese Journal of Applied Physics, Vol. 26, 12, 2033-2036. https://doi.org/10.1143/JJAP.26.2033

[15]. 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

[16]. 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, Part III, 1487-1490.

[17]. 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

[18]. El Hadji, N., Sahin, G., Thiam, A., Dieng, M., Ly Diallo, H., Ndiaye, M. and Sissoko, G. (2015). Study of the Intrinsic Recombination Velocity at the Junction of Silicon Solar under Frequency Modulation and Irradiation. Journal of Applied Mathematics and Physics, 3, 1522-1535. https://doi.org/10.4236/jamp.2015.311177

[19]. Diallo, H.L., 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 Multi-Junction Silicon Solar Cell. Research Journal of Applied Science, Engineering and Technology, 4, 2626-2631.

[20]. Ly Diallo, H., Wade, M., Ly, I., NDiaye, M., Dieng, B., Lemrabott, O.H., Maïga, A.S. and Sissoko. G. (2012) 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, 1672-1676. http://www.maxwell.org

[21]. Ly, I., Zerbo, I., Wade, M., Ndiaye, M., Dieng, A., Diao, A., Thiam, N., Thiam, A., Dione, M.M., Barro, F.I., Maiga, A.S. and Sissoko, G. (2011) Bifacial Silicon Solar Cell under Frequency Modulation and Monochromatic Illumination: Recombination Velocities and Associated Equivalent Electrical Circuits. Proceedings of 26th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, 5-9 September 2011, 298-301.

[22]. Gueye, M., Diallo, H., Moustapha, A., 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. doi: 10.4236/wjcmp.2018.84013.

[23]. Diallo, H.L., Wereme, A., Maiga, A.S. 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

[24]. Traore, Y., Thiam, N., Thiame, M., Thiam, A., Ba, M., Diouf, M., Diatta, I., Mballo, O., Sow, E., Wade, M. and Sissoko, G. (2019) AC Recombination Velocity in the Back Surface of a Lamella Silicon Solar Cell under Temperature. *Journal of Modern Physics*, **10**, 1235-1246. doi: 10.4236/jmp.2019.1010082.

[25]. Mandelis, A., Ward, A. and Lee, K.T. (1989) Combined AC Photocurrent and Photothermal Reflectance Response Theory of Semiconducting p-n Junctions. Journal of Applied Physics, 66, 5572-5583. https://doi.org/10.1063/1.343662

[26]. Sudha, G., Feroz, A. and Suresh, G. (1988) A Method for the Determination of the Material Parameters, D, L_o, S and α from Measured A.C. Short-Circuit Photocurrent. Solar Cells, 25, 61-72. https://doi.org/10.1016/0379-6787(88)90058-0

[27]. Luc, B., Shahriar, M., Dean, H., Marco, S., Manuela, A. and Claudio, N. (1994). Investigation of Carrier Transport through Silicon Wafers by Photocurrent Measurement. Journal of Applied Physics, 75, 4000-4008. https://doi.org/10.1063/1.356022

[28]. Rajman, K., Singh, R. and Shewchun, J. (1979). Absorption Coefficient for Solar Cell Calculations. Solid State Electronics, 22, 793-795. https://doi.org/10.1016/0038-1101(79)90128-X

[29]. G. Sissoko, S. Sivoththanam, M. Rodot, P. Mialhe **(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, poster 1B, 12-16 October, 1992, Montreux, Switzerland, pp.352-54

[30]. Ly, I., Ndiaye, M., Wade, M., Thiam, N., Gueye, S. and 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, 5, 203-208. https://doi.org/10.19026/rjaset.5.5105

[31]. Sall, M., Diarisso, D., Faty Mbaye Fall, M., Diop, G., Ndiaye, M., Loum, K. and Sissoko, G. (2021) Back Illuminated N/P/P^+ Bifacial Silicon Solar Cell under Modulated Short-Wavelength: Determination of Base Optimum Thickness. *Energy and Power Engineering*, **13**, 207-220. doi: 10.4236/epe.2021.135014.

[32]. Mamadou Sall, Mame Faty Mbaye Fall, Ousmane Diasse, Gora Diop, Ibrahima Diatta, Oumar Dia, Khady Loum, Mamadou Wade And Gregoire Sissoko (2022). Determination of optimum thickness of the base of $n^+/p/p^+$ 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, Vol. 11, N^0 4, 064-077. https://doi.org/10.24214/jcbps.C.11.4.06477

[33]. 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. https://doi.org/10.4236/epe.2020.121003394008

[34]. Malick Ndiaye, Ousmane Sow, Ibrahima Diatta, Gora Diop, Dibor Faye, Khady Loum, Youssou Traore, Moustapha Thiame, Mamadou Wade And Gregoire Sissoko (2022). Optimisation de l'épaisseur de la base de taux de dopage (Nb) de la photopile ($n^+/p/p^+$) au silicium à multi jonctions verticales connectées en série et placée sous éclairement monochromatique en modulation de fréquence. Journal of Chemical, Biological and Physical Sciences, Vol. 12, N^0 4, 266-280. https://doi.org/10.24214/jcbps.C.12.4.26680

[35]. Dede, M.M.S., Ba, M.L., Ba, M.A., Ndiaye, M., Gueye, S., Sow, E. H., Diatta, I., Diop, M.S., Wade, M. and Sissoko, G. (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://doi.org/10.4236/epe.2020.127027

[36]. Diop, G., Ba, H.Y., Thiam, N., Traore, Y., Dione, B., Ba, M.A., Diop, P., Diop, M.S., Mballo, O. and Sissoko, G. (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, 14, 4078-4085.

[37]. Thiaw, C., Ba, M.L., Ba, M.A., 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. https://doi.org/10.4236/jemaa.2020.127009

[38]. 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

[39]. 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

[40]. Masse Samba Diop, Hamet Yoro Ba, Ibrahima Diatta, Youssou Traore, Marcel Sitor DIOUF, El Hadji SOW, Oulymata Mballo and Gregoire Sissoko, (2019). Concept de la vitesse de recombinaison surfacique, appliqué à la détermination de l'épaisseur optimum de la base de la photopile au silicium avec effet du taux de dopage. International Journal of Innovation and Applied Studies, Ijias, Vol. 27 No. 3, pp. 809-817, http://www.ijias.issr-journals.org/abstract.php?article=IJIAS-19-261-22

[41]. Faye, D., Gueye, S., Ndiaye, M., Ba, M.L., Diatta, I., Traore, Y., Diop, M.S., Diop, G., Diao, A. and Sissoko, G. (2020). Lamella Silicon Solar Cell under Both Temperature and Magnetic Field: Width Optimum Determination. Journal of Electromagnetic Analysis and Applications, 12, 43-55 https://doi.org/10.4236/jemaa.2020.124005

[42]. Sega Diagne, Ousmane Sow, Gora Diop, Richard Mane, Ibrahima Diatta, Djiby Ndiongue , Youssou Traore, Lemrabott HabiboullahMamadou Wade and Gregoire Sissoko. (2022) Optimization of silicon solar cell base thickness, while illuminated by a long wavelength monochromatic light: influence of both Lorentz law and Umclapp process. International Journal of Advanced Research, 10(08), 133-143. http://dx.doi.org/10.21474/IJAR01/151508

[43]. Nouh Mohamed Moctar Ould Mohamed, Ousmane Sow, Sega Gueye, Youssou Traore, Ibrahima Diatta, Amary Thiam, Mamour Amadou Ba, Richard Mane, Ibrahima Ly, Gregoire Sissoko (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

[44]. Meusel, M., Benssch, W., Berdunde, T., Kern, R., Khorenko, V., Kostler, W., Laroche, G., Torunski, T., Zimmermann, W., Strobl, G., Guter, W., Hermle, M., Hoheisel, R., Siefer, G., Welser, E., Dimroth, F., Bett, A.W., Geens, W., Baur, C., Taylor, S. and Hey, G. (2007). Development and Production of European III-V Multijunction Solar Cells. Proceeding of the 22nd European Photovoltaic Solar Energy Conference, 16-51.

[45]. Kopach, V.R., Kirichenko, M.V., Shramko, S.V., Zaitsev, R.V. and Bondarenko, S.A. (2008) New Approach to the Efficiency Increase Problem for Multi-Junction Silicon Photovoltaic Converters with Vertical Diode Cells. Functional Materials, 15, 253-258.

[46]. 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, 122, 1-10. https://doi.org/10.1016/j.solener.2015.08.005