Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2020, 7(4):138-145

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Minority Carriers' Diffusion Length Determination in the Base of a Silicon Vertical Junction Solarcell by Use of the Short-Circuit Current Calibration Curve Technique

Mamour Amadou BA, Sega GUEYE, Amadou DIAO, Ibrahima DIATTA, Youssou TRAORE, Mamadou Lamine BA, Babou DIONE, Gregoire SISSOKO

Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal
e-mail: gsissoko@yahoo.com

Abstract The L_{eff} determination technique is applied to the lamella base of parallel vertical junction silicon solar cell under steady state. The theoretical current density's expression generated by the lamellasolar cell under polychromatic illumination is established. The short-circuit current's calibration curve compared to the experimental one yields the minority carriers effective diffusion length. The purpose of this paper is to improve curves calibration technique by proposing a method based on an algorithm called "$Find\_L_{eff}$".

Keywords Vertical silicon solar cell- Diffusion length- Algorithm

Introduction

In order to improve the photovoltaic conversion's efficiency, solar cells, in particular silicon solar cells, have undergone architectural modifications. Consisting by an emitter-base junction (n/p), the illumination is provided by the front surface (monofacial), which constitutes the emitter. As a result, the structure has become (n^+-p-p^+), improving the quality of both the emitte rand the base. At the back of the base (p-p+) where an electric field is produced using the (p+) layer, which returns the electric charges to the junction [1-5]. Illumination may be performed either from the front (n +) and from the rear (p +) or simultaneously from both sides (bifacial or double side surface field solar cells) [6-8].

The lateral (or parallel) illumination of junction (space charge region)plane of (n/p) or (n+/p/p+) has led to the realization of new architectures, which are the vertical junction (VJ) solar cells [9-10]. The vertical junction gives the advantage of uniform photo-creation of electric charges near (n/p) or (p/p+) surfaces, in order to promote their collection and to contribute to the photocurrent. Thus the unit structures (n/p) and (n+/p/p+) can be reproduced and connected to give multiple vertical junction solar cells (MVJs) [11-13]. These (MVJs) lead to two connection possibilities. These are serial MVJs and parallel MVJs. Serial MVJs mainly use (n+/p/p+) connected in series to increase the output electrical voltage [14], whereas parallel MVJs use (n/p) structures which are connected to each other in parallel, i.e. the bases connected to each other and the emitters connected to each other, in order to increase the output electrical current, from the contribution of the different areas of the structure [11-12, 15].

These structures allow the creation of electrical charges close to the surfaces (n/p) and (p/p+), and give the advantage of choosing poor quality silicon base materials with low optoelectronic properties (weak lifetime and diffusion length) and also can be submitted to concentration of incident light (number of suns) [16-17].

Thus this work brings the interest of minority charge carriers' diffusion length determination in the base(p) of parallel vertical junction solar cell. The intercept technique of the calibration curve of the theoretical photocurrent with the experimental short-circuit current, represented as a function of minority carriers' diffusion length, is improved by the new method (Leff find).

Theoretical Study

Figure 1 shows a parallel vertical junction silicon solar cell under polychromatic illumination.

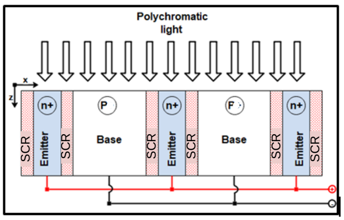

Figure 1: Solar cell with vertical junction connected in parallel

Diffusion Continuity Equation

When the solar cell is illuminated, there are the establishment of phenomena's such as, absorption- generation, diffusion and recombination of excess minority carriers charges δ (x, z) at the abscissa x and the depth z in the base. In steady state, these phenomena are take into account through the continuity equation given by following relation [11, 18]:

$$\frac{\partial^2 \delta(x)}{\partial x^2} - \left(\frac{1}{L^2}\right).\delta(x) = -\frac{G(z)}{D} \quad (1)$$

L and D, represent respectively the diffusion length and coefficient of minority carriers in the base and linked by Einstein's relationship:

$$L^2 = D\tau \quad (2)$$

G(z) denotes the minority carrier generation rate, at depth z in the base, while the solar cell is illuminated with polychromatic light. Its expression is given by:

$$G(Z) = n\sum_{i=1}^{3} a_i e^{-b_i Z} \quad (3)$$

Where the coefficients a_i and b_i, represent the tabulated values under the solar light spectrum, corresponding to n= 1 sun [19, 20]. The sun irradiation concentration is represented by n [15-17, 21]

The general solution's expression of differential equation with second member is given by following relation:

$$\delta(x,z,Sf,n) = A(z,Sf,n).\cosh\left(\frac{x}{L}\right) + B(z,Sf,n).\sinh\left(\frac{x}{L}\right) + \sum_{i=1}^{3} K(n).e^{-b_i z} \quad (4)$$

Where $K(\mathrm{n}) = \frac{n \cdot a_i \cdot L^2}{D[1-(\mathrm{L}\cdot \mathrm{b}_i)^2]}$, A and B are determined using the following boundary conditions:

Boundary Conditions

At junction in x = 0:

$$D_n \cdot \frac{\partial}{\partial x}\delta(x,z)\bigg|_{x=0} = S_F \cdot \delta(0,z) \quad (5)$$

Sf, represents the excess minority carrierre combination velocity at the junction, and characterizes charge current flow through the junction surface [22-24]. It indicates also the solar cell operating point through the variation of the gradient at the junction, from ideal open circuit (Sf = 0) to short circuit condition i.e. large Sf values. In real open circuit condition an additional component (Sf0) is taken into account, associated to losses through shunt resistance [25-28].

At base middle, at x = H/2, base can be split in two, to get two H/2 base solar cells, with two adjacent emitters (Figure 2). Then each half appears to be an ideal back surface field solar cell, with zero back surface recombination velocity (Sb= 0) [11-12, 18, 28-32] :

$$\frac{\partial}{\partial x}\delta(x,z)\bigg|_{x=\frac{H}{2}}=0 \qquad (6)$$

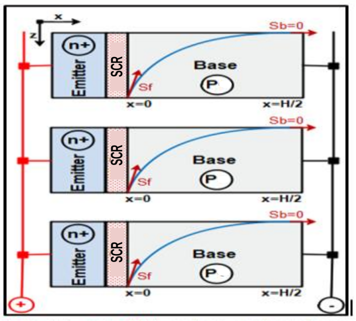

Figure 2: Solar cell with vertical junction connected in parallel

Photocurrent density and short-circuit photocurrent density

Fick's Law, allows us to establish photocurrent density equation due to charge carrier's diffusion through the junctions that frame base [11].

$$J_{ph}=2\cdot q\cdot D_n\cdot\frac{\partial}{\partial x}\delta(x,z)\bigg|_{x=0} \qquad (7)$$

Figure 3 shows photocurrent and short circuit photocurrent densities' profiles versus junction recombination velocity.

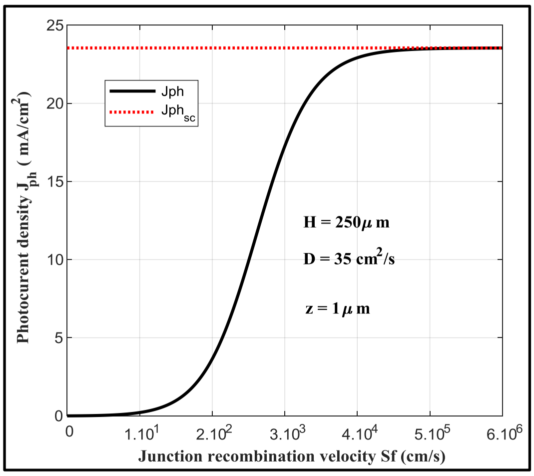

Figure 3: Photocurrent and short-circuit photocurrent versus Sf

Short-circuit photocurrent density

Near very high junction recombination velocity's values, photocurrent density (Jph) tends towards a constant value which corresponds to the short-circuit current (Jph_{SC}).

$$J_{sc}=\lim_{s_F\to high\,value}J_{ph} \qquad (8)$$

Figure 4 shows short-circuit current's profile versus diffusion length.

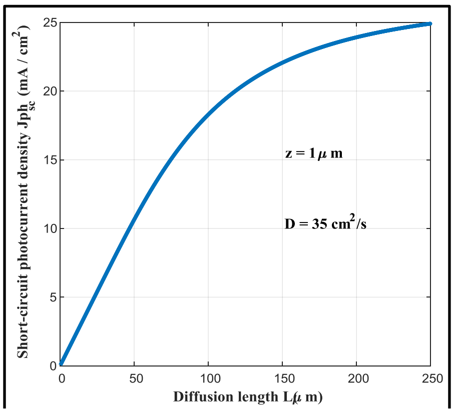

Figure 4: Variation of short-circuit current (Jph_{SC}) versus diffusion length

Effective diffusion length L_{eff} measurement

Determination method of L_{eff}value

The short-circuit current calibration curve technique

This method is based on intersection point of theoretical short-circuit current density curve with experimental curve [12, 25, 33]. The orthogonal projection intercept point of theoretical and experimental curves on diffusion length axis corresponds to L_{eff} value.

New determination method based on an algorithm

The freehand projection on short-circuit photocurrent density curve to determine L_{eff} value probably induces errors, and considerably influences the interpreted results. The new method proposed in this paper consists to calculate effective diffusion length value by using an algorithm called "$Find\_L_{eff}$" described by Figure 5.

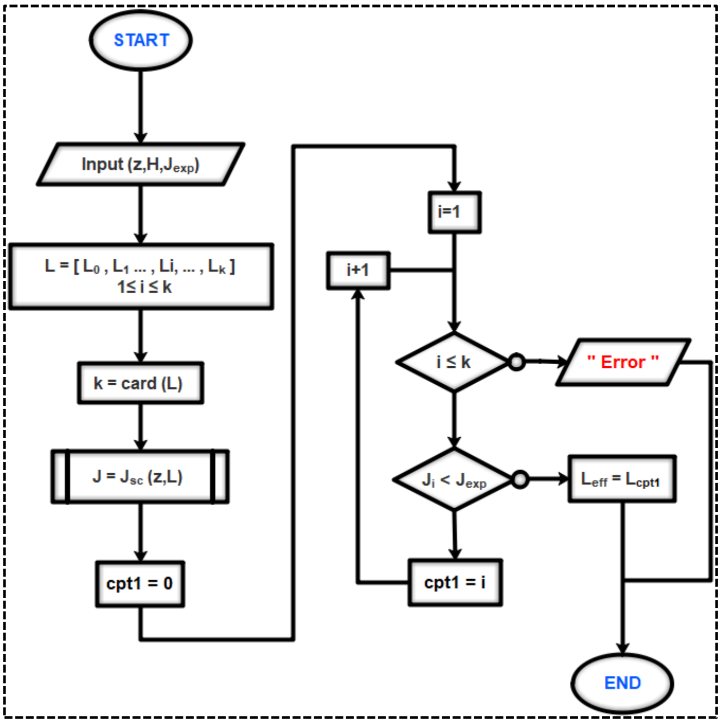

Figure 5: L_{eff} calculation method flowchart

The new L_{eff} calculating method using in this paper consists: firstly, discretizing the solar cell base width value, then determining corresponding photocurrent values. Thus a short-circuit photocurrent density vector evolving as a function of the solar cell base width is generated by the algorithm.

$$\left.\begin{array}{l} J = J_{sc}(z, L), \\ L = \left[L_1, \dots, L_j, \dots, L_q \right] \text{ and } 1 \le i \le k \end{array}\right\} \Leftrightarrow J = \left[J_1, \dots, J_i, \dots, J_k \right] \quad (9)$$

The final step corresponds to curves calibration by defining a counting variable which will make it possible to enumerate comparison of the short-circuit photocurrent density with respect to a known experimental value, as the comparison process progresses, the counter variable is incremented at same rate. At end, algorithm returns the "ith" J_{sc} value which respectsto the condition:

$$J_i \le J_{exp} \quad (10)$$

The effective diffusion length is "ith" element's value of vector L. Figure 6 shows L_{eff} graphical determination for different experimental photocurrent (J_{exp}) values obtained in [34] using the algorithm "$Find\_L_{eff}$" [12, 25, 33].

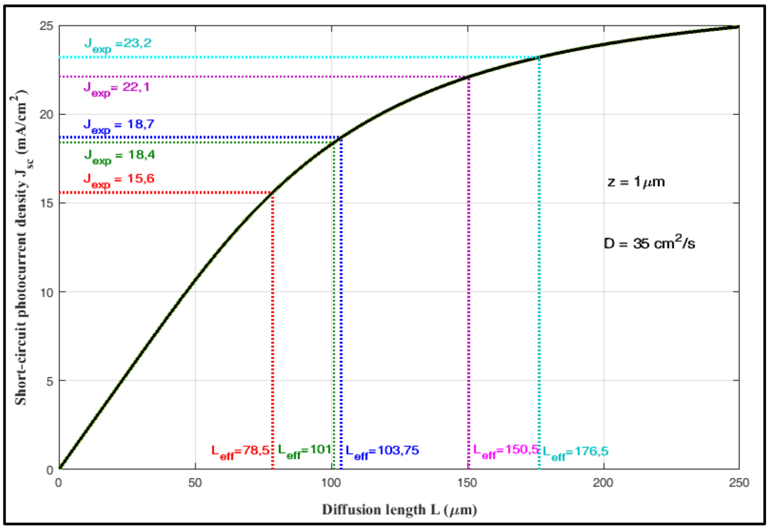

Figure 6: Graphical determination of L_{eff} for different specific J_{exp} values

The results shown in Figure 6 allow us to draw up the following table of correspondence:

Table 1: L_{eff} values obtained from our algorithm with different experimental short-circuit currents

Samples	Experimental J_{SC} (mA) [34]	L_{eff}(μm)
A	15.6	78.50
B	18.4	101
C	18.7	103.75
D	22.1	150.5
E	23.2	176.5

The application of this new algorithm is a great contribution in the precision in the results obtained in the determination of L_{eff} from samples prepared under different elaboration processes [34], having produced these short-circuit current. The L_{eff} obtained is in good agreement with the lamella silicon solar cells processing.

Based on this innovation brought by the Leff finder algorithm, further investigations will be carried out on lamella, using models that take into account the real excess minority carriers effective recombination velocity Sb [35-36].

Conclusion

In this paper, we investigated the determination of the diffusion length of minority carriers in the base of a silicon-parallel vertical junction solar cell using the short-circuit current calibration curve technique. This study highlights diffusion length importance on solar cell manufacturing.

New method proposed in this paper allows an automatically L_{eff} determination by using an algorithm, which considerably reduces the errors risk compared to classical method.Effective diffusion length's knowledge will permit to determine junction intrinsic recombination velocity's of minority carriers in solar cell. Other way, use algorithmic method offers possibility of better studying L_{eff} 'behaviour under the influence of external parameters such as temperature, magnetic field, electric field, and light irradiation intensity.

References

[1]. M. P. Godlewski, C. R. Baraona, and H. W. Brandhorst, Jr., (1973); Low High Junction Theory Applied to Solar Cells, Tenth IEEE Photovoltaic Specialists Conference, Palo Alto CA, pp. 13-15

[2]. J.G. Fossum, R.D. Nasby, and E. L. Burgess (1978). Development of high-efficiency p+-n-p+ back-surface fied silicon solar cell. Rec. 13th IEEE Photovoltaic Specialist Conf. (IEEE Cat. N°. 78CH1319-3ED).

[3]. S. R. Dhariwal and N. K. Vasu (1981). A generalized approach to lifetime measurement in pn junction solar cells. Solid-State Electronics, Vol. 24, No10, pp915-927.

[4]. Chin & Yuan Wv and Wen-Zen Shen, (1980). The open-circuit voltage of back-surface-field (BSF) p-n junction solar cells in concentrated sunlight. Solid-State Electronics Vol. 23. pp. 209-216.

[5]. Le Quang Nam M. Rodot (1992). Solar cells with 15.6% efficiency on multicrystalline silicon, using impurity gettering back surface field and emitter passivation. Int. J. Solar Energy, vol. 11, pp. 273-279.

[6]. J. Del Alamo, J. Eguren and A. Luque (1981). Operating Limits of Al-Alloyed High-Low Junctions For Bsf Solar Cells. Solid-Sfah Ekcfmnicr Vol 24. pp. 415A20.

[7]. Luque A, Ruiz JM, Cuevas A, Eguren J, Agost MG. (1997). Double side solar cells to improve static concentrator. Proceedings of the 0st European Photovoltaic Solar Energy Conference, Luxembourg. Pp. 269-27.

[8]. H. Ohtsuka, M. Sakamoto, K. Tsutsui and Y. Yazawa, (2000). Bifacial Silicon Solar Cells with 21.3% Front Efficiency and 19.8% Rear Efficiency. Prog. Photovolt. Res. Appl. 8; pp. 385-90.

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

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

[11]. A Gover, and P. Stella (1974). Vertical Multijunction Solar-Cell One-Dimensional Analysis. IEEE Transactions on Electron Devices, Vol. ED-21:6. Pp. 351-356,

[12]. M.M. Dione, H. Ly Diallo, M. Wade, I. Ly, M. Thiame, F. Toure, A. Gueye Camara, N. Dieme, Z. Nouhou Bako, S. Mbodji, F. I. Barro, G. Sissoko (2010). Determination of the shunt and series resistances of a vertical multijunction solar cell under constant multispectral light. 26th European Photovoltaic Solar Energy Conference and Exhibition, pp. 250-254.

[13]. Y. Xing, P. Han, S. Wang, P. Liang, S. Lou, Y. Zhang, S. Hu, H. Zhu, Y. Mi, C. Zhao (2013). Analysis of effects of front and back surface dopants on silicon vertical multi-junction solar cell by 2D numerical simulation.Sci China Tech Sci, 56(11), Pp. 2798-2807.

[14]. C. Hu, J. K. Carney, R. I. Frank (1977). New analysis of a highvoltage vertical multijunction solar cell. Journal of Applied Physics. Vol.48, pp.442-444,

[15]. Ayvazian, G.E., Kirakosyan, G.H. and Minasyan, G.A. (2004). Characteristics of Solar Cells with Vertical p-n Junction. Proceedings of 19th European Photovoltaic Solar Energy Conference, Paris, 7-11 June. Pp. 117-119.

[16]. Pozner, Roni & Segev, Gideon & Sarfaty, Rona & Kribus, Abraham & Rosenwaks, Yossi. (2012). Vertical junction Si cells for concentrating photovoltaics. Progress in Photovoltaics Research and Applications. Vol.20, pp. 197-208, 10.1002/pip.1118.

[17]. 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 (2011). Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, 5-6 September. Pp. 145-147.

[18]. J. H. Heinbockel, G. H. Walker (1988). Three-Dimensional Models of Conventional and Vertical Junction Laser-Photovoltaic Energy Converters, NASA-TM-4039 19880014727.

[19]. J. Furlan, S. Amon (1985). Approximation of the carrier generation rate in illuminated silicon. Solid-State Electronics, vol. 28, No. 12, pp. 1241-1243.

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

[21]. G. Paternoster Pierluigi Bellutti Amos Collini Lorenza Ferrario F. Ficorella Francesca Mattedi (2013). Back-Contact Vertical Junction Silicon Solar Cells for Concentrating Photovoltaics. 28th European Photovoltaic Solar Energy Conference and Exhibition at Paris. Pp-672-675.

[22]. 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 (Montreux, Switzerland). Pp. 352-54.

[23]. G. Sissoko, C. Museruka, A. Corréa, I. Gaye, A. L. Ndiaye (1996). Light spectral effect on recombination parameters of silicon solar cell. World Renewable Energy Congress, Vol. 3, pp. 1487-1490, 15-21, Denver-USA.

[24]. Diallo, H. L., A. S. Maïga, A. Werene, G. Sissoko. (2008). New approach of both junction and back surface recombination velocities in a 3D modeling study of a polycrystalline silicon solar cell. Eur. Phys. J. Applied. Phys. 42, 203-211.

[25]. G. Sissoko, E. Nanéma, A. Corréa, P.M. Bitéye, M. Adj, A.L. Ndiaye. (1998). Silicon Solar cell recombination parameters determination using the illuminated I-V characteristic. World Renewable Energy Congress Vol. 3, pp. 1848-1851.

[26]. Dione, M.M., Mbodji, S., Samb, M.L., Dieng, M., Thiame, M., Ndoye, S., Barro, F.I. and Sissoko, G. (2009). Vertical Junction under Constant Multispectral Light: Determination of Recombination Parameters. Proceedings of the 24th European Photovoltaic Solar Energy Conference, Hamburg, 21-25 September 2009, 465-469. http://www.eupvsec-proceedings.com

[27]. El Hadji Ndiaye, Gokhan Sahin, Amary Thiam, Moustapha Dieng, Hawa Ly Diallo, Mor Ndiaye, Grégoire Sissoko. (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, Vol. 4, No. 22 http://www.scirp.org/journal/jamp

[28]. Fatimata Ba, boureima Seibou, mamadou Wade, marcel Sitor Diouf, brahima Ly and grégoire Sissoko (2016). Equivalent Electric Model of the Junction Recombination Velocity limiting the Open Circuit of a Vertical Parallel Junction Solar Cell under Frequency Modulation. IPASJ International Journal of Electronics & Communication (IIJEC), Volume 4, Issue 7, pp.1-11.

[29]. Z. Nouhou Bako, H. Ly Diallo, A. GueyeCamara, M. Thiam, D. M. Abouzeidi, S. Madougou, G. Sissoko (2013). Three Dimensional Study of Spectral Response of Polycrystalline Silicon Solar Cells: Vertical Junction Frequency Modulation Scheme. Journal of Energy and Power Engineering Vol. 7, pp. 903-906.

[30]. Oulimata MBALLO, Boureima SEIBOU, Mamadou WADE, Marcel Sitor DIOUF, Ibrahima LY, Seni TAMBA, Grégoire SISSOKO (2016). Influence of the Depth base on the Electrical parameters of a Parallel Vertical Junction Silicon Solar Cell under Polychromatic illumination. International Journal of Electrical Engineering (IIJEE); Volume 4, Issue 7, pp. 6-16.

[31]. Moussa Ibra Ngom, Amary Thiam, Gokhan Sahin, Mohamed Abderrahim Ould El Moujtaba, Khady Faye, Marcel Sitor Diouf, Grégoire Sissoko, (2015). Influence of Magnetic Field on the Capacitance of a Vertical Junction Parallel Solar Cell in Static Regime, Under Multispectral

Illumination. International Journal of Pure & Applied Sciences & Technology. Vol. 31 Issue 2, pp. 65-75.

[32]. Gokhan Sahin, Moustapha Dieng, Mohamed Abderrahim Ould El Moujtaba, Moussa 1ibra Ngom, Amary Thiam, Grégoire Sissoko. (2015). Capacitance of Vertical Parallel Junction Silicon Solar Cell Under Monochromatic Modulated Illumination. Journal of Applied Mathematics and Physics, 3, 1536-1543.

[33]. G. Sissoko, E. Nanema, Y. L. B. Bocandé, A. L. Ndiaye, M. Adj (1996). Minority Carrier Diffusion Length Measurement in Silicon Solar Cell under Constant White Bias Light. World Renewable Energy Congress, 1594-1597.

[34]. Terheiden, B., Hahn, G., Fath, P. and Bucher, E. (2000). The Lamella Silicon Solar Cell. Proc. 16th European Photovoltaic Solar Energy Conference, Glasgow U.K, 1-5 May 2000, 1377-1380.

[35]. 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.

[36]. 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.