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Research Article

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Influence of Temperature and Magnetic Field on the Capacity and Power of a Silicon Solar Cell under Polychromatic Illumination in Static Conditions

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Abstract The objective of this article is to study the effect of temperature and magnetic field on the capacitance and electrical power of a silicon solar cell under polychromatic illumination, in static conditions. From the continuity equation, the expressions for the photocurrent density, and the phototension were determined. Using the expression for the phototension of the solar cell, we deduced the expression for the capacitance. Then, we also deduced the power taking into account the diode current.

Keywords Temperature, Solar cell, Capacity, Power, Face recombination speed

1. Introduction

A solar cell is made up of three zones which are the transmitter, the base and the rear zone. Between the transmitter and the base is a space charge area. This area is generally similar to a planar capacitor called the transition capacitance due to the ionization of fixed charges [1,2,3]. The diffusion of minority charge carriers creates a diffusion capacity whose thickness depends on the rate of recombination at the junction that fixes the operating point, from open circuit to short circuit [4,5,6].

Much research has been carried out on the diffusing capacity and power of a solar cell [7,8]. Under the operating conditions of the solar cell under darkness or under lighting, the temperature and the magnetic field influence the electrical parameters and consequently the efficiency of the solar cell [9,10,11,12]. In this work, we will study the effect of the temperature and the magnetic field on the capacitance C and the power P of a silicon solar cell in a static regime under polychromatic illumination.

2. Theoretical study

The solar cell considered is of the n + -p-p + type and its structure is shown in figure 1 [13,14].

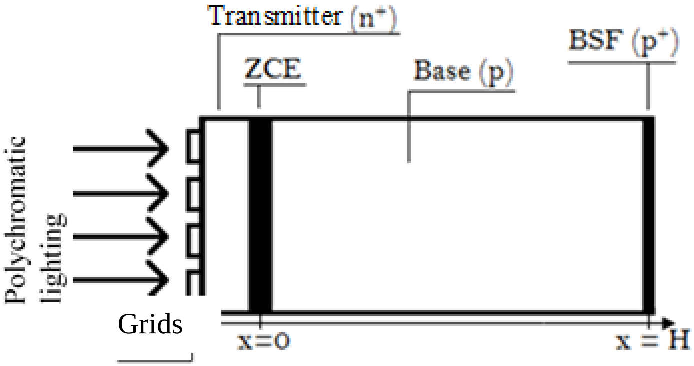

Figure 1: Structure of a silicon solar cell n+-p-p+

When the solar cell is illuminated, there is a creation of electron-hole pairs in the base. The density of excess minority carriers in the base is modeled by the following continuity equation:

$$\frac{\partial^2\delta(x)}{\partial x^2}-\frac{\partial\delta(x)}{L^2}=-\frac{G(x)}{D^*} \tag{1}$$

With δ(x) is the density of the electrons generated in the base at position x.
G (x) is the generation rate of minority carriers at position x of the base [15] given by:

$$G(x)=\sum_{i=1}^{3} a_i \times \exp\left(-b_i \times x\right) \tag{2}$$

The coefficients ai and bi are obtained from the tabulated values of the radiation under A.M1, 5 [16].
These coefficients are given by:
a_1=6, 13.1020 cm^{-3}/s; a2=0, 54.1020cm^{-3}/s; a_3=0.0991.1020cm^{-3}/s; b_1=6630cm^{-1}; b_2=1000cm^{-1}; b_3=130cm^{-1},

$$L^2(T,B)=\tau\times D^*(T,B) \tag{3}$$

L is the diffusion length of electrons in the base, it depends on the temperature,
τ is the lifetime of the electrons in the base,

$$D^*(T,B)=\frac{D(T)}{1+\mu^2(T).B^2} \tag{4}$$

With

$$D(T)=\mu(T)\times\frac{K_b\times T}{q} \tag{5}$$

D is the diffusion coefficient of the electrons in the base [17].

$$\mu(T)=1{,}43.10^9\times T^{-2{,}42}\ \mathrm{cm^2V^{-1}s^{-1}} \tag{6}$$

$\mu(T)$ is the electron mobility coefficient [8],
kb is Boltzmann's constant,
q is the elementary charge of the electron,
The general solution of equation (1) is:

$$\delta(x,T,B)=A(T,B)\cosh\left(\frac{x}{L(T,B)}\right)+B(T,B)\sinh\left(\frac{x}{L(T,B)}\right)+\sum_{i=1}^{3}\frac{a_i\times L^2(T,B)\times\exp\left(-b_i\times x\right)}{D^*(T,B)\bullet\left[L^2(T,B)\bullet b^2 i-1\right]} \tag{7}$$

The expressions of A and B are determined from the following boundary conditions [18]:
i) At the junction (x=0):

$$\left.\frac{\partial\delta(x,T,B)}{\partial x}\right|_{x=0}=\frac{S_f}{D^*(T,B)}\times\delta(x,T,B)\Big|_{x=0} \tag{8}$$

ii) At the back (x = H):

$$\left.\frac{\partial\delta(x,T,B)}{\partial x}\right|_{x=H}=-\frac{S_b}{D^*(T,B)}\times\delta(x,T,B)\Big|_{x=H} \tag{9}$$

Sf denotes the rate of recombination of minority charge carriers at the base junction and also indicates the operating point of the solar cell [18,19] and Sb denotes the rate of recombination of minority charge carriers on the rear face of the solar cell. cell. base [20].

3. Photovoltage

The photovoltage of the solar cell is given by the Boltzmann relation [21]:

$$V_{Ph}\left(S_f,T,B\right)=V_T\cdot\ln\left(\frac{N_b}{n^2{}_i(T)}\cdot\delta(0,Sf,B,T)+1\right) \tag{10}$$

Where V_T is the thermal voltage, it is defined as follows

$$V_T=\frac{K_b\cdot T}{q} \tag{11}$$

N_b is the doping rate,

n_i is the intrinsic density of the minority charge carriers with

$$n^2{}_i(T)=A\cdot T^3\cdot\exp\left(\frac{E_g}{K_b\cdot T}\right) \tag{12}$$

E_g is the gap energy, and corresponds to the difference between the energy of the conduction band E_c and that of the valence b and E_g.

A is a constante. A = $3,87.10^{16}$ cm^{-3} $K^{-3/2}$[22]

4. Capacity

Using the expression of phototension, the capacity of the solar cell is expressed as [23,24,25].

$$C\left(S_f,T,B\right)=\frac{dQ\left(S_f,T,B\right)}{dV\left(S_f,T,B\right)} \tag{13}$$

$$Q\left(S_f,T,B\right)=q\times\delta\left(x,S_f,T,B\right)\Big|_{x=0} \tag{14}$$

Taking into account the expression of phototension and the density of minority carriers, we obtain the following expression:

$$C\left(S_f,T,B\right)=q\times\frac{n_i^2(T)}{V_T}+q\times\frac{\delta\left(x,S_f,T,B\right)\Big|_{x=0}+\sum_{i=1}^{3}K_i}{V_T} \tag{15}$$

$$C\left(S_f,T,B\right)=C_0(T)+C_d\left(S_f,T,B\right) \tag{16}$$

Where,

$$C_0(T)=q\times\frac{n_i^2(T)}{V_T} \tag{17}$$

$$C_d\left(S_f,T,B\right)=q\times\frac{\delta\left(x,S_f,T,B\right)\Big|_{x=0}+\sum_{i=1}^{3}K_i}{V_T} \tag{18}$$

$C_0(T)$ is the capacity of the solar cell when it is short-circuited.

C_d (Sf, B, T) is the diffusion capacity of the solar cell at temperature T, and of the magnetic field at an operating point given by Sf.

We model the capacity on the following figure:

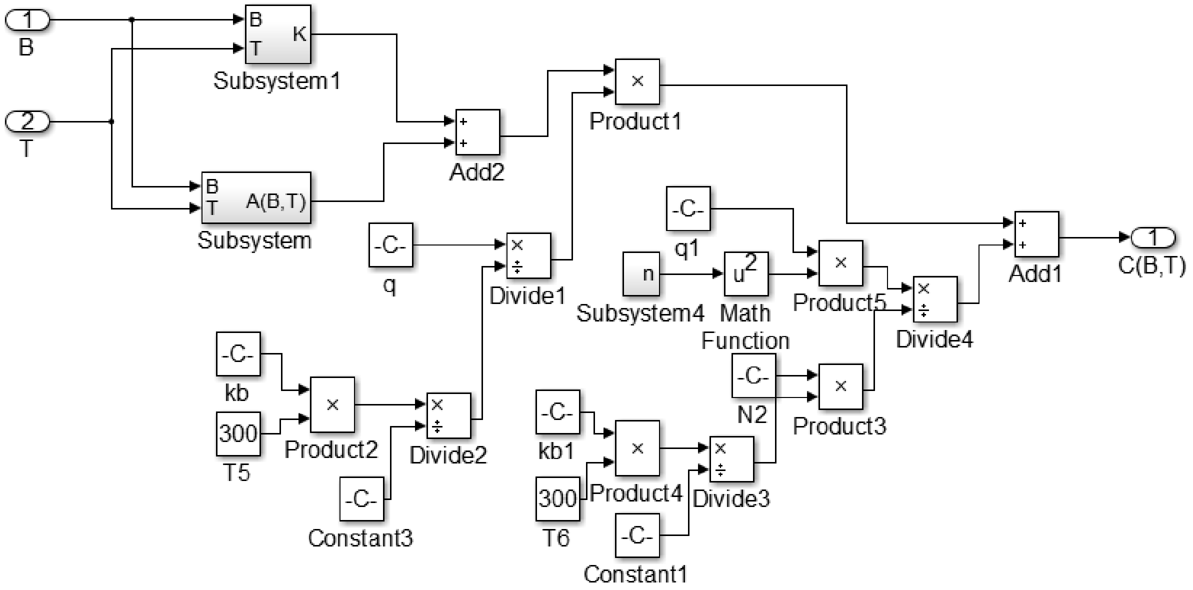

Figure 2: Simulink model of capacity

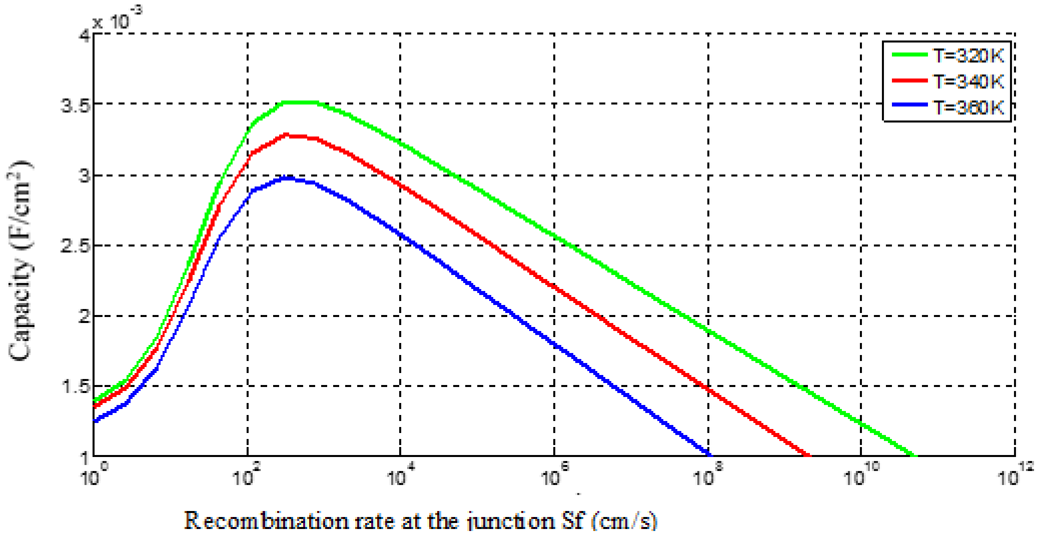

Figure 3: Curve of the capacitance as a function of the recombination rate at the junction for different values of the temperature and for $B = 10^{-5}\ T$

The capacity curve is decreasing and has two levels:

a) The first level corresponds to the values of the recombination speed at the Sf junction less than 2.102 cm.s-1, the capacity is maximum and constant. At this stage we tell ourselves that the solar cell works in open circuit. Minority charge carriers are stored at the junction because the thickness of the associated planar capacitor is small.

b) The second level corresponds to the junction recombination speed values greater than 4.10^{4} cm.s^{-1}, the capacity also becomes minimal and constant. At this level we say that the solar cell operates in short circuit. There the minority charge carriers will be able to cross because there is an enlargement of the thickness of the planar capacitor.

For the recombination speeds at the junction, 2.10^2 cm.s^{-1} < Sf <4.10^4cm.s^{-1}, the capacity of the solar cell decreases considerably. This phase is this phase of discharge of the minority charge carriers.

The effect of temperature on capacity is most noticeable in open circuit operation. At this operating point, the capacitor can be associated with a capacitor with a large thickness which depends on the temperature.

The following figure represents the capacitance as a function of the recombination rate at the Sf junction for different values of the magnetic field.

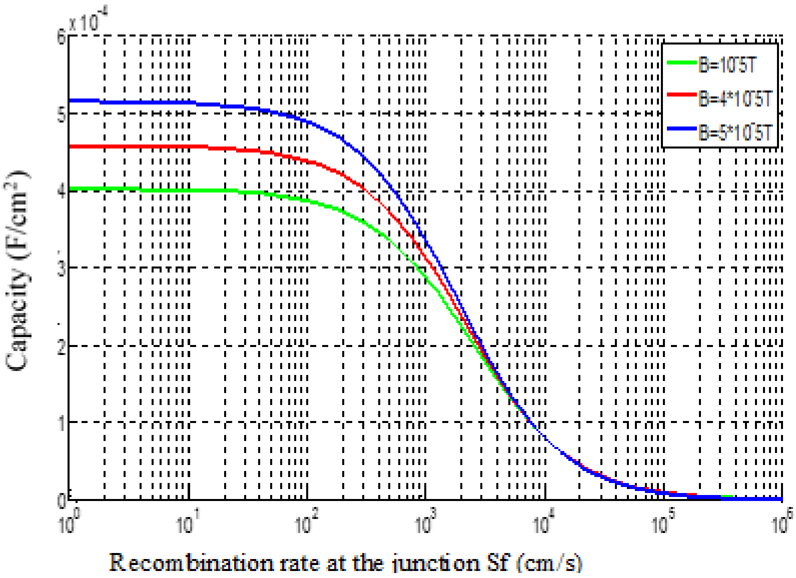

Figure 4: Curve of the capacitance as a function of the rate of recombination at the junction for different values of the temperature and for T = 300K

When we are in open circuit operation, we notice that the capacitance is maximum for the different values of the magnetic field. This is reflected by the fact that in open circuit, the carriers are stored at the junction.

For the recombination speeds at the junction, 2.10^2 cm.s^{-1} < Sf <4.10^4cm.s^{-1}, the capacity of the solar cell drops dramatically. This is due to the rapid discharge of the minority charge carriers.

We observe that the capacitance increases when the magnetic field increases because the magnetic field blocks carriers which will not be able to cross the junction.

The effect of the magnetic field on capacitance is most noticeable in open circuit operation. At this operating point, the capacitance can be associated with a capacitor with a large thickness which depends on the magnetic field

5. Power

The power of the solar cell is given by the following expression [26,27,28]:

$$P\left(S_f,T,B\right)=\left[J_{Ph}\left(S_f,T,B\right)-J_d\left(S_f,T,B\right)\right]\times V_{Ph}\left(S_f,T,B\right) \tag{19}$$

The diode current is given by the following relation [29]

$$J_d\left(S_f,T,B\right)=q\cdot S_{f0}\cdot\delta\left(x,S_f,T,B\right)\Big|_{x=0} \tag{20}$$

J_d which represents the diode current will be modeled in the following figure 5.

Sf intrinsic recombination rate

q the elementary charge of the electron.

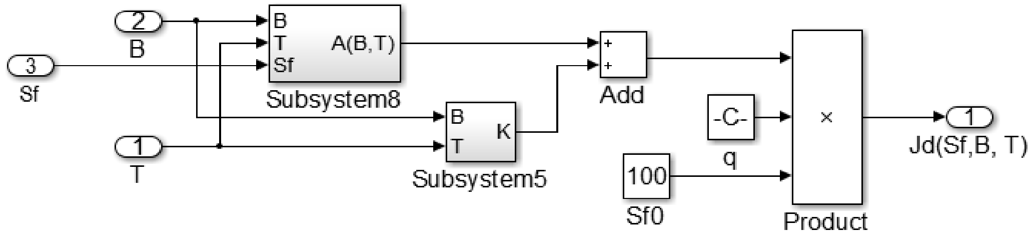

Figure 5: Modeling of the diode current

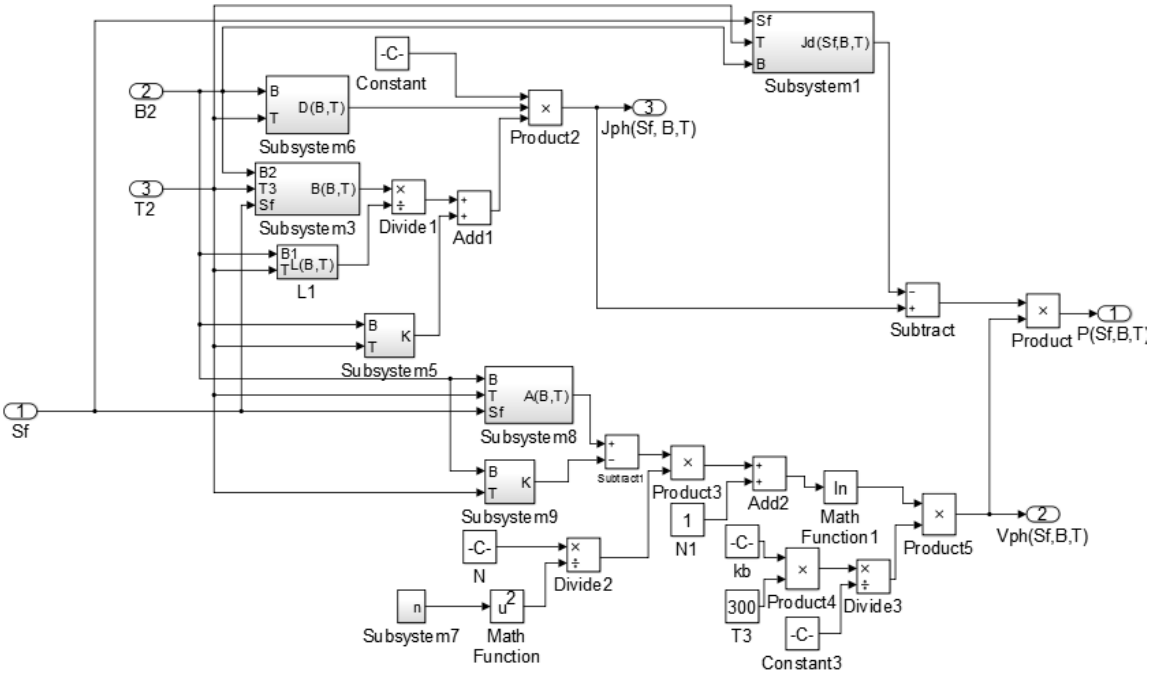

Figure 6: Simulink power model

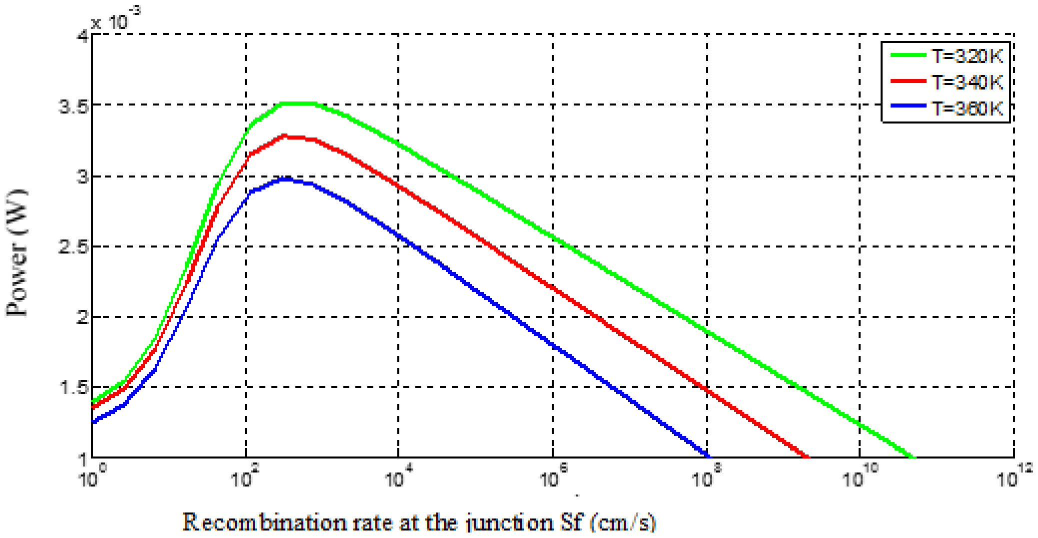

Figure 7: Power curve as a function of the recombination rate at the junction for different temperature values with $B = 10^{-5}\ T$

We observe here for low recombination speeds at the junction, the current is low, we are in the vicinity of the open circuit which results in a low power of the solar cell.

However, when the recombination rate at the junction begins to increase, the current gradually increases, causing the power to increase until it reaches a maximum value. When we are in the vicinity of the short circuit, the photo voltage tends to cancel out, which simultaneously causes a decrease in power.

Also, as can be seen the increase in temperature results in a decrease in maximum power. We can therefore expect a decrease in the quality of the solar cell with the increase in temperature.

In the following figure, we have studied the behavior of power as a function of the recombination rate under the effect of the magnetic field.

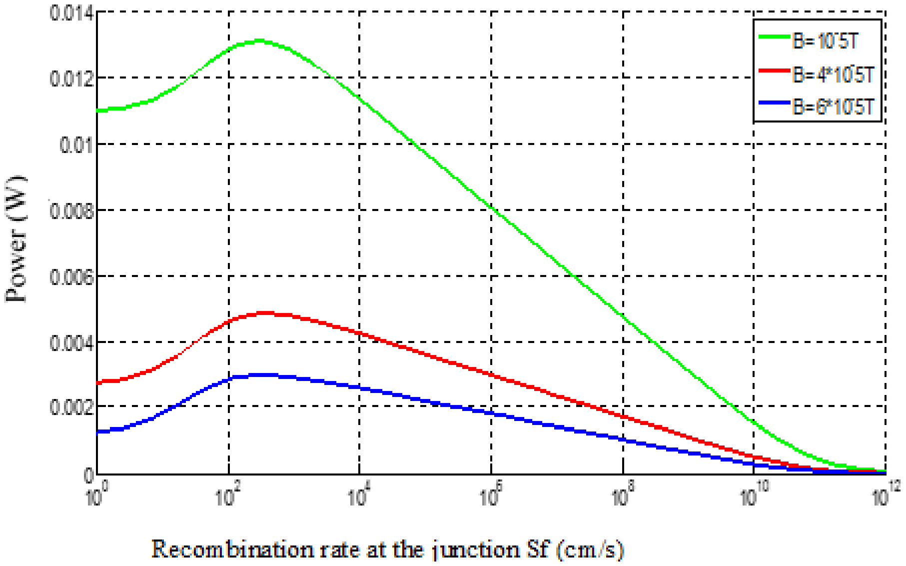

Figure 8: Power curve as a function of the recombination speed at the junction for different values of the magnetic field with T = 300K

We find that the potency increases with increasing recombination speed and reaches a maximum. Then after this maximum, it begins to decrease as the rate of recombination at the Sf junction increases. We also find that these maximums decrease as the magnetic field increases. This can be explained by the fact that when the magnetic field increases, the minority carriers will be blocked at the junction and will not participate in the creation of the photocurrent. We can say that the magnetic field has a negative influence on the efficiency of the solar cell.

6. Conclusion

In this work after solving the continuity equation, the expression of phototension, capacitance and power have been proposed. Thus, we put into practice the effect of temperature and that of the magnetic field on the capacity and power of a solar cell. We note that the temperature is a very important parameter in the behavior of solar cells because the electrical performance of a solar cell is very sensitive to it. Likewise, the magnetic field decreases the efficiency of a solar cell.

References

[1]. G. Sissoko, B. Dieng, A. Corréa, M.Adj, D. Azilinon (2004). Silicon Solar cell space charge region width determination by a study in modelling. Renewable Energy, vol-3, pp. 1852-1855-Elsevier Science Ltd, 0960-1481/98/#.

[2]. B.R. Chawla, H.K. Gummel, (1971) “Transition Region. Capacitance of Diffusion p-n Junction”, IEEE Transactions on. Electron Devices, ED-18, 3, pp: 178-195

[3]. S. Mbodji, M. Dieng, B. Mbow, F. I. Barro, G. Sissoko, (2009). Influence of grain size and grain boundary recombination velocity on the diffusion capacitance of a polycrystalline bifacial silicon solar cell, Journal des Sciences Pour l'Ingénieur N°11 pp:64-69

[4]. Jakubowski, (1981) « Graphic method of substrate doping determination from C-V characteristics of MIS capacitors », Solid-State Electronics, Vol. 24, No. 10, pp 985-987.

[5]. G. Sissoko, E. Nanéma, A. Corréa, P. M. Biteye, M.Adj, A. L. Ndiaye (1998). Silicon Solar cell recombination parameters determination using the illuminated I-V characteristic. Renewable Energy, vol-3, pp.1848-51- Elsevier Science Ltd, 0960-1481/98/#.

[6]. M. Kunst, and A. Sanders, (1992). Transport of excess carriers in silicon wafers, Semicond. Sci. Technol. 7, pp: 51-59 in the UK

[7]. G. Yaron and D. F.-Bentchkowsky, (1980) Capacitance voltage characterization of poly Si-SiO2-Si structures, Solid-State Electronics, Vol. 23, pp 433-439.

[8]. D. K. Schroder, J. D. Whitfield, and C. J. Varker, (1984). Recombination lifetime using the pulsed MOS capacitor », IEEE Transactions on electron devices, Vol. ED-31, No. 4, 462-467

[9]. Dieng, N. Thiam, A. Thiam, A.S. Maiga and G. Sissoko (2011). Magnetic Field Effect on the Electrical Parameters of a Polycrystalline Silicon Solar Cell, Research Journal of Applied Sciences, Engineering and Technology ISSN 2040-7467 vol 3 n°7 602-611

[10]. M. Kunst, G. Muller, R. Schmidt and H. Wetzel (1988). Surface and volume decay processes in semiconductors studied by contactless transient photoconductivity measurements Appl. Phys. Vol. 46, pp77-85.

[11]. N.D. Arora, J. R. Hauser, D. J. Roulston (1982). Electron and hole mobilities in silicon as a function of concentration and temperature. IEEE. Trans. Electron devices, vol. ED-29, pp.292-295R. L. Streever; J. T. Breslin and E. H. Ahlstron (1980). Surface states at the n-GaAs-SiO2 interface from conductance and capacitance measurements. Solid State Electronics Vol. 23, pp. 863-868

[12]. Zerbo, I., Zoungrana, M., Sourabie, I., Ouedraogo, A., Zouma, B. et Bathiebo, DJ (2015) External Magnetic Field Effect on Bifacial Silicon Solar Cell's Electric Power and Conversion Efficiency. Journal turc de physique, 39, 288-294.

[13]. C. Longeaud, J.P. Kleider, (1992). General analysis of the modulated-photocurrent experiment including the contribution of holes and electrons. Physical Review B, Vol. 45, N0 20, Part 1, pp. 355-358

[14]. 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. 11.

[15]. Furlan, J. and Amon, S. (1985) Approximation of the Carrier Generation Rate in Illuminated Silicon. Solid State Electronics, 28, pp1241-1243.

[16]. Mohammad, S.N. (1987) An Alternative Method for the Performance Analysis of Silicon Solar Cells. Journal of Applied Physics, 61, 767-772.

[17]. D. Vanmaekelbergh and F. Cardon (1992). Recombination in semiconductor electrodes investigation by the electrical impedance. Electrochimica Acta. Vol. 37 N0 5. Pp. 837-846

[18]. H.L. Diallo, A. Seïdou. Maiga, A. Wereme, and G. Sissoko, (2008). "New approach of both junction and back surface recombination velocities in a 3D modelling study of a polycrystalline silicon solar cell" Eur. Phys. J. Appl. Phys. 42, pp: 203–211

[19]. 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, pp.352-354.

[20]. G. Sissoko, C. Museruka, A. Corréa, I. Gaye and A. L. Ndiaye (1996). Light spectral effect on recombination parameters of silicon solar cell. Renewable Energy, Vol 3, pp.1487-1490. Pergamon, 0960-1481

[21]. Zerbo, F.I. Barro, B. Mbow, A.Diao, S. Madougou, F. Zougmore, G. Sissoko, (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 (7-11 June, Paris, France), pp. 258-261

[22]. Nd. Thiam, A. Diao, M. Ndiaye, A. Dieng, A. Thiam, M. Sarr, A.S. Maiga and G. Sissoko (2012). Electric equivalent models of intrinsic recombination velocities of a bifacial silicon solar cell under frequency modulation and magnetic field effect. Research Journal of Applied Sciences, Engineering and Technology Vol. 4 , (22): 4646-4655

[23]. Hamidou, A. Diao, S. A. Douani, A. Moissi, M. Thiame, F. I. Barro and G. Sissoko (2013), Capacitance determination of a Vertical Parallel Junction Solar Cell under Multispectral Illumination in steady state. International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-2, Issue-3.

[24]. Diatta. I., Ly. I., Wade. M, Diouf. M.S, 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, 6, 261- 268. http://www.scirp.org/journal/wjcmp

[25]. S. Madougou, F. Made, M. S. Boukary, and G. Sissoko (2007) "I –V Characteristics For Bifacial Silicon Solar CellStudied Under a Magnetic Field"; Advanced Materials Research Vols. 18-19 pp. 303-312

[26]. M. Zoungrana, B. Dieng, O.H. Lemrabott, F. Toure, M.A. Ould El Moujtaba, M.L. Sow and G. Sissoko(2012). External Electric Field Influence on Charge Carriers and Electrical Parameters of Polycrystalline Silicon Solar Cell. Research Journal of Applied Sciences, Engineering and Technology 4(17); 2967-2972.

[27]. A Dieng, I Zerbo, M Wade, A S MaigaAnd G Sissoko (2011). Three-dimensional study of a polycrystalline silicon solar cell: the influence of the applied magnetic field on the electrical parameters. Semicond. Sci. Technol. 26 095023 (9pp).

[28]. Skoplaki E., Palyvos J. A., (2009). On the Temperature Dependence of Photovoltaic Module Electrical Performance: A review of efficiency/power correlations, Science-Direct, Elsevier, Solar Energy, 83 (83), p. 614–624.

[29]. B D DSylla, I Ly, O Sow, B Dione, Y Traore, G Sissoko (2018) Junction Surface Recombination Concept as Applied to Silicon Solar Cell Maximum Power Point Determination Using Matlab/Simulink: Effect of Temperaure" Journal of Modern Physics, 9, p. 172-188, http://www.scirp.org/journal/jmp