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Junction Recombination Velocity Induced Open Circuit Voltage For A Silicon Solar Cell Under External Electric Field

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Abstract - In this paper, we study the influence of the electric field on the junction recombination velocity for a silicon solar cell in open circuit condition. The excess minority carrier's density in the base is determined from the continuity equation. The photovoltage and the open circuit voltage are obtained from the excess minority carrier's density. We study, the junction recombination velocity limiting the open circuit and the open circuit voltage for different electric field.

Keywords - Silicon Solar Cell, Recombination velocity, Open circuit voltage.

I. INTRODUCTION

Photovoltaic conversion is a direct transformation of light into electrical energy through a solar cell device. Because of their modest performance, many studies have been conducted in order to improve their quality during the different production phases **[1]** and characterization techniques under both, static **[2]** and dynamic modes (transient and frequency) **[3].** Our contribution in this work is to study the effect of electric field polarization on recombination and electrical parameters **[4]-[5]-[6].**

II. THEORY.

We consider a n^+pp^+ solar cell type **[7]-[8]-[9]**, under polychromatic illumination and external electric field polarization by applying a voltage. The effect of external electric field is studied with Quasi Neutral Base (QNB) theory **[10]**.

Figure 1 shows the structure of the solar cell.

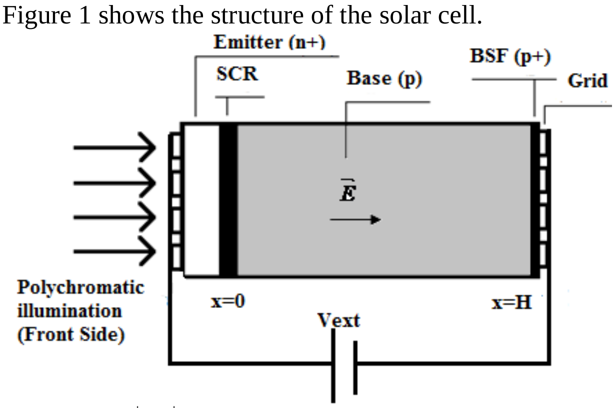

Figure 1: n^+pp^+ Solar cell under electric polarization and polychromatic illumination.

II.1. Determination of the minority carrier's density

The continuity equation for the excess minority carrier's density photo-generated in the base under influence of the electric field is:

$$\frac{\partial^2\delta(x)}{\partial x^2}+\frac{\mu.E}{D}\cdot\frac{\partial\delta(x)}{\partial x}+\frac{G(x)}{D}-\frac{\delta(x)}{L^2}=0 \quad (1)$$

δ(x) is the excess minority carriers density according to the depth x in the base;

D and L are respectively diffusion coefficient and diffusion length;

Whether μ is the carrier mobility and E is the electric field;

$$L_E=\frac{\mu.E.L^2}{D} \quad (2)$$

L_E is the diffusion length under electric polarization

Equation (1) becomes:

$$\frac{\partial^2\delta(x)}{\partial x^2}+\frac{L_E}{L_n{}^2}\cdot\frac{\partial\delta(x)}{\partial x}+\frac{G(x)}{D}-\frac{\delta(x)}{L^2}=0 \quad (3)$$

The generation rate expression **[11]** at the x depth in the base can be written in the following form as

$$G(x)=\sum_{i=1}^{3}a_i\cdot\xi.e^{-b_i} \quad (4)$$

The parameters a_i and b_i stem from the modeling of the incident illumination as defined under A.M 1.5 condition **[12]**.

Where, a_1 = 6.13x10^{20} cm^{-3}/s; a_2 = 0.54x10^{20} cm^{-3}/s; a_3 =0.0991x10^{20} cm^{-3}/s; b_1 = 6630 cm^{-1}; b_2 = 103 cm^{-1}; b_3 =130 cm^{-1};

The solution δ(x) of the carriers' diffusion equation (1) is presented by the following equation.

$$\delta(x)=e^{\beta x}\cdot[A\cdot ch(\phi\cdot x)+B\cdot sh(\phi\cdot x)]+\sum_{i=1}^{3}c_i\cdot e^{-b_i.x} \quad (5)$$

With:

$$\phi=\frac{(L^2{}_E+4\cdot L^2{}_n)^{\frac{1}{2}}}{2\cdot L^2{}_n} \qquad \beta=\frac{-L_E}{2\cdot L_n^2}$$

$$c_i=-\frac{a_i\cdot L^2{}_n}{D_n\cdot[L^2{}_n\cdot b^2{}_i-L_E\cdot b_i-1]}$$

The coefficients A and B are obtained with the boundary conditions at the emitter – base junction and at the back surface of the cell **[12, 13]**:

-at the junction *(x=0)*:

$$Sj = \frac{D_n}{\delta(0)} \cdot \left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0} \qquad (6)$$

-at the back surface (*x=H*):

$$Sb = -\frac{D_n}{\delta(H)} \cdot \left.\frac{\partial\delta(x)}{\partial x}\right|_{x=H} \qquad (7)$$

Sj and Sb are respectively the junction and back surface recombination velocities **[14, 15]**.

We plot in figure 2 the minority carrier's density versus base depth for different electric field values.

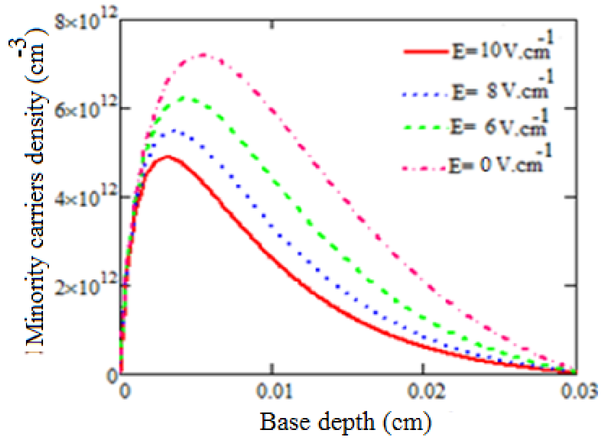

Figure 2: Minority carrier's density versus base depth for different values of electric field ($Sj=4.10^4$cm/s, $\mu=10^3 cm^2V^{-1}s^1$, L=0,02cm, H=0,03 cm, $D=26cm^2.s^{-1}$,$Sb=10^4$cm/s)

II.2. Photovoltage

The expression of the photovoltage is obtained from the Boltzmann relation

$$V_{ph} = V_T \ln\left(\frac{N_b}{n_i^2}\delta(0) + 1\right) \qquad (8)$$

V_T is the thermal voltage, n_i the intrinsic carrier density at thermal equilibrium and N_B the base doping density.

We plot in figure 3, the photovoltage versus junction recombination velocity.

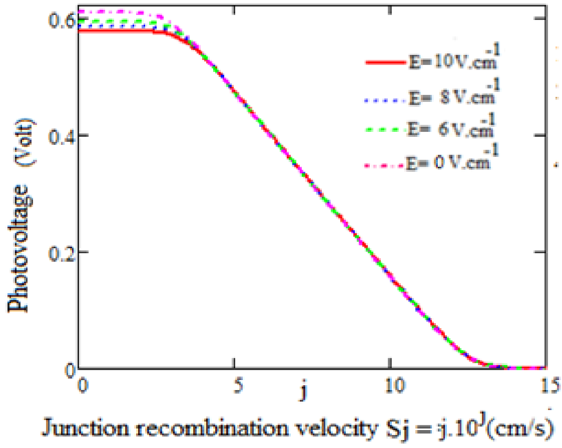

Figure 3: Photovoltage versus junction recombination velocity for different values of electric field ($\mu=10^3cm^2V^{-1}s^{-1}$, L=0,02cm, H=0,03cm, $D=26cm^2.s^{-1}$)

II.2. Determination of the junction recombination velocity in open circuit condition.

For the low junction recombination velocity values, photovoltage is maximum. Indeed, the charge carriers are stored at the junction, leading to a maximum of minority carrier's density. We then obtain an open circuit condition; from which following equation is deduced:

$$Vph\,(Sj) - Voc = 0 \qquad (9)$$

The open circuit voltage (Voc) is given by:

$$V_{oc} = \lim_{Sj \to Sjoc} V_{ph}(Sj) \qquad (10)$$

The recombination velocity at the junction is expressed by:

$$Sjoc = \frac{U.Y - D.b_i.Z - W.X}{X.Z + T.Y} \qquad (11)$$

With:

$$X = (D^2.\phi^2 - (D.\beta + Sb).D.\beta)Sh(\phi.H) + D.\alpha.Sb.Ch(\phi.H) \qquad (11\text{-}1)$$

$$Y = D.\phi.(Sb - D.b_i)e^{-H.(\beta+b_i)} + D.b_i.[D.\phi.Ch(\phi.H) + (D.\beta + Sb).Sh(\phi.H)] \qquad (11\text{-}2)$$

$$W = D.\phi.(Sb - D.b_i)e^{-H.(\beta+b_i)} \qquad (11\text{-}3)$$

$$Z = D.\phi.Ch(\phi.H) + (D.\beta + Sb)Sh(\phi.H) \qquad (11\text{-}4)$$

$$T = (D.\beta + Sb)Sh(\phi.H) - D.\phi.Ch(\phi.H) \qquad (11\text{-}5)$$

$$U = D^2.\phi^2 - D.\beta.(D.\beta + Sb) \qquad (11\text{-}6)$$

The back surface recombination can be expressed as [13].

$$Sb = D \cdot \sum_{i=1}^{3} \frac{\phi \cdot b_i \cdot (ch(\phi\cdot H) - e^{-H\cdot(\beta+b_i)}) - [\phi^2 - \beta\cdot(b_i+\beta)]\cdot sh(\phi\cdot H)}{\phi\cdot(ch(\phi\cdot H) - e^{-H(\beta+b_i)}) - (b_i+\beta)\cdot sh(\phi\cdot H)} \qquad (11\text{-}7)$$

We plot in Figure 4, the junction recombination velocity limiting the open circuit and the open circuit voltage versus the electric field.

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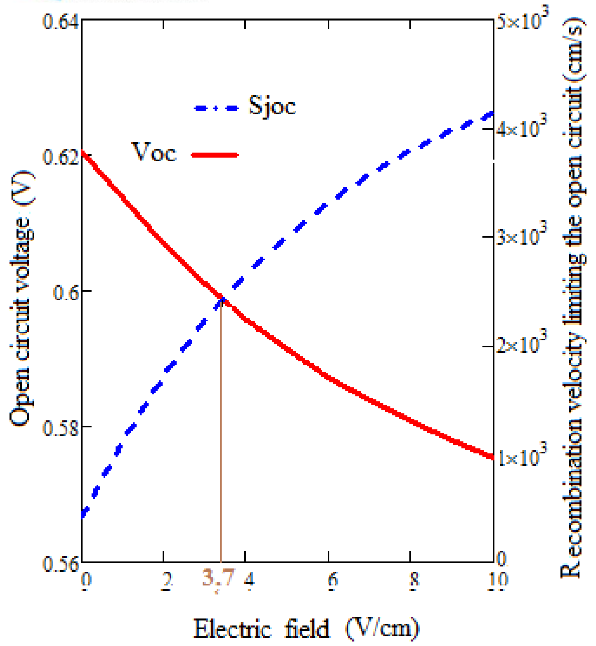

Figure 4: Junction recombination velocity and open circuit voltage versus electric field
(D=26cm^2/s, μ=10^{3}cm^2.V^{-1}s^{-1}, τ=10^{-5}s)

Figure 4 shows that the applied electric field decreases the open circuit voltage and increases the junction recombination velocity limiting the open circuit. Indeed, the electric field increases the flow of minority charge carriers across the junction. This means that the electric field sweeps carriers across the junction. This phenomenon brings about a decrease in the amount of carriers stored to the junction, which lowers the open circuit voltage. The increase of the junction recombination limiting the open circuit is promoted by the electric field polarization. At the intersection of the two curves, we obtain a value of the electric field which limited the open circuit voltage (3.7 V/cm) **[16]**.

Conclusion

In this work, the excess minority charge carriers density in the base is determined and plotted versus base depth for different values of electric field. The photovoltage is deducted from the minority carrier's density and their profile depending of junction recombination velocity for different electrical field values is presented. Thus, the junction recombination velocity limiting the open circuit operating point is studied for different values of electrical field

References

[1] M. Zoungrana, B. Dieng, O.H. Lemrabott, F. Toure, M.A. Ould El Moujtaba, M.L. Sow and G. Sissoko. «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. 2012.

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

[3] S. Mbodji, A. S. Maiga, M. Dieng, A. Wereme and G. Sissoko « Renoval charge technic applied to a bifacial solar cell under constant magnetic field », Global journal of pure and applied sciences vol 16, N° 4 pp. 469- 477(2010)

[4] H. El. Ghitani and S. Martizinuz, «Influence of dislocations on electrical properties of large grained polycrystalline silicon cells» J. App. Phys. 66(4), 1989, pp. 1717-1726.

[5] I.ly, M. Ndiaye, M. Wade, Ndeye Thiam, Sega Gueye and G. Sissoko. 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(1): 203-208, 2013.

[6] H. Ly Diallo, B. Dieng, I. Ly, M.M. Dione, M. Ndiaye, O.H. Lemrabott, Z.N. Bako, A. Wereme and G. Sissoko «Determination of the Recombination and Electrical Parameters of a Vertical Multijunction Silicon Solar Cell». Research Journal of Applied Sciences, Engineering and Technology 4(16): 2626-2631, 2012

[7] H. Mathieu, «Physics of semiconductors and electronic components» (Masson, paris, 1987)

[8] Amadou Diao, Ndeye Thiam, Martial Zoungrana, Gokhan Sahin, Mor Ndiaye, Grégoire Sissoko « Diffusion coefficient in Silicon Solar Cell with applied magnetic field and under frequency: electric equivalent circuits ». World Journal of Condensed Matter Physics, 2014, 4, 84-92.

[9] Le Quang Nam, M. Rodot, J. Nijs, M. Ghannam and J. Coppye. «Spectral response of high efficiency multicrystalline silicon solar cells. » J. Phys. III (France 2, 1992), pp. 1305-1316.

[10] D. L. Pulfrey, «Understanding Modern Transistors and Diodes. », Cambridge University Press, 2010

[11] Furlan, J. and S. Amon, «Approximation of the carrier generation rate in illuminated silicon. Solid State Electron», 28 (1985), pp. 1241–43.

[12] S. N. Mohammad, «An alternative method for the performance analysis of silicon solar cells.» J. Appl. Phys. 61(2) 1987, pp. 767-777

[13] Ali Hamidou, Amadou Diao, Séré Ahmed Douani, Ali Moissi, Moustapha Thiame, Fabé Idrissa Barro, Grégoire Sissoko; «Capacitance

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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, January 10, 2013.

[14] Ali Moissi, Martial Zoungrana, Abdourrahmane Diallo, Senghane Mbodji, Hawa Ly Diallo, Ali Hamidou, Mor Ndiaye and Grégoire Sissoko; «Base Transceiver Station (BTS) Antenna Electric Field Influence on the Space Charge Region in Silicon Solar Cell»; Research Journal of Applied Sciences, Engineering and Technology 7(12): 2554-2558, 2014

[15] O. Sow, I. Zerbo, S. Mbodji, M. I. Ngom, M. S. Diouf and G. Sissoko; «Silicon solar cell under electromagnetic waves in steady state: electrical parameters determination using the I-V and P-V characteristics»; International Journal of Science, Environment and Technology, Vol. 1, No 4, 2012, 230 – 246

[16] Nd. Thiam, A. Diao, M. Ndiaye, A. Dieng, A. Thiam, M. Sarr, A.S. Maiga and G. Sissoko. «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 (Published: November 15, 2012). Vol. 4, (22): 4646-4655.