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***Journal of Scientific and Engineering Research*, 2022, 9(10):21-27**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Three-Dimensional Modeling Study of the Effect of Irradiation on the Density of Minority Carriers for a Single-Face Polycrystalline Silicon Photocell under Multispectral Illumination

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Abstract A three-dimensional modeling study of a polycrystalline silicon mono-facet photopile under multi-spectral illumination is presented highlighting the effect of irradiation energy (Φ) and damage coefficient (Kl) on the macroscopic parameters of the photopile. From this three-dimensional model, the expression of the excess minority charge carrier density in the base of the polycrystalline silicon single-face photopile is obtained. This study takes into account the irradiation energy and the damage coefficient on the quality of the polycrystalline silicon photopile.

Keywords solar cell, Polycrystalline, Solar Cell, Junction Recombination Velocity, Density of minority charge carriers

Introduction

Several techniques for the characterization of the silicon material, for the determination of the phenomenological and electrical parameters have been developed in the static regime [1], and others in the dynamic frequency regime [2]. Extensive studies on the recombination parameters [3], [4] have been carried out in 3 dimensions [1] [4] [5] [6]-[8] for these two regimes.
Our contribution consists in determining the minority charge carrier density of a silicon solar cell in the static regime placed under (K_l, Φ) irradiation and multi-spectral illumination.
We briefly present a theoretical study in which we schematize a grain of the silicon solar cell diffusion equation. Then we discuss the obtained results before concluding.

Theoretical analysis

The BSF polycrystalline silicon solar cell studied is an n^+-$p^-$$p^+$ structure as shown in *figure 1.a.* Silicon consisting of several grain of various sizes, for our study, we use the 3D columnar model where each grain has a rectangular shape as shown in *figure1.b* below [4], [9], [10].

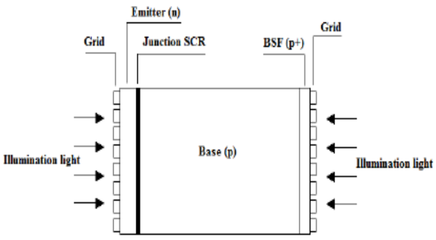

Figure 1.a: Bifacial Silicon solar cell Structure

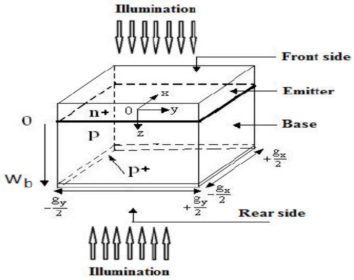

Figure 1.b: Polycristalline Silicon columnar grain model

In this study, we assume that:

- the contribution of the emitter is neglected. We take into account only the base contribution [4].
- The illumination is uniform. We then have a generation rate depending only with base depth *z* [10].
- The existing crystalline field within the base is neglected, in the simulation, we have equality between the grain size along x and y axes, ie $g_x = g_y = g$ (square cross section), and that the recombination velocity at grain boundaries is perpendicular to the junction and independent to the generation rate under AM 1.5 [4] [7].

Excess Minority Carriers Density

Considering the emitter as a dead area, the excess minority carrier distribution in the base, seen as a greater contribution to the photo-conversion, is derived from the continuity equation [4] [12]:

$$D(Kl,\phi)\times\left[\frac{\partial^2\delta(x,y,z)}{\partial x^2}+\frac{\partial^2\delta(x,y,z)}{\partial y^2}+\frac{\partial^2\delta(x,y,z)}{\partial z^2}\right]-\frac{\delta(x,y,z)}{\tau}+G(z)=0 \quad (1)$$

$D(Kl,\phi)$ is the diffusion coefficient in the presence of irradiation. It is expressed as follows:

$$D(Kl,\phi)=\frac{L(Kl,\phi)^2}{\tau} \quad (2)$$

In this expression, G(z) represents the generation rate of minority charge carriers in the base [13] whose expression is given by the following equation:

$$G(z)=\sum_{i=1}^{3}a_i\times\exp(-b_i\times z) \quad (3)$$

The values ai and bi are the values tabulated from the modeling of the absorption spectrum of the photocell for AM 1.5 [7], [9], [14].

L depend on the irradiation energy Φ and the damage coefficient Kl through the following expression [14], [16]:

$$L(Kl,\phi)=\sqrt{\frac{1}{\frac{1}{L_0^2}+Kl\times\phi}} \quad (4)$$

L_0 is the diffusion length without irradiation.

The solution of the equation can be written as follows [4], [7], [17]:

$$\delta(x,y,z)=\sum_k\sum_j Z_{k,j}(z)\times\cos(C_k\times x).\cos(C_j\times y) \quad (5)$$

k, j : are the indices for the x and y directions respectively.

Ck and Cj are obtained from the conditions at the grain boundaries $\pm\frac{g_x}{2}$ et $\pm\frac{g_y}{2}$ [4], [7], [9], [18]:

$$\left[\frac{\partial\delta(x,y,z)}{\partial x}\right]_{x=\pm\frac{g_x}{2}}=\mp\frac{Sgb}{D(Kl,\phi)}\delta\left(\pm\frac{g_x}{2},y,z\right) \quad (6)$$

$$\left[\frac{\partial \delta(x,y,z)}{\partial y}\right]_{y=\pm\frac{g_y}{2}} = \mp \frac{Sgb}{D(Kl,\phi)}\delta\left(x \pm \frac{g_y}{2}, z\right) \quad (7)$$

gx is the grain width, gy the grain length Sgb the recombination velocity at the grain boundaries.
From equations (6) and (7) we obtain two transcendental equations [21] which are:

$$\tan\left(C_k \times \frac{g_x}{2}\right) = \frac{Sgb}{2.C_k \times D(Kl,\phi)} \quad (8)$$

$$\tan\left(C_j \times \frac{g_y}{2}\right) = \frac{Sgb}{2.C_j \times D(Kl,\phi)} \quad (9)$$

By replacing δ(x, y, z) in the continuity equation and the fact that the cosine function is orthogonal, we obtain the following differential equation:

$$Z_{k,j} = A_{k,j} \times \cosh\left(\frac{z}{L_{k,j}}\right) + B_{k,j} \times \sinh\left(\frac{z}{L_{k,j}}\right) - \sum_{i=1}^{3} K_{i,j,k} \times \exp(-b_i \times z) \quad (10)$$

Or $K_{i,j,k} = \frac{L_{k,j}^2}{D_{k,j} \times [b_i^2 \times L_{k,j}^2 - 1]} \times a_i$ (11)

With: $L_{k,j} = \left[C_k^2 + C_j^2 + \frac{1}{L(Kl,\phi)^2}\right]^{-\frac{1}{2}}$ (12)

And $D_{k,j} = D(Kl,\phi) \times \frac{[C_k \times g_x + \sin(C_k \times g_x)].[C_j \times g_y + \sin(C_j \times g_y)]}{16.\sin\left(C_k \times \frac{g_x}{2}\right).\sin\left(C_j \times \frac{g_y}{2}\right)}$ (13)

The coefficients Ak,j and Bk,j are calculated from the following boundary conditions [2], [4], [11], [19] :

- At the junction $(z = 0)$:

$$\left[\frac{\partial \delta(x,y,z)}{\partial z}\right]_{z=0} = \frac{Sf}{D(Kl,\phi)}\delta(x,y,0) \quad (14)$$

Sf is the junction recombination velocity, written as [2], [4], [8], [13], [20] $Sf = Sf_0 + Sf_j$ with Sf_0 being the intrinsic junction recombination velocity related to the shunt resistance due to losses occurring across the junction and Sf_j is the imposed junction recombination velocity due external load. It defines the current flow that is the operating point of the cell. For each illumination mode, the intrinsic junction recombination velocity was calculated using the method described in [2], [4], [8], [13], [20].

At the back side ($z = \omega b$):

$$\left[\frac{\partial \delta(x,y,z)}{\partial z}\right]_{z=0} = -\frac{Sb}{D(Kl,\phi)}\delta(x,y,\omega b) \quad (15)$$

Sb is the back surface recombination velocity. It quantifies the rate at which excess minority carriers are lost at the back surface of the cell [2] [4] [8] [20]. The derivation of the photocurrent with respect to Sf, provides for each illumination mode the expression of Sb, as in [2] [4] [8] [20].

$$A_{k,j} = \sum_{i=1}^{3} K_{i,k,j} \times \frac{\frac{1}{L_{k,j}}.\left(\frac{Sf}{D(Kl,\phi)} - b_i\right) \times \exp(-b_i \times \omega b) + Y_{k,j}\left(\frac{Sf}{D(Kl,\phi)} + b_i\right)}{\frac{Sf \times Y_{k,j}}{D(Kl,\phi)} + \frac{X_{k,j}}{L_{k,j}}} \quad (16)$$

$$B_{k,j} = \sum_{i=1}^{3} K_{i,k,j} \times \frac{\frac{Sf}{D(Kl,\phi)} \cdot \left(\frac{Sb}{D(Kl,\phi)} - b_i\right) \times \exp(-b_i \times \omega b) + X_{k,j}\left(\frac{Sf}{D(Kl,\phi)} + b_i\right)}{\frac{Sf \times Y_{k,j}}{D(Kl,\phi)} + \frac{X_{k,j}}{L_{k,j}}} \quad (17)$$

With: $$X_{k,j} = \frac{1}{L_{k,j}} \times \sinh\left(\frac{\omega b}{L_{k,j}}\right) + \frac{Sb}{D(Kl,\phi)} \times \cosh\left(\frac{\omega b}{L_{k,j}}\right) \quad (18)$$

$$Y_{k,j} = \frac{1}{L_{k,j}} \times \cosh\left(\frac{\omega b}{L_{k,j}}\right) + \frac{Sb}{D(Kl,\phi)} \times \sinh\left(\frac{\omega b}{L_{k,j}}\right) \quad (19)$$

Results & Discussion

In figure 2, the effect of the irradiation energy (Φ) is highlighted in the representation at the curve of the minority charge carrier density as a function of the depth in the base.

In figure (3), we have illustrated the profile of the density of excess electrons in the base as a function of the depth z in the base by variation of the damage coefficient Kl.

By observing these figures, we note that the density of minority charge carriers decreases as the irradiation energy and the damage coefficient increase.

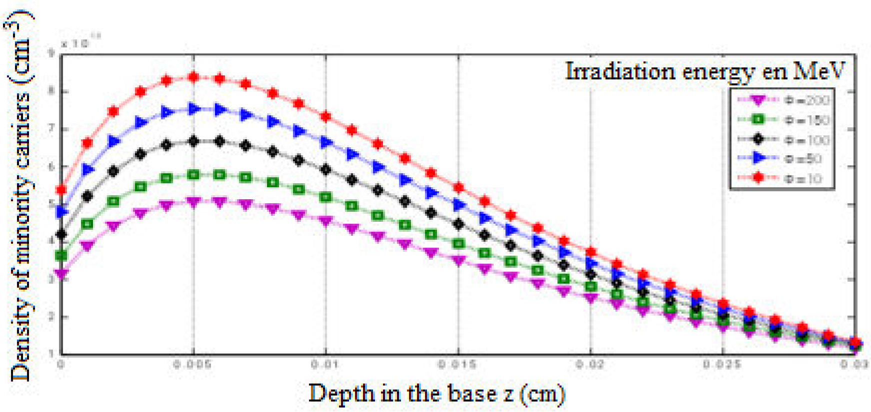

Figure 2: Density of minority charge carriers as a function of depth z in the base for a grain size g =0.0005cm and for different values of irradiation energy

(Sgb=4.5x10^6 cm/s; Kl=10,5 cm-2/MeV; Sfj =6X10^6 cm/s; τ=10^{-5} s; ωb=0.03 cm and AM 1)

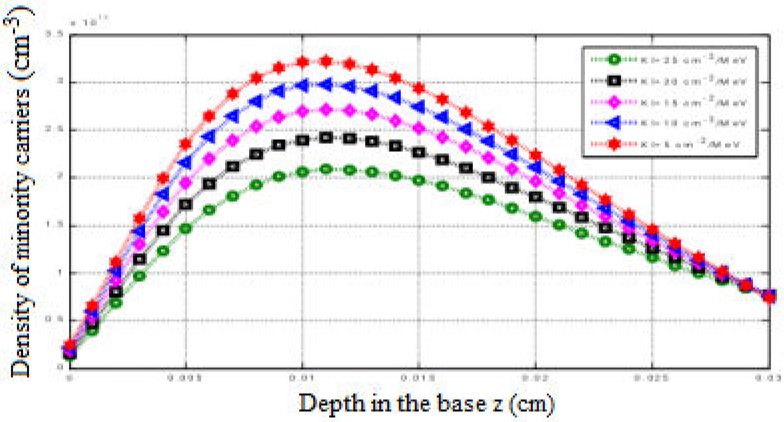

Figure 3: Density of minority charge carriers as a function of depth z in the base for a grain size g =0.0005cm and for different values of the damage coefficient;

(Sgb=4.5x10^6 cm/s H=0,03 cm; Φ=150 MeV; Sf_j =6x10^6 cm/s ; ωb=0.03 cm and AM 1.5)

The passage of a charged particle, and in particular of an ion through the material generates damaged regions along its trajectory, which become centers of carrier trapping. The irradiation creates intrinsic defects by the interaction between the charged particles and the electrons of silicon. The charged particles lose their energy in the material and the electron density decreases. We note that if the damage coefficient Kl increases, it means that the material becomes more sensitive to degradation caused by possible particles. Consequently, the density of minority charge carriers decreases.

Conclusion

In this paper we have made a three-dimensional study of a polycrystalline silicon photocell in the static regime under irradiation and multispectral illumination. This study showed us that the density of minority charge carriers, decrease with the irradiation (ϕ, Kl). In summary the irradiation energy (Φ) and the damage coefficient (Kl) reduce the performance of the photocell.

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- Page type will be A4 with ner margin, word spacing should be 1.
- No space will be added before or after paragraph.
- The references should be represented as large brackets e.g [1], [2] in the text.

Materials and Methods

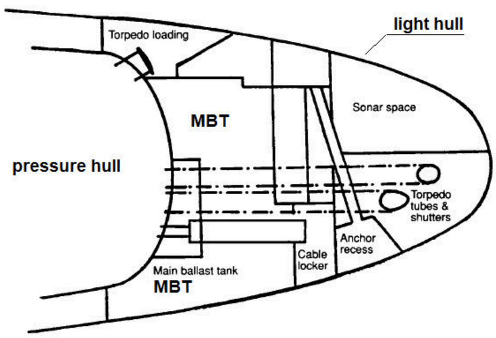

Figure 1: Typical bow arrangement

Results & Discussion

Table 1: Specification of Models in stage

Nf	Rt	Aw	Cd*1000	V/(Cd*10)	Cv*100
1	1944	11.16	3.484	59.99	2.38
1.15	1820	11.79	3.087	73.20	2.11

Conclusion

Acknowledgment

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