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RESEARCH ARTICLE

ANALYSE OF IMPACT OF TEMPERATURE, GRAIN SIZE, AND MAGNETIC FIELD ON EFFECTIVE DIFFUSION LENGTH

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ABSTRACT

In this work, thanks to 3D modelling, we were able to express the effective broadcast length as a function of dimensions (x, y) of crystal, loss rate at the limits of x and y, temperature and magnetic field, based on the distribution of carriers in the base volume, obtained from the minority carrier continuity equation. The effective broadcast length and short circuit current were calculated as a function of grain size, magnetic field and temperature. It was found that the short-circuit current is independent of the effective broadcast length but also on the grain size, magnetic field and temperature. This shows that the electrical parameters cannot be extrapolated to larger effective broadcast lengths since it is limited for a given optimal temperature, magnetic field and grain size. Also, a small effective broadcast length can be due to a small carrier scattering length, a small grain size, a high temperature or a high magnetic field.

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INTRODUCTION

The understanding of the effective broadcast of photogenerated carriers within polycrystalline silicon solar cells is the subject of several studies. Different works have focused on the effective broadcast length (Leff) as defined by experimental evaluations of the effective scattering coefficient in polycrystalline silicon [1], [2], using the surface photovoltage method (SPV method). This work is a contribution to the determination of the effective broadcast length of a polycrystalline silicon photocell subjected to external factors such as temperature and magnetic field. The effective broadcast length and the short-circuit current are a function of grain size,loss rate at the limits of x and y[3], temperature and magnetic field are deduced from the distribution of excess minority carriers in a square-shaped grain obtained by solving the carrier continuity equation. The aim is to assess the impact of temperature, magnetic field and grain size on the effective broadcast length in order to study its influence on the short-circuit current, as it influences to a large extent the short-circuit photocurrent and to a lesser extent the open-circuit voltage of silicon photocells [4].

Theorical Study

Our studyfocuses on an n+/p/p+ polycrystal line solar cell under multicolour front illumination. For the three-dimensional modelling, westarted from Fick's first law in one dimension, giving the number of electrons diffusing per unit of time and volume, which we generalised to three dimensions (Figure 1). From this generalised law in three dimensions, wedetermined the diffusion currentdensity, assuming that the solarcellis not polarised. Wethereforeconsidered a columnar model [5] (Figure 1) in whicheach grain of the crystalisassumed to have asquare form.

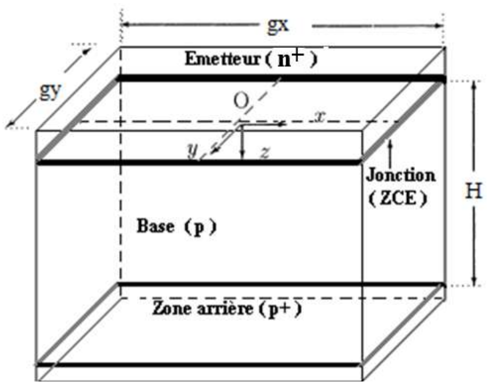

Figure 1. Schematic of graingrain of silicon crystal

The continuityequation for photogeneratedminority carriers in the base is: (1) :

$$\frac{\partial^2 \delta n(x,y,z)}{\partial x^2}+\frac{\partial^2 \delta n(x,y,z)}{\partial y^2}+\frac{\partial^2 \delta n(x,y,z)}{\partial z^2}-\frac{\delta n(x,y,z)}{Ln^*(B,T)^2}=-\frac{G(z)}{D^*(B,T)} \quad \text{.....................(1)}$$

G(z) the rate of generation of minority charge carriers at depth z.

$Ln^*(B,T)$ is the transition length of the charge carriers in the p zone,depending on the magnetic field B and the temperature T:

$D^*(B,T)$ is the diffusion coefficient of the minority carriers in the base which depends on the magnetic field B [6] and the temperature T:

$$D^*(B,T)=\frac{D0(T)}{1+(\mu(T)\cdot B)^2} \quad \text{.....................(2)}$$

$D0(T)$ is the diffusion coefficient of electrons in the base as a function of temperature and magnetic field.

$\mu(T)$ is the mobility of minority carriers depending of temperature T and q is the carriers charge:

$$\mu(T)=1.43\cdot 10^9\cdot T^{-2.42}cm^2\cdot V^{-1}\cdot s^{-1} \quad \text{.........................(3)}$$

To solve the continuity equation (1), we will use solutions of the type given by equation 4 [5],[8]:

$$\delta n(x,y,z)=\sum_k\sum_j Z(z)\cdot\cos(c_k\cdot x)\cdot\cos(c_j\cdot y) \quad \text{................(4)}$$

Where Ck and Cj are space eigenvalues obtained from the following grain boundary condition:

$$\left[\frac{\partial \delta n(x,y,z)}{\partial x}\right]_{x=\pm\frac{g_x}{2}}=\mp\frac{Sg}{D^*(B,T)}\cdot\delta n\left(\pm\frac{g_x}{2},y,z\right) \quad \text{.....................(5)}$$

$$\left[\frac{\partial \delta n(x,y,z)}{\partial y}\right]_{y=\pm\frac{g_y}{2}}=\mp\frac{Sg}{D^*(B,T)}\cdot\delta n\left(x,\pm\frac{g_y}{2},z\right) \quad \text{........................(6)}$$

By replacing the minority carrier density by its expression given by equation 8 in the two boundary conditions above, we obtained the two transcendental equations below:

$$c_k\cdot\tan(c_k\cdot\frac{g_x}{2})=\frac{Sg}{D^*(B,T)} \quad \text{............................(7)}$$

$$c_j\cdot\tan(c_j\cdot\frac{g_y}{2})=\frac{Sg}{D^*(B,T)} \quad \text{..............................(8)}$$

From these two transcendental equations, we can determine graphically or by programming the values of Ck and Cj. By injecting the Eq 4 in excess into the continuity equation (1) and then multiplying each member of this equation by the product before applying the cosine orthogonality conditions and the integral along x and y (9 and 10) we obtained the differential equations given by equations 12.

$$\int_{-\frac{g_x}{2}}^{+\frac{g_x}{2}}\cos(c_k\cdot x)dx=\frac{2}{c_k}\cdot\sin\left(c_k\cdot\frac{g_x}{2}\right) \quad \text{........................(9)}$$

$$\int_{-\frac{g_y}{2}}^{+\frac{g_y}{2}}\cos(c_j\cdot y)dy=\frac{2}{c_j}\cdot\sin\left(c_j\cdot\frac{g_x}{2}\right) \quad \text{.......................(10)}$$

$$\frac{\partial^2 Z_{kj}(z)}{\partial z^2}-\left(c_k^2+c_j^2+\frac{1}{Ln*(B,T)^2}\right)\cdot Z_{kj}=-\frac{16\cdot\sin\left(c_k\cdot\frac{g_x}{2}\right)\cdot\sin\left(c_j\cdot\frac{g_y}{2}\right)}{D*(B,T)[\sin(c_k\cdot g_x)+c_k\cdot g_x]\cdot[\sin(c_j\cdot g_y)+c_j\cdot g_y]}\cdot G(z) \quad \text{...............(11)}$$

$$\frac{\partial^2 Z_{kj}(z)}{\partial z^2}-\frac{1}{L_{kj}^2}\cdot Z_{kj}=-\frac{1}{Dkj(B,T)}\cdot G(z) \quad \text{..................(12)}$$

Thus, we obtain the expression for the effective broadcast length which depends of the loss rate at the limits of x and y (Sg), the grain size and the external factors B (Tesla) and T (Kelvin). (13):

$$L_{kj}(g,B,T)=\left[c_k^2+c_j^2+Ln^*(B,T)^{-2}\right]^{-\frac{1}{2}} \quad \text{..................(13)}$$

RESULTANTS AND DISCUSSION

Study of the Space Eigenvalues: The values of C_k and C_j are obtained from the transcendental equations given by equations 14 and 15 by the graphical method or by programming. We used the graphical method to extract the values of C_k and C_j.f(C_k) and h(C_k) are plotted in the same frame of reference. The points of intersection of the curves of these two functions give the values of C_k and C_j. The crystal grain is assumed to be square, so $C_k = C_j$(Camara and al., 2020), (Kosso and al., 2018). We note that the transcendental equation links Ck to the recombination rate at the limits of x and y(Sg), the dimension along x; yand the external factors B (Tesla) and T (Kelvin). In figure (2) we show the effect of the external factors B (Tesla) and T (Kelvin) on the Ck solutions.

$$f(C_k)=\tanh\left(C_k\cdot\frac{g_x}{2}\right) \quad \text{.........................(14)}$$

$$h(C_k)=\frac{S_g}{C_k\cdot Dn*(B,T)} \quad \text{.........................(15)}$$

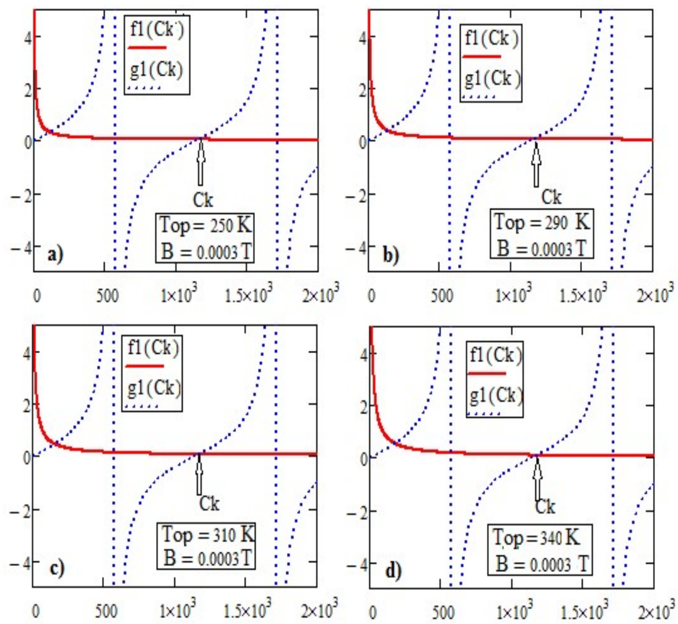

Figure 2. Effect of temperature on the space eigenvalues for Sg ≤ $10^{3.0}$ cm/s

Variations in temperature and recombination rate at the interfaces (Sg) [9] and magnetic field [10].do not affect Ck values if Sg ≤ $10^{3.0}$ cm/s. The results obtained from Figure 2 are shown in the table below.

We have checked these values for several grain boundary recombination velocities Sg ≤ 10^3 cm/s and for values of T(k) and B(Tesla); the values of Cj (or Ck) are approximately equal to the values of Table 1. For $10^{3.0}$ cm/s < Sg < $10^{5.0}$ cm/s theCj (or Ck) values vary and grow with increasing temperature and magnetic field, as shown in Table 2. We find also that the size according to x and y (g) has a strong influence on the Own values whatever loss rate at x and y limits [9], [10], T (K) and B (Tesla) [10]. We used the same method to determine graphically the eigenvalues for the dimensions of the crystal used. These values, are given in Table 3.

conclusion that small values of the magnetic field leave the effective diffusion length insensitive; however, the effective diffusion length is sensitive to the magnetic field above values of $10^{-4.0}$ Tesla.This reduction in the effective diffusion length under the influence of the magnetic field is justified by the role played by the magnetic field on all charge carriers. This role is to divert them from their direction of propagation.This role, which intensifies with the magnetic field, considerably increases the negative effect of B (Tesla) on the carrier diffusion length. We also note that when the magnetic field is less than $10^{-3.0}$ Tesla, the effective diffusion length decreases as the

Tableau 1. C_k for Sg ≤ $10^{3.0}$ cm/s et pour B = 0.0003 T.

T (K)	Own values $C_k = C_j$ (cm^{-1}) ;j= 0, 1, 2, 3, 4, 5					
250	286,494	1,252. 10^3	2,326. 10^3	3,797.10^3	4,316.10^3	5,986.10^3
290	286,494	1,252. 10^3	2,797. 10^3	1,326.10^3	4,316.10^3	5,986.10^3
310	286,494	1,252. 10^3	2,797. 10^3	1,326.10^3	4,316.10^3	5,986.10^3
340	286,494	1,252. 10^3	2,797. 10^3	1,326.10^3	4,316.10^3	5,986.10^3

Tableau 2. Own values C_k for Sg = $10^{3.0}$ cm/s

T (K)	Own values Ck = C_j (cm^{-1}) ;j= 0, 1, 2, 3, 4, 5					
250	541,615	2,597. 10^3	3,676. 10^3	4,774. 10^3	5,883. 10^3	6,870. 10^3
290	546,426	2,603. 10^3	3,682. 10^3	4,779. 10^3	5,889. 10^3	6,875. 10^3
310	551,735	2,610. 10^3	3,690. 10^3	4,786. 10^3	5,895. 10^3	6,875. 10^3
340	562,905	2,623. 10^3	3,703. 10^3	4,800. 10^3	5,907. 10^3	6,876. 10^3

Tableau 3. C_k for Sg = 10^3 $cm.s^{-1}$ et Topt = 310 K, B = 0.0003 T

g(µm)	Own valuesCk = C_j (cm^{-1}) ; K= 0, 1, 2, 3, 4, 5				
50	286,494	1,252. 10^3	2,326. 10^3	3,797.10^3	4,316.10^3
100	201,494	666,932	995,797	1,326.10^3	1,986.10^3
190	180.230	345.120	513.145	682.047	851.310
280	146.811	278.639	413.461	549.144	685.184
370	108.010	201.742	298.192	395.470	493.098
460	95.716	177.500	261.870	347.050	432.577

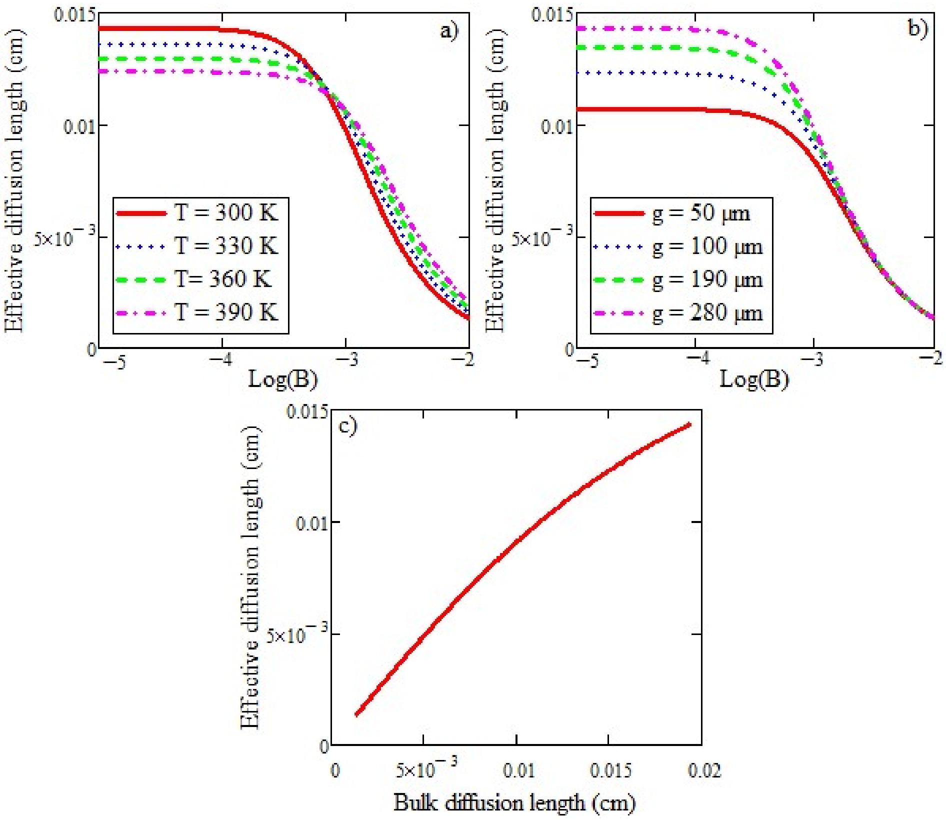

Figure 3. Effect of magnetic field, temperature, scattering length and grain size on the effective transition length for Sg = 10^3 $cm.s^{-1}$

Study of the magnetic field and the diffusion length of minority carriers on the effectivediffusion: The profiles in Figure 3.a show that for small values of the magnetic field (B≤ $10^{-4.0}$ Tesla), the effective diffusion length is practically constant, leading to the

temperature rises. Thus, for magnetic fields between $10^{-4.0}$ Tesla and $10^{-3.0}$ Tesla, the increase in temperature and magnetic field leads to a degradation of the intrinsic properties of the photocell. In this magnetic field range, we note that the effective diffusion length is more sensitive to temperature (Figure 3.a) and grain size (Figure 3.b). we observe an inversion when B is greater than $10^{-3.0}$ Tesla, where the diffusion length increases with temperature. Thus, in areas of high magnetic field, high temperatures lead to an increase in the effective diffusion length. As the diffusion length of the minority carriers increases, the effective diffusion length increases and reaches a limiting value which depends on the crystal dimensions, temperature and magnetic field Figure 3.c. For magnetic fields between $10^{-4.0}$ Tesla and $10^{-3.0}$ Tesla, despite the decrease, the effective broadcast length is strongly influenced by the temperature and the grain size (the grain size g is the main parameter characterizing polycrystalline materials); therefore, we will determine the optimal temperature for a better broadcast length in this area. Since for strong magnetic fields the grain size has almost no influence on the effective broadcast length Figure 3.c.

Study of Temperature on effective diffusion length: In this section, the optimum temperature for maximum effective broadcast length is determined using the graphical method. In Figure 4.a, the maximum values of the effective broadcast length are determined as a function of the optimum temperature for different values of the magnetic field. For a given value of magnetic field, the optimum temperature is obtained when the broadcast length reaches its maximum; thus, we give in Table 4 the values found graphically. We note from Table 4 that increasing the magnetic field leads to a decrease in the transition length and an increase in the optimum temperature.

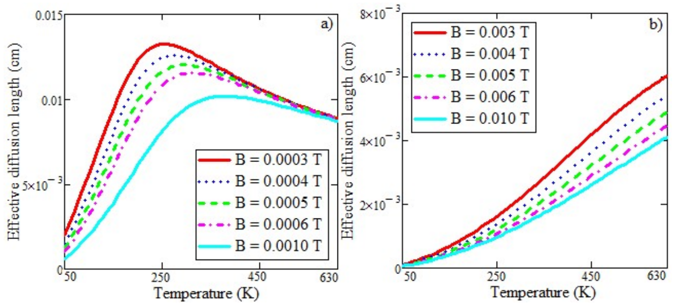

Figure 4. Profile of effective diffusion length as a function of temperature for different values of the magnetic field

Table 4. Maxima of the effective scattering length and the optimal temperature for different magnetic fields obtained by the graphical method

B(T)	3.10^{-4}	4.10^{-4}	5.10^{-4}	6.10^{-4}	10^{-3}
Ln(µm)	182	167	157	149	130
Top(K)	250	290	310	340	390
Lkj (µm)	132	125	120	115	101

Table 5. Maxima of scattering length and optimum temperature for different crystal dimension obtained by the graphical method

B = 0.0003 T et Ln = 182 µm						
g (µm)	50	100	190	280	370	460
Lkj (µm)	64	83	106	121	132	139
Topt(K)	250	250	250	250	250	250
B = 0.0004 T et Ln = 167 µm						
g (µm)	50	100	190	280	370	460
Lkj (µm)	58	76	98	112	122	129
Topt(K)	290	290	290	290	290	290
B = 0.0005 T et Ln = 157 µm						
g (µm)	50	100	190	280	370	460
Lkj (µm)	55	72	92	106	115	122
Topt(K)	310	310	310	310	310	310
B = 0.0006 T et Ln = 149 µm						
g (µm)	50	100	190	280	370	460
Lkj (µm)	52	68	88	101	109	116
Topt(K)	340	340	340	340	340	340

On the other hand, for magnetic fields higher than 10^{-3} T, the effective broadcast length is very small despite the fact that it increases with temperature, figure 4.b. In order to obtain good efficiency, it is necessary to use silicon with a broadcast length greater than about 100 micrometers [1]. We note that increasing the grain size has no influence on the optimum temperature table 5. We also observe that the variation of the magnetic field always leads to the growth of the optimum temperature even if we increase the grain size table 5: the grain size has no impact on the effect of the magnetic field on the optimum temperature Table 5. From tables 4 and 5, it should be noted that a small effective diffusion length can occur due to either a small minority carrier diffusion length, a large magnetic field, a large optimum temperature or a small grain size.

CONCLUSION

In this paper we have shown that a low effective diffusion length can be due to a small carrier scattering length, a small grain size, a high temperature or a high magnetic field. It is also clear from this study that the electrical parameters cannot be extrapolated to larger effective diffusion lengths since Leff is limited for a given optimal temperature, magnetic field and grain size.

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