RESEARCH ARTICLE

LAMELLA SILICON OPTIMUM WIDTH DETERMINATION UNDER TEMPERATURE

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Manuscript Info	*Abstract*

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Geometric parameters are an important data for the choice of solar cell architecture, for better conversion performance. As poor opto-electronic material is used, i.e. short minority carrier's diffusion length and under concentrated light which increases the temperature, it is then important to optimize the width of the lamella in order to have better photogenerated charge collection. Thus the intent of this work is the determination of the width of the lamella structure, presented through phenomelogical parametersmodeling study. These are the diffusion length and coefficient, as well as the surfacerecombination velocity of the photogenerated carriers in the base of the lamella silicon. The result gives a mathematical relationship between the optimum width and the operating temperature of the lamella solar cell, allowing to influence the industrial manufacturing process for the material economy.

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Introduction:-
The study of geometric parameters [1, 2, 3, 4, 5] of solar cells aims to improve conversion efficiency and reduce commercial cost [6, 7, 8].

The lamella structure [9, 10, 11] is one of the latest innovations for improving solar cell conversion efficiency[12, 13], with poor opto-electronic material properties and under concentrated illumination.

Previous studies [14] have shown the importanceof this structure, particularly through the concept of back surface recombination velocity [15, 16] of minority carriers at (p/p^+) junction [17, 18, 19, 20, 21]. The work we present aims to determine the optimum width of the lamella under the influence of temperature [22, 23,24, 25, 26] through the study of the expression of this recombination velocity [13, 20, 27, 28].

The diffusion equation for the density of excess minority carriers is resolved with boundary, conditions that highlight, the carriers' recombination velocity (Sf) and (Sb)[16, 29, 30, 31 , 32, 33, 34]respectively at thejunction (x = 0) and at the back surface (x = H).

From this solution, the density of photocurrent is derived, and represented for each temperature, versus the minority carriers'recombination velocity (Sf) at the junction. The latterrepresents the phenomelogical parameter that defines the solar cell operating point [16, 23, 34, 35].

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The operatingshort-circuit situation of thesolar cellcorresponds to the high values of the carriers'recombination velocity (Sf) at the junction, and therefore gives the density of short-circuit current, which is constant for a given temperature. Expressions of back surface recombinationvelocity (Sb) are deduced [16, 32, 33].

Thus the analysis of the expressions of this recombination velocity (Sb), through its representation as function of the width of the lamella leads to the extraction of the optimum width (Hopt), which is modeled according to both the temperature and the effective diffusion coeffient.

Theory:
The vertical multi-junction(VMJ) solar cells are successionof series-connected (n+-p-p+) lamella [10, 11]. The structure of the seriesvertical multi-junction solar cells is represented by figure .1.They are illuminated by a polychromatic light and subject to temperature variation.
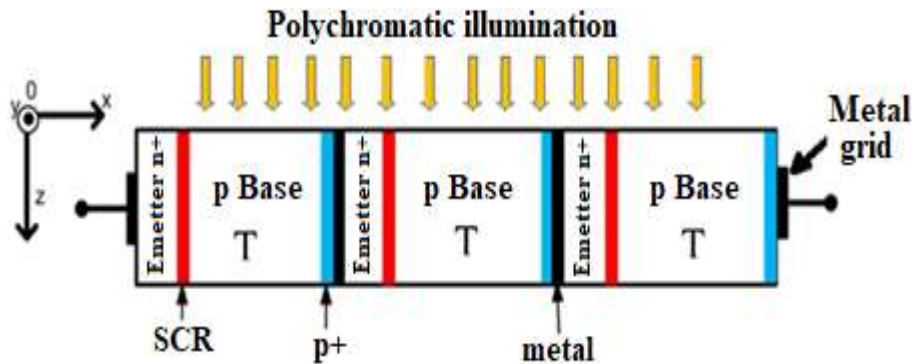

Figure 1:- Vertical series junction silicon solar cell(the n[+]-p-p[+])type under polychromatic illumination and temperature.
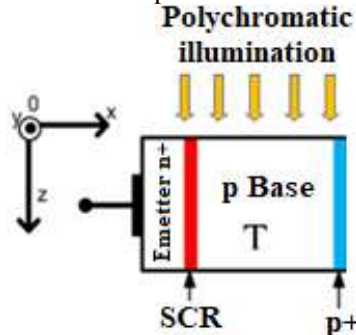

Figure 2:- Gives the unit cell under study.
Figure 2:- Unit vertical series junction solar cell under polychromatic illumination and temperature.

The illumination arrives parallel to the junction of the lamella under the influence of temperature. There is absorption of photons, generation of electron-hole pairs, which can diffuse or recombine in the bulk and on surfaces (front and rear). These physical mechanisms are governed by the following continuity equation [5, 11]:

$$D(T)\frac{\partial^2 \delta(x,z,T)}{\partial x^2} - \frac{\delta(x,z,T)}{\tau} + G(z) = 0 \quad (1)$$

$\delta(x,z,T)$ represents the excess minority carriers' density in the base-lamella temperature dependent, at the z depth.

D (T) is the coefficient of electron scattering in the (p) base depending on the temperature. Its expression is defined by Einstein's well-known relationship given as:

$$D(T) = \mu(T) \times \frac{K_b}{q} \times T \quad (2)$$

$\mu(T)$ is excess minority carriers' mobility coefficient temperature dependent[36, 37, 38, 39, 40, 41].Its expression is given by the following equation

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

K_b is the Boltzmann constant, q is the elementary charge

And τ is the excess minority carrier lifetime related to the diffusion coefficient and diffusion length (L(T)) by:

$$\tau = \frac{L^2(T)}{D(T)} \text{ (4)}$$

$G(z)$ is theexcess minority carriers generation rate at depth z, and expressed as [42. 43]:

$$G(z) = n \times \sum_{i=1}^{3} a_i \times e^{(-b_i \times z)} \text{ (5)}$$

Coefficient n is the number of sun and ai and bi are derived from the modelling study of the incident irradiation. Then the solution of continuity equation related to excess minority carriers is given as:

$$\delta(x,z,T) = A \times \cosh\left(\frac{x}{L(T)}\right) + B \times \sinh\left(\frac{x}{L(T)}\right) + \sum_{i=1}^{3} \frac{a_i \times L^2(T)}{D(T)} \times e^{(-b_i \times z)} \text{ (6)}$$

Coefficients A and B are determined from the following boundary conditions as:
i) At the junction(n$^+$/p): x = 0

$$\left.\frac{\partial \delta(x,z,T)}{\partial x}\right|_{x=0} = \frac{S_f}{D(T)} \times \delta(0,z,T) \text{(7)}$$

S$_f$is the minority carrier recombination velocity at the junction, imposed by the external load. It also characterizes the solar cell operating point, varying from the open circuit to the short circuit [16, 32, 35, 44]
ii) At the back surface(p/p$^+$): x = H

$$\left.\frac{\partial \delta(x,z,T)}{\partial x}\right|_{x=H} = -\frac{S_b}{D(T)} \times \delta(H,z,T) \text{ (8)}$$

S$_b$ is theexcess minority carrier's recombination velocity at the back surface. It is the result of the electric field produced by the p/p$^+$ junction and characterizes the behaviour of the density of the charge carriers at the(p/p$^+$)junction[16, 30, 31].

Photocurrent density is defined by the following relationship:

$$Jph(S_f,z,T) = q \times D(T) \times \left.\frac{\partial \delta(x,z,T)}{\partial x}\right|_{x=0} \text{ (9)}$$

For high values of excess minority carrier's recombination velocity at the junction $(S_f \geq 10^4 \text{cm.s}^{-1})$, the photocurrent density is constant, and corresponds to the short-circuit density current (J$_{SC}$). In this solar cell operating condition, the derivative of Jph (Sf, z,T) with respect to Sf, vanishes, and allows to establish the following equation:

$$\left.\frac{\partial Jph(Sf,z,T)}{\partial Sf}\right|_{Sf \geq 10^4 cm.s^{-1}} = 0 \quad \text{(10)}$$

The resolution of this equation, gives two solutions Sb1 (H, T) and Sb2 (H, T) which are expressions of the excess minority carrier's recombination velocity at the back surface. They are dependent on the geometric parameter (H)

(which is the width of the lamella), the parameters of diffusion and recombination in the bulk, as well as the temperature (T). They are given by [19, 20, 45]:

$$Sb_1(H,T) = \frac{D(T) \times \sinh\left(\dfrac{H}{L(T)}\right)}{L(T) \times \left(1 - \cosh\left(\dfrac{H}{L(T)}\right)\right)} \quad (11)$$

$$Sb_2(H,T) = -\frac{D(T)}{L(T)} \times \tanh\left(\frac{H}{L(T)}\right) \quad (12)$$

Results and Discussions:-
Density of excess minority carriers in thelamella:
Figure (3) produces the profile of the carriers'densitywith the width of the lamella under short circuit. The minority carriers'maximum density increases under thermal agitation, in accordance with the Umklapp process [20, 25, 26, 46, 47].
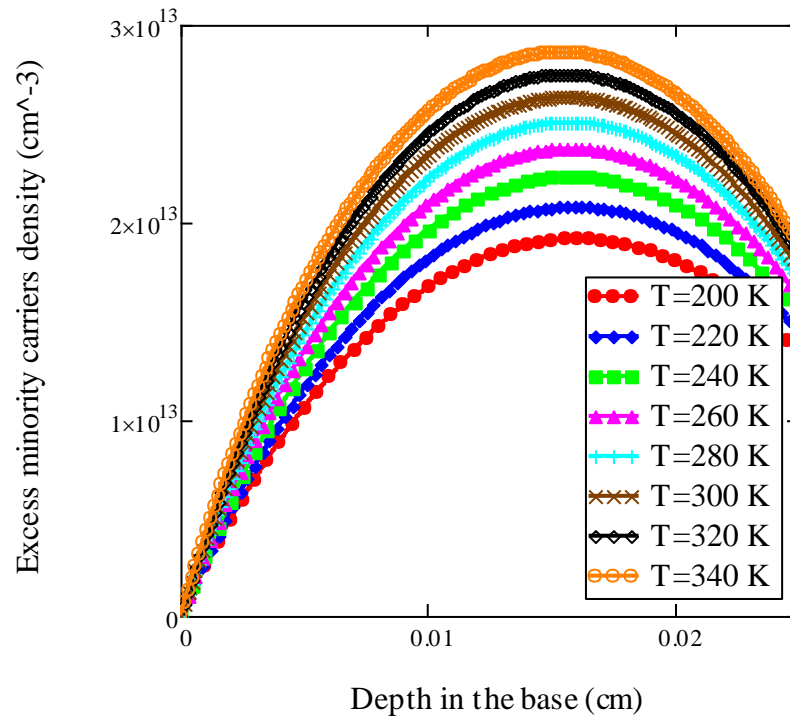

Figure 3:- Excess minority carriers density versus depth in the base for different temperature values with Sf=6x10^{6} cm/s,z=0.015 cm, Sb1(T) cm/s.

Photocurrent density:
Figure (4) shows the plot of Jph (Sf, T) photocurrent density versus onthe excess minority carrier's recombination velocity(Sf) at the junction for a given temperature. The effect of temperature is manifested at highSfvalues (short-circuit situation), showing a decrease in the collection of excess minority carriers across the junction [17, 18].
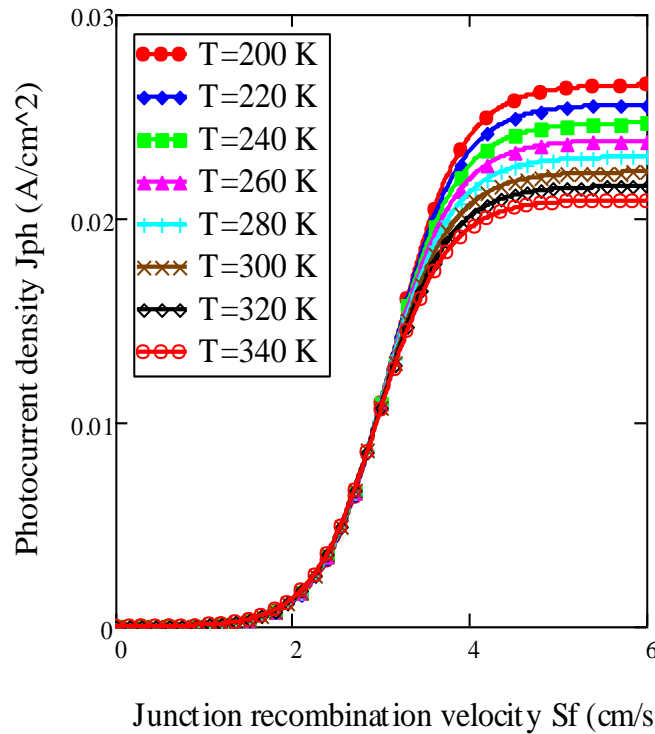
Figure 4:- Photocurrent density versus junction recombination velocity for different temperature values with z=0.015 cm, Sb1(T) cm/s.

Figure (5)shows the effect of generation and collection, by increasing the density of short-circuit photocurrent through the variation in the width (H) of the lamella, for(H/L >> 1) [17, 18, 48].
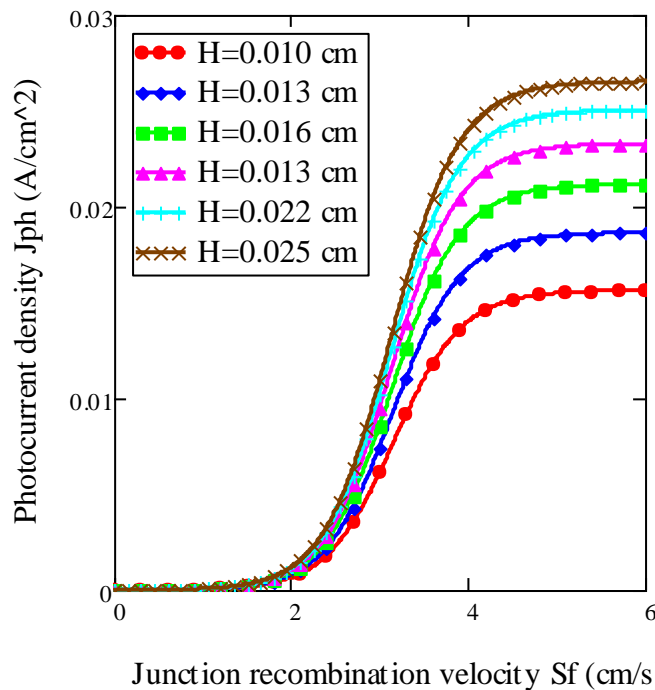

Figure 5:- Photocurrent density versus junction recombination velocity for different depth in the base values with z=0.015 cm, Sb1(T) cm/s.

Lamella optimum width determination:
By the curves intersection technique representing the excess minority carrier's recombination velocity at the back surfaceaccording to the width of the lamella, for each temperature (Figure. 6), the optimum width (Hopt) is deduced, and summarized in the table. 1.
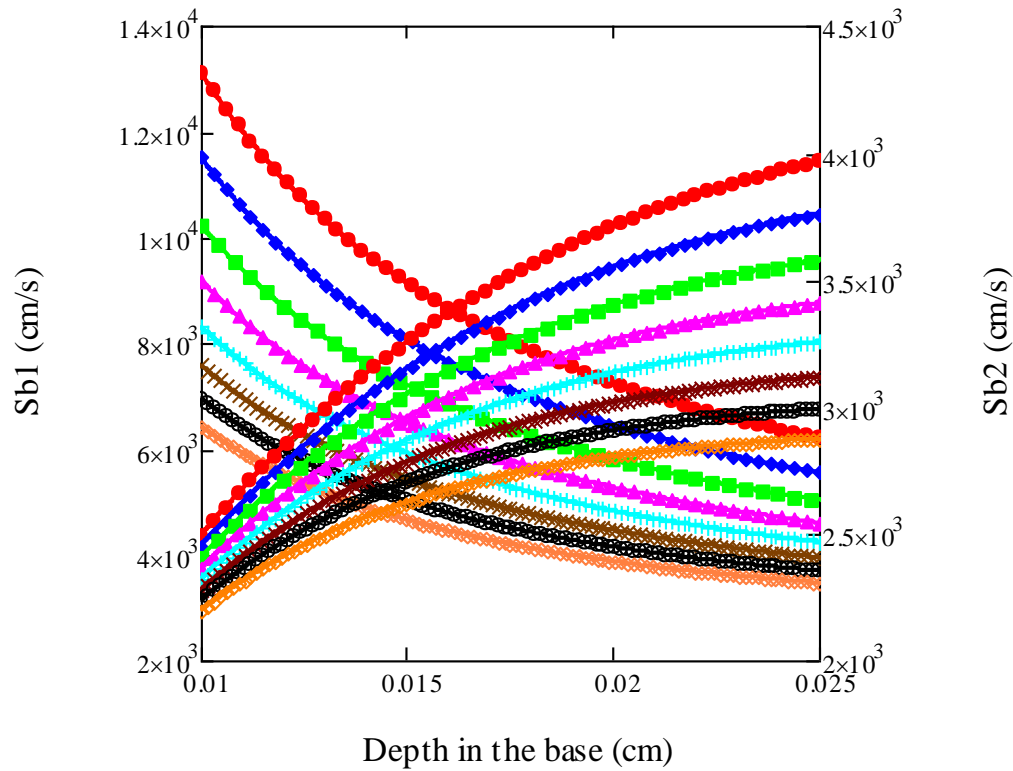

Figure 6:- Back surface recombination velocity versus lamella width.

The optimum thickness values are extracted from Figure 6 and are shown in Table 1 below. They are represented, for each temperature, by the abscess of the intersection of the two curves representing the recombination velocity expressions [19, 20, 27, 45, 49, 50, 51, 52], one of which also represents the intrinsic velocity at the junction [11], allowing to obtain the maximum of extracted photocurrent density

Table 1:- Lamella optimum (Hopt) width for different temperature values.

T(K)	200	220	240	260	280	300	320	340
Hopt(cm)	0.01614	0.01563	0.01527	0.01492	0.01466	0.01451	0.01440	0.01430
D(cm^2/s)	63.245	55.239	48.819	43.574	39.221	35.561	32.447	29.771

The results of Table 1 allow curves representing variations in optimum width versus both the temperature (T) (Figure. 7) and the effective diffusion coefficient (D(T)) (Figure. 8).
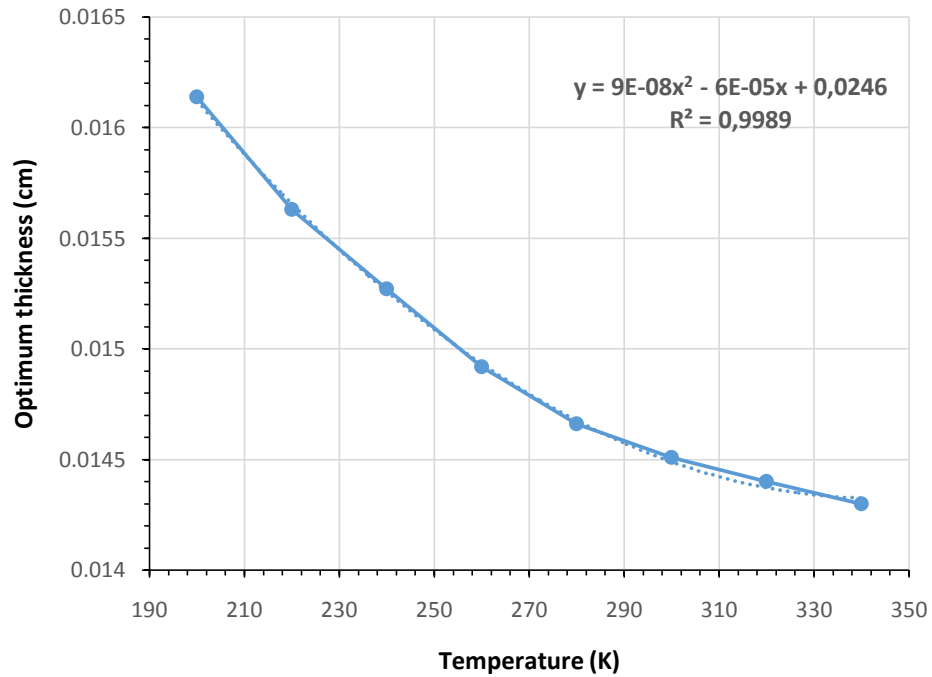
Figure 7:- Optimum thickness versus temperature.

The following correlation equation is deduced from the figure (7), giving Hopt a decreasing temperature function (T): $Hopt(cm) = 9 \times 10^{-8} \times T^2 - 6 \times 10^{-5} \times T + 0.0246$ (13)

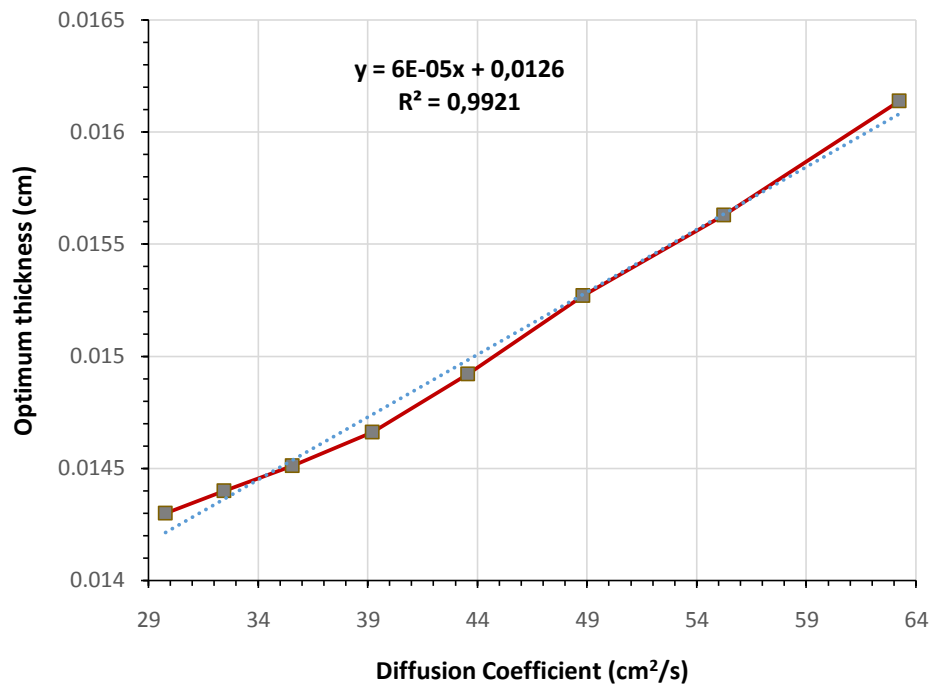With: $\chi = 9 \times 10^{-8}$ cm.K^{-2} ; $\psi = 6 \times 10^{-5}$ cm.K^{-1} ; $\sigma = 0.0246$ cm

Figure 8:- Optimum width versus diffusion coefficient.

On the other hand, Figure 8 gives the optimum width (Hopt) of the lamella as an increasing function of the effective diffusion coefficient (D) of excess minority carriers, through the following modeling relationship:

$$Hopt(cm) = a \times D + b \quad (14)$$

With: $a = 6 \times 10^{-5}\, cm^{-1}.s$; $b = 0.0126\, cm$

These modelling results on optimum width, expand the circle of those already presented by previous works on solar cells, by variation of:

the diffusion coefficient of minority carrier under the action of:

applied magnetic field [19, 20]

doping rate [49]
magnetic field and temperature [50, 51]

flow and intensity of irradiation by charged particles [27, 45]
the excess minority carrier's recombination velocity at the backunder the action of:

the variation in the monochromatic absorption coefficient [52].

Conclusion:-
The results of this work are an important contribution to optimize the performance of the lamella solar cells, under the conditions of temperature variation. The width of the lamella depending on the temperature, will lead to the determination of the electrical parameters of the solar cells. Thus the application of these results, combined with the previous ones constitute references in the choice of the width of the base of the lamella in the process of its industrial manufacture.

Further work will be carried out by combining the different experimental conditions of the study of the solar cells, including the use of monochromatic incident light in frequency modulation.

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