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Study the recombination speed at the rear face of a silicon solar cell under polychromatic illumination: Effect of depth and temperature with Matlab / Simulink.

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Abstract :

During this study, we are interested in the recombination speed at the rear face of a silicon solar cell under polychromatic illumination. We have highlighted the effect of depth and temperature on the speed of rear face recombination. This speed is deduced from the expression of the density of photocurrent. The photocurrent density was obtained from the derivative of the density of minority carriers, which was obtained by solving the equation of continuity of minority carriers in the solar cell base.

Keywords: Solar cell; recombination rate; Temperature; Depth.

I . Introduction :

Solar cells are devices that allow photovoltaic conversion. These solar cells can be classified under conventional ones and those with rear surface field or BSF (Back Surface Field) [1,2, 3]. Much research has been carried out on solar cells to optimize better and have better conversion efficiency. The conversion efficiency may depend on the nature of the material structure, the technique and the manufacturing process [4]. Thus, several techniques have been proposed to measure the optoelectric properties of basic semiconductor materials that manufacture solar cells. These non-destructive techniques maintain the solar cell in a static or dynamic regime (transient or frequency) [5, 6, 7]. These technologies aim to evaluate the imperfections (uncontrolled impurities, dislocations, dosage and impurity profile) of solar cells, which are at the basis of the recombination processes [8, 9, 10,11] of minority carriers charges photogenerated. These recombinations of the photogenerated charge carriers are thus the basis of a reduction in their collection and, consequently, the photovoltaic conversion efficiency. This article aims to study the effect of temperature and depth on the rate of rear face recombination.

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II. THEORY

The solar cell considered is of the n + -p-p + type, and its structure is presented in figure 1 [12].

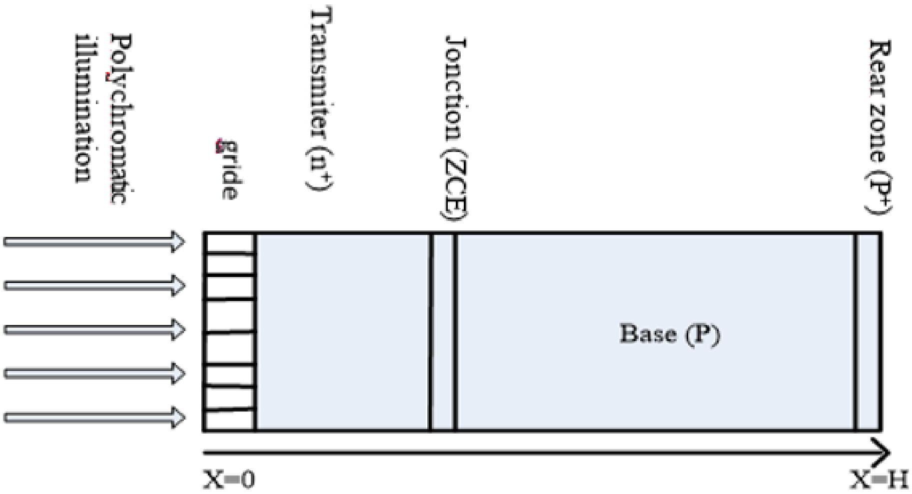

Figure 1 Structure of an n + -p + p- silicon solar cell

The transfer of minority photogenerated charge carriers is the fundamental principle of the solar cell. The continuity equation of these one-dimensional carriers is given by the following equation [13]:

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

with

δ (x) is the density of electrons generated in the base at position x

G(x) is the generation rate of minority carriers at position x of the base [14,15] given by:

$$G(x) = \sum_{i=1}^{3} a_i e^{-b_i x} \qquad (2)$$

The coefficients ai and bi are obtained from the tabulated values of the radiation under illumination A.M1.5 [16]. These coefficients are given by:
a_1=6,13.10^{20} cm^{-3}/s; a_2=0,54.$10^{20}$$cm^{-3}$/s ; a_3=0,0991.$10^{20}$$cm^{-3}$/s ; b_1=6630cm^{-1}; b_2=1000cm^{-1}; b_3=130cm^{-1},

$$\left(L(T)\right)^2 = \tau D(T) \qquad (3)$$

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

τ is the lifetime of the electrons in the base,

$$D(T) = \mu(T)\frac{k_b}{q}T \qquad (4)$$

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

$$\mu(T) = 1{,}43.10^{9}T^{-2{,}42}\ cm^{2}V^{-1}s^{-1} \qquad (5)$$

$\mu(T)$ is the electron mobility coefficient [8],

k_b is the Boltzmann constant,

q is the elementary charge of the electron

The general solution of equation (1)

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

The expressions of A and B are determined from the following boundary conditions [18]:

i) At the junction (x = 0)

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

ii) At rear (x = H)

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

S_f denotes the recombination rate of the minority charge carriers at the base junction and indicates the solar cell's operating point [20,21], and Sb denotes the recombination rate of the minority charge carriers at the rear face of the base [22].

II.1 Expression of photocurrent density

The expression of the photocurrent is obtained [9]

$$J_{ph}(T,H) = q \times D(T) \times \frac{\partial\delta(x,T)}{\partial x}|_{x=0} \qquad (9)$$

The rear face recombination rate represents the area where the photocurrent gradient is zero on the curve of the variation of the photocurrent density as a function of the recombination rate at the Sf junction [23,24,25]. This allows us to write :$\frac{\partial J_{Ph}}{\partial Sf} = 0$ and to give an expression of the recombination rate to the rear face.

$$Sb(T,H) = \frac{\sum_{i=1}^{3} b_i \times (e^{-b_i.H} - \cosh\left(\frac{H}{L(T)}\right)) + \sinh\left(\frac{H}{L(T)}\right)}{\frac{1}{D(T)}\times[\sum_{i=1}^{3} b_i \times \sinh\left(\frac{H}{L(T)}\right) + e^{-b_i.H} - \cosh\left(\frac{H}{L(T)}\right)]} \qquad (13)$$

II.2 Rear face recombination speed Simulink model

In this paragraph, we represent the Simulink model of the rear face recombination rate. For each value of the coefficients ai and bi, we have given the corresponding Simulink model then the complete Simulink model of the recombination rate.

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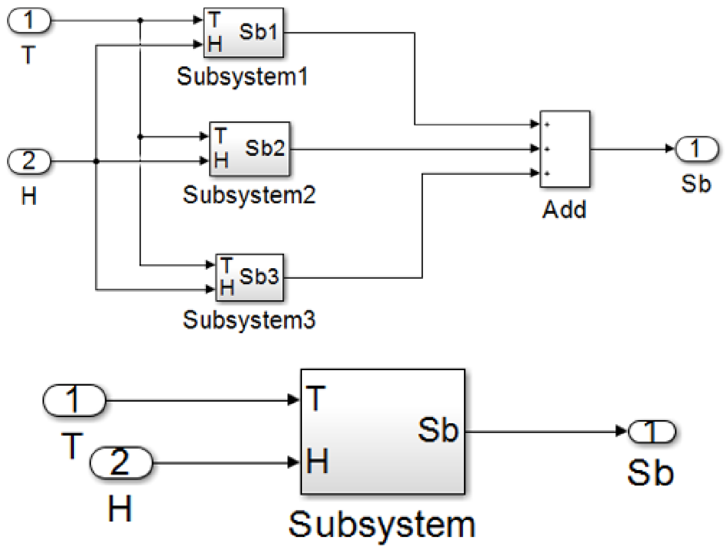

Figure 2 Simulink model of the recombination rate at the back face Sb

III. Results and discussions

In Figure 3, we represent the profile of the recombination rate at the rear face for different depths as a function of temperature. This curve represents recombination speed's variation at the rear face as a function of the temperature for different values of the depth of a solar cell. We observe that this recombination rate is much greater for average temperatures and decreases when the temperature increases. Indeed, for large values of Sb, we have ohmic solar cells, and for low values of Sb, we have BSF (Back Surface Field) solar cells, also called rear electric field solar cells. This electric field allows the minority carriers to be returned to the base, decreasing the recombination rate. We notice that the rear face recombination speed decreases with increasing depth. We can also say that recombination speed is more important for solar cells with thin thicknesses than solar cells with thick edges.

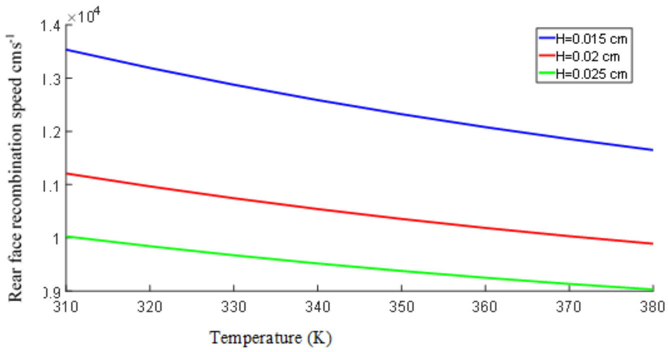

Figure 3: Recombination rate at the rear face in temperature concentration for different depth values

This is because the more the illumination decreases, the deeper you go. And so few minority carriers will arrive at the rear face. Figure 4 represents the logarithm profile of the recombination rate at the rear face for different depth values as a function of the temperature.

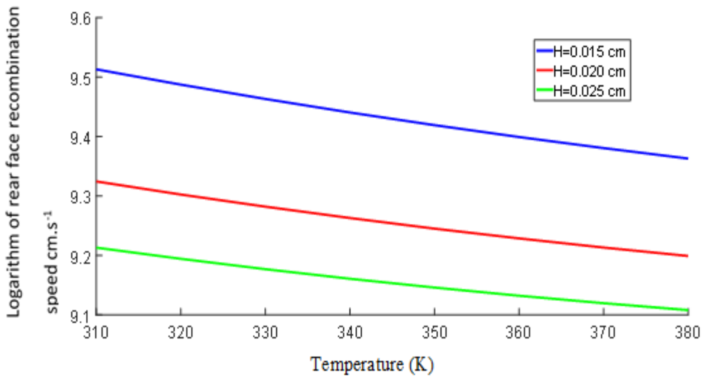

Figure 4: Logarithm of the rear face recombination rate depending on the temperature for different depth values

This figure allows us to observe the effect of depth on the recombination rate as a function of temperature. We note the same effects as the previous figure.

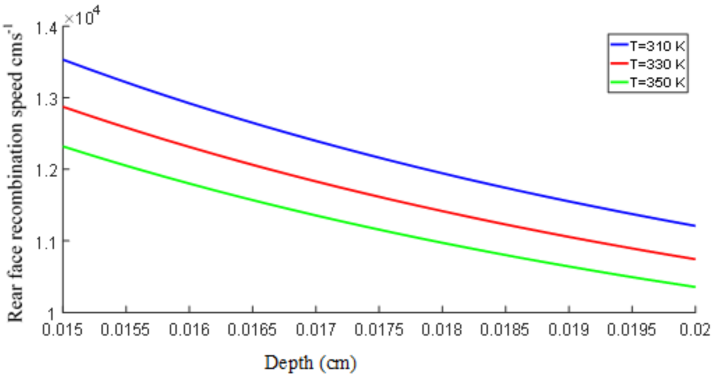

Figure 5: Rear panel recombination rate as a function of depth for different temperature values

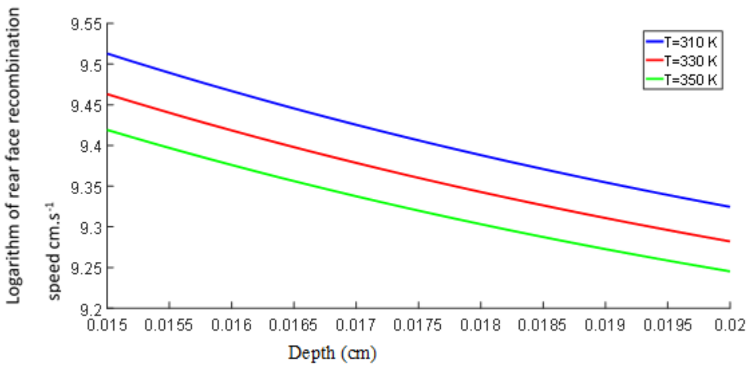

Figure 6: Recombination speed on the rear face depending on the depth for different temperature values

Figure 5 shows the variation of the rear face recombination speed as a function of depth. We notice that for low values of the depth of the recombination rate is maximum. It decreases as the depth increases. So, for low depth values with high recombination rates, we have ohmic solar cells, and for large depth values with low recombination rates, we have back electric field solar cells that will pull the minority carriers in the base, decreasing the rate of recombination. We also notice that the rate of recombination decreases with increasing temperature.

The rear face recombination speed of a function on the too depth observations effect of the temperature is shown in figure 6. We are witnessing the same phenomena as in figure 4.

IV. Conclusion

we studied here the variation of the recombination speed at the backside of a solar cell as a function of temperature and depth. We noticed that the recombination rate decreased for both parameters. This was more noticeable for rear electric field solar cells than for ohmic solar cells. Finally, we can say that the rear face recombination speed is safe for the car. The more it increases, the more the efficiency of the solar cell decreases.

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