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Study of a silicon solar cell under dynamic frequency regime: Effect of irradiation energy on the surface recombination rate Sb with matlab/Simulink

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ABSTRACT

This aims of this article is to be able to use matlab/Simulink to study the behaviour of the recombination rate on the backside under the influence of the irradiation energy. In the continuity equation where the diffusion coefficient appear, we have deduced the diffusion length L. Thus, we have modelled the equations of the diffusion length and the recombination rate by a Simulink model. After modelling, we were able to obtain results allowing to infer that the recombination rate increases when the irradiation energy increases which affects the efficiency of the solar cell. To capture this we have increased the excitation frequency of the the solar cell. This makes for high-value irradiation energy, the recombination rate decreased as the pulse increased. The mathematical analysis approach is very flexible to change the parameters of a solar cell.

Key words: Irradiation energy; Pulsation; Diffusion length; Recombination rate Matlab/Simulink; Solar cell

INTRODUCTION

The techniques used to measure phenomenological parameters in solar cell can be classified into three parts. These techniques are those that maintain the solar cell in static, frequency dynamis, and transient dynamic [1,2,3,4]. However, these techniques, which are essential for the development of high-performance solar cell, alter the initial structure and cause defects (contamination by diffusion). These defects, also called vacant sites in the crystal structure, will be the recombination site for photogenerated carriers [4,5,6,7]. We will observe at interfaces that is to say contact between different areas of the solar cell of losses of carriers by recombination phenomena.

Thus, to define the performance and the optimization of the quality of all these areas of the solar cell, it is necessary to measure the different parameters involved in the processes at the surface, by volume and at the interfaces. This is the recombination rate on the front and the recombination rate on the back [8,9,10].

In this article, it will be a question of studying the rate of recombination at the rear face of a silicon solar cell in a dynamic frequency regime under the effect of irradiation energy.

THEORETICAL STUDY

The solar cell considered is of the n+-p-p+ type and its structure is presented in figure1 [11,12].

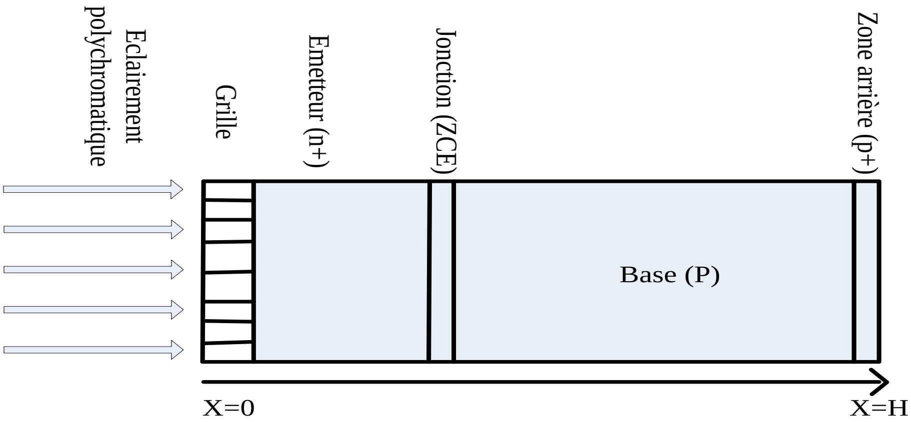

Fig. 1 Structure of a silicon solar cell n+-p-p+

The effect of an excitation (optical or electric) leads to a generation of load carriers in the base of the solar cell. The carriers thus generated will undergo two effects:
Either cross the space load zone where they will participate in the external current,
They either undergo surfaces or volumes recombination.

$$D^* \frac{\partial^2 \delta_n(x,t)}{\partial x^2} - \frac{\delta_n(x,t)}{\tau} - \frac{\partial \delta_n(x,t)}{\partial t} = -G_n(x,t) \tag{1}$$

With $\delta_n(X,t)$ is the density of the electrons generated given by equation (2):

$$\delta_n(x,t) = \delta_n(x).\exp(jwt) \tag{2}$$

G_n (x, t) is the generation rate of minority holders [15] given by equation (3)

$$G_n(x,t) = g_n(x).\exp(jwt) \tag{3}$$

With $$g_n(x) = \phi(\lambda).\alpha(\lambda).(1-R(\lambda)).\exp(-\alpha(\lambda).x) \tag{4}$$

D* is the diffusion coefficient [16] which is a very important parameter in the characterization of semiconductor material which may depend on several parameters. The complex diffusion coefficient D_ω [17] is given by equation (5):

$$D_w = \frac{1+w^2.\tau^2}{(1-w^2.\tau^2)^2 + 4w^2.\tau^2}.(1-j.w^2.\tau^2) \tag{5}$$

τ the lifetime of the carriers depending on the irradiation energy and the damage coefficient [18]. It is given by equation (6):

$$\tau = \frac{1}{\tau_0} + kl.\phi_p \tag{6}$$

The coefficient of diffusion without excitation, which depends on the temperature, is given by equation (7):

$$D(T) = \frac{k_b.T}{q} + \mu(T) \tag{7}$$

µ(T) represents the mobility of minority carriers depending on temperature [19]. It is given by equation (8):

$$\mu(T) = 1{,}43.10^9.T^{2{,}42}\,\frac{cm^2}{V.s} \tag{8}$$

K_b is the boltwzmann constant and q the elementary charge of the electron.

From equation (7) we deduce the diffusion length depending on the temperature denoted L0 and given by:

$$L_0(T) = \sqrt{D(T).\tau} \tag{9}$$

The diffusion length of excess minority carriers in the base of the solar cell noted L is related to the flow of irradiating particles as well as to the damage coefficient by the following relationship [20]:

$$L(kl,\phi_p,T) = \sqrt{\frac{1}{\frac{1}{L_0(T)^2} + kl.\phi_p}} \tag{10}$$

From equation (10), we give the expression of the temperature dependent diffusion coefficient, the irradiation energy and the damage coefficient in (11) [21]:

$$D(kl,\phi_p,T)=\frac{L(kl,\phi_p,T)^2}{\tau} \qquad (11)$$

In the frequency dynamic regime, the diffusion length depending on the pulsation, the damage coefficient is given the following equation (12):

$$L^*(\omega,kl,\Phi p,T)=L(Kl,\Phi p,T)\sqrt{\frac{1-j.\omega.\tau}{1+(j.\omega)^2}} \qquad (12)$$

$$D^*(\omega,kl,\Phi p,T)=\frac{L^*(\omega,kl,\Phi p,T)^2}{\tau} \qquad (13)$$

$$\delta(x,\omega,kl,\phi_p,T)=A(x,\omega,kl,\phi_p,T)\cdot\cosh\left(\frac{x}{L(\omega,kl,\phi_p,T)}\right)+B\cdot\sinh\left(\frac{x}{L(\omega,kl,\phi_p,T)}\right)-\frac{\phi(\lambda)\alpha(\lambda)L^2(\omega,kl,\phi_p,T)(1-R(\lambda))e^{-(\alpha(\lambda)x)}}{D(\omega,kl,\phi_p,T)\left[L^2(\omega,kl,\phi_p,T)\alpha^2(\lambda)-1\right]} \qquad (14)$$

The expression A and B are determined from the conditions at the following limits [22]:

At the junction (x=0)

$$\left.\frac{\partial\delta_n(x,w,kl,\phi_p,T)}{\partial x}\right|_{x=0}=\frac{S_f}{D(\phi_p,w,kl,T)}.\delta_n(x,w,kl,\phi_p,T)\Big|_{x=0} \qquad (15)$$

At the back (x=H)

$$\left.\frac{\partial\delta_n(x,w,kl,\phi_p,T)}{\partial x}\right|_{x=H}=-\frac{S_b}{D(\phi_p,w,kl,T)}.\delta_n(x,w,kl,\phi_p,T)\Big|_{x=H} \qquad (16)$$

The diffusion length depending on the pulsation, the temperature, the damae coefficient and the irradiation energy given by equation (12), is modeled in figure 2 which represents its Simulink model.

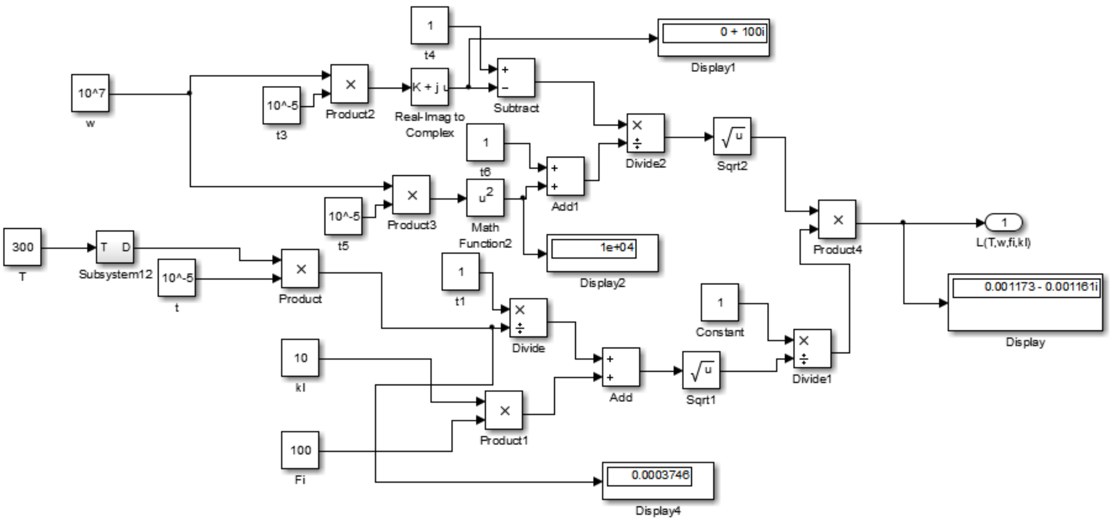

Fig. 2 Simulink model of the diffusion length

Simulink model of recombinant speed on the rear face Sb

Sb designates the recombination speed of the rear facing carriers; it translates the way the carriers are lost at the rear interface of the solar cell.

This recombination speed on the backside represents the area where the photocourant gradient is equal to zero [18, 24]. This allows us to write:

$$\frac{\partial J_{ph}(w,kl,\phi_p,T)}{\partial S_f}=0 \tag{17}$$

With

$$J_{ph}(w,kl,\phi_p,T)=q.D(w,kl,\phi_p,T).\left.\frac{\partial\delta_n(x,w,kl,\phi_p,T)}{\partial x}\right|_{x=0} \tag{18}$$

And give the expression of the recombination speed on the backside.

$$S_b\left(\omega,Kl,\Phi_p,T\right)=\frac{D\left(\omega,Kl,\Phi_p,T\right)}{L\left(\omega,Kl,\Phi_p,T\right)}.\frac{\sinh\left(\frac{H}{L\left(\omega,Kl,\Phi_p,T\right)}\right)-\alpha_t.L\left(\omega,Kl,\Phi_p,T\right)\left(\cosh\left(\frac{H}{L\left(\omega,Kl,\Phi_p,T\right)}\right)-\exp(-H.\alpha_t)\right)}{\alpha_t.L\left(\omega,Kl,\Phi_p,T\right)\sinh\left(\frac{H}{L\left(\omega,Kl,\Phi_p,T\right)}\right)-\left(\cosh\left(\frac{H}{L\left(\omega,Kl,\Phi_p,T\right)}\right)+\exp(-H.\alpha_t)\right)} \tag{19}$$

The Simulink model of the recombinant speed on the rear face is given in figure 3:

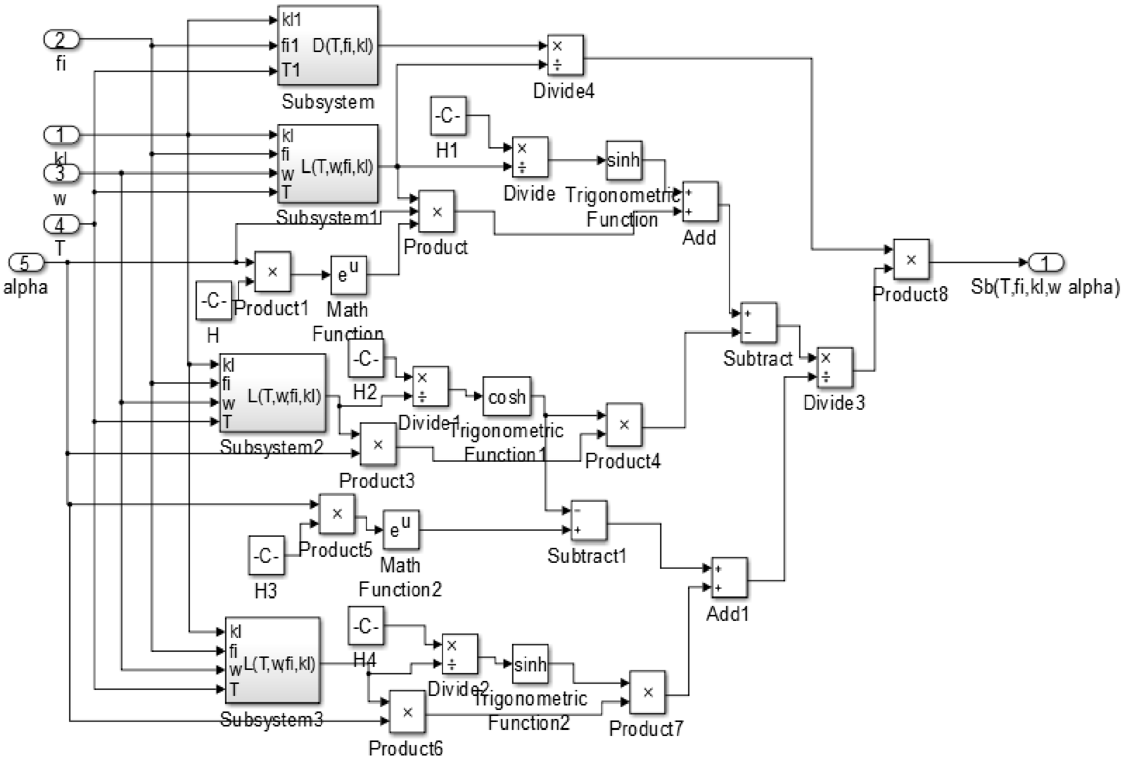

Fig. 3 Simulink model of recombinant speed on the rear face Sb

RESULTS AND DISCUSSION

Figure 4 shows the scatter length for different irradiation energy values Φ (MeV).

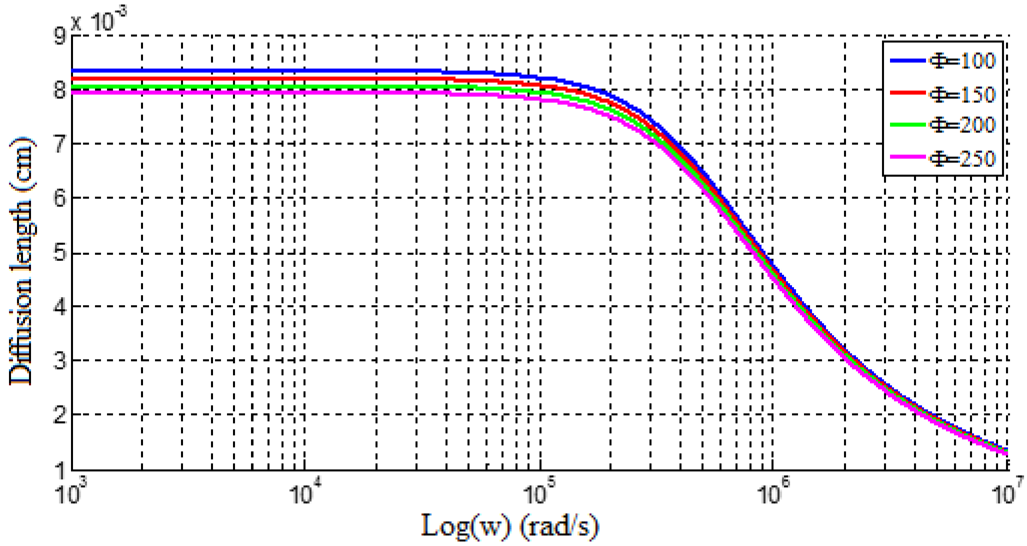

Fig. 4 Curve of the diffusion length as a function of the logarithm of the pulsation with T=300K; kl=10 cm^2/s ; H=0.03 cm

We note that the diffusion length is almost constant for pulsation values below $\omega \leq 10^5 rad / s$. It decreases as the pulsation becomes greater than $\omega \leq 10^5 rad / s$. We also notice a decrease in the diffusion length as the irradiation energy increases. Indeed, irradiation energy creates intrinsic defects by the interaction between charged particles and silicon electrons.

The charged particles lose their in the material which leads to a decrease in the diffusion length.

Figure 5 shows the scatter length as a function of pulsation for different values of the irradiation energy Φ (MeV).

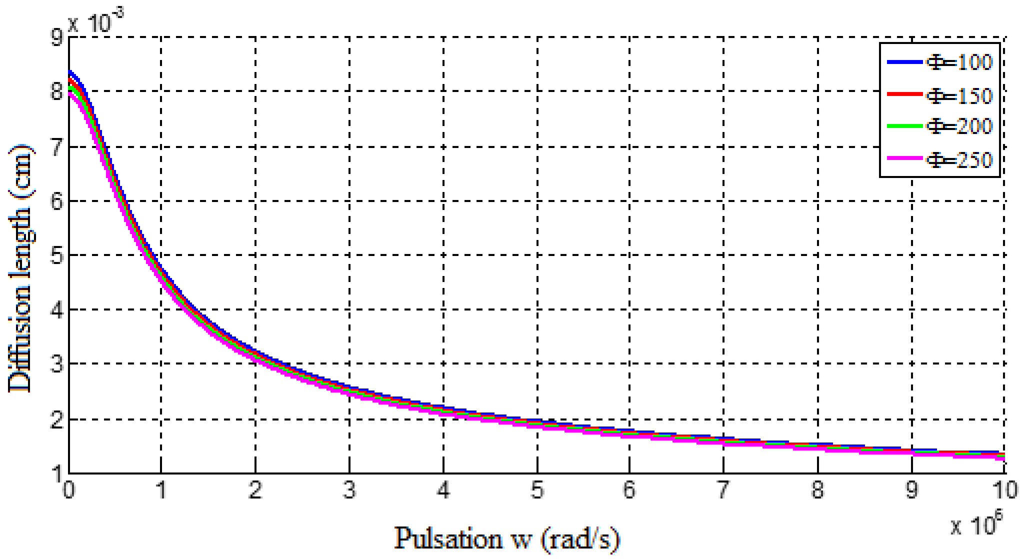

Fig. 5 Curve of the diffusion length as a function of the logarithm of the pulsation with T=300K; kl=10 cm^2/s; H=0.03 cm

We observe that the diffusion length is maximum for low pulsation values. We can say that the frequency of excitation is low, which means that the carriers will be able to travel a fairly long distance before recombine. Then the diffusion length begins to decrease when the pulse is high enough.

We also note that as the irradiation energy increases, the diffusion length decreases. We can say that the irradiation energy blocks the carriers which causes the particles to lose their energy which decreases the diffusion length.

Figure 6 shows the recombination velocity curve on the back side as a function of the pulsation for different values of the irradiation Φ (MeV).

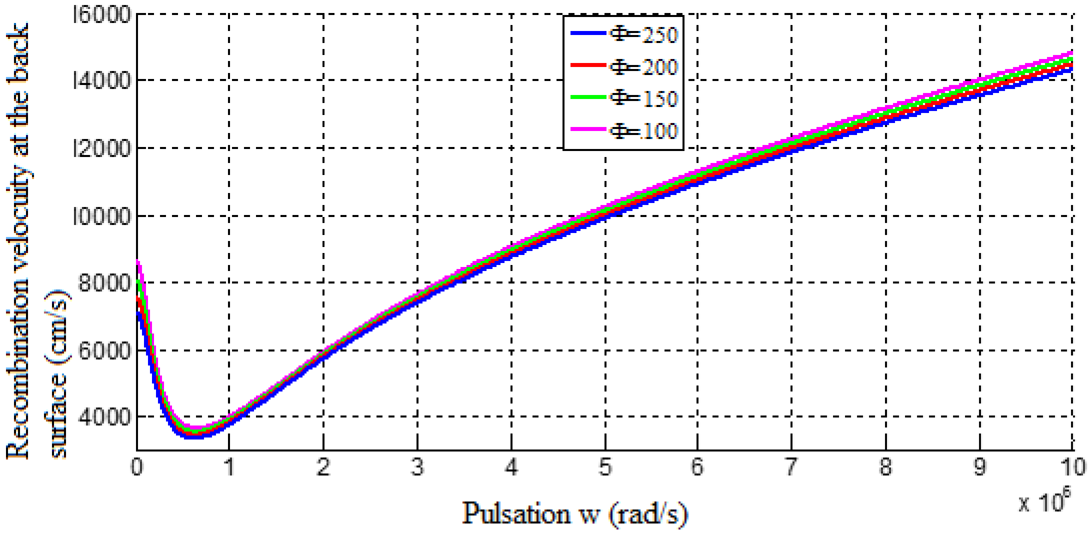

Fig. 6 Recombination speed on the backside as a function of pulsation with T=300K; Kl=10 cm^2/s, H=0,03 cm

We note that this figure shows two areas: the first zone corresponds to the vicinity of the weak pulsations where we notice that the recombination speed at the rear face decrease but this on with the increase of the irradiation energy. The second zone corresponds to the increase in recombination speed at the back side as the pulse increases. We observe the same phenomenon decrease when the irradiation energy increases.

The increase in the frequency of illumination constitutes a blockage for minority holders photogenerated in the base. Because the solar cell does not have time to relax and there is little charge that will cross the junction to participate in the photocurrent.

Figure 7 shows the curve of the recombination velocity at the back surface as a function of the logarithm of the pulsation for different values of the irradiation energy Φ (MeV).

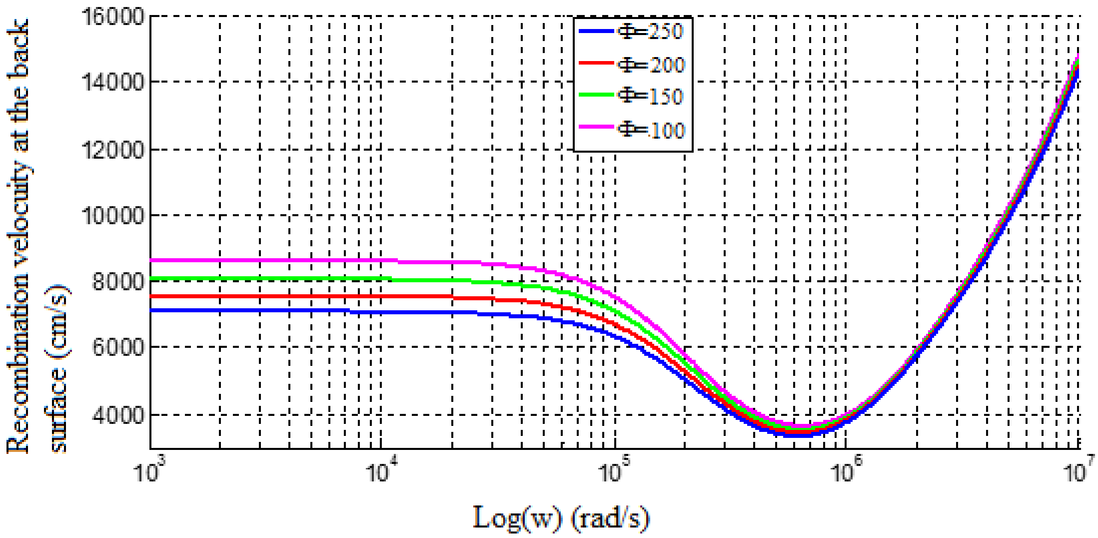

Fig. 7 Recombination velocity curve on the backside as a function of the logarithm of the pulsation for different values of the irradiation energy with T=300K; Kl=10 cm^2/s, H=0,03 cm

For values of $\omega \leq 10^5 rad/s$ corresponding to the quasi-static regime, we notice that the recombination speed is almost constant. In this area we note a simultaneity between the optical excitation of the minority carriers and their response in the base. And for values of $\omega \geq 10^5 rad/s$ we notice that the recombination speed decreases to $\omega = 10^6 rad/s$ and the increases as the logarithm of the pulse increases. This zone corresponds to the frequency regime during which there is a phase shift between the optical excitation and the diffusion of minority carriers. When we vary the irradiation energy, we notice that the rate of recombination decreases.

CONCLUSION

During this article, we were able to see that the recombination speed at the backside is a very important parameter for the operation of the solar cell. It follows that different losses in the rear face could influence the operating parameters of the solar cell. As a result, the damage caused depends not only on the pulsation but also on the irradiation energy.

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