IMPROVEMENT OF IRRADIATION RESISTANCE OF SOLAR CELLS BY VARIATION OF THE DEVICE PARAMETERS: APPLICATION TO N+/P InGaP

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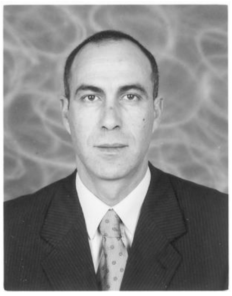
The degradation of solar cell materials in space has already been studied and is a consequence of the defects induced by electron and proton irradiation. The nature, characteristics and introduction rates of these defects are typical of a specific material. We propose here a method allowing to study the variation of the short circuit current J_{sc} and open circuit voltage V_{oc} versus the fluence of the irradiation using a new approach taking account of the dependence of two minority carriers lifetime τ_{0n} and τ_{0p} before irradiation. Then we show the effect of the device parameters, i.e. the variation of different values of parameters respectively the emitter thickness, base thickness, emitter doping, base doping and the front surface recombination velocity.

Keywords: photovoltaic effect in semiconductor structures; modelisation, degradation



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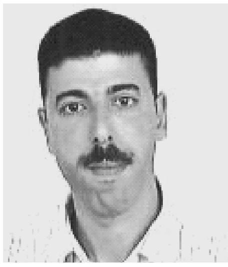

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Introduction

Previously we have proposed a new method, justified theoretically and experimentally, allowing to deduce τ_{0n} versus τ_{0p}, the minority carriers lifetime respectively in the base and in the emitter of solar cell, before irradiation and τ_{jn} versus τ_{jp}, the minority carriers lifetime respectively in the base and in the emitter, after irradiation, and versus φ_j, the fluence irradiation. The validity of this method was illustrated in the case of the degradation of the n+/p InGaP cells [1]. In this paper, we recall briefly the calculation principle of new approach and we will show the effect of the device parameters, i.e. the emitter thickness and doping (X_n, N_d) and base thickness and doping (X_p, N_a) and the front surface recombination velocity, S_p, on the variation of characteristics and consequently on the resistance to electron irradiation of solar cells.

Principle of calculation of minority carrier lifetime

The electron or proton irradiation introduces recombination centres which tend to affect solar cell performance by reducing the minority carrier lifetimes τ_{jn} and τ_{jp} through equation [2],

$$\frac{1}{\tau_{jn}} = \frac{1}{\tau_{0n}} + k\sigma_n \nu_n \varphi_j , \quad \frac{1}{\tau_{jp}} = \frac{1}{\tau_{0p}} + k\sigma_p \nu_p \varphi_j ,$$

where the subscripts 0n, 0p and jn, jp indicate values before and after irradiation in the n and p region.
The lifetimes τ_{0np} associated with the recombination of minority carriers (electrons and holes in the emitter and (or) base before irradiation) depend on the nature and concentration of the native recombination centres, i.e. on the mode of growth of the material and on the process treatments which are applied to realize the cell.

In the previous work, we have shown that the minority carrier lifetime can be written as:

$$\tau_{jn} = \left[\left(a_j r_n \sqrt{\tau_{jp}} + b_j\right) / \left(J_{scj} \sqrt{\tau_{jp}} - a_j r_p\right)\right]^2.$$

The complete expressions for a_j, b_j, r_n and r_p of last equation were derived from [1].

Mecanism of degradation and parameters effects

Mecanism of degradation

It is possible to calculate, and hence predict, the degradation of *n+/p* InGaP solar cell, when the thickness and doping respectively of the emitter and base are given. The parameters of the studied cell are listed in Table 1 below.

Table 1

Calculated parameters of *n+/p* InGaP cells

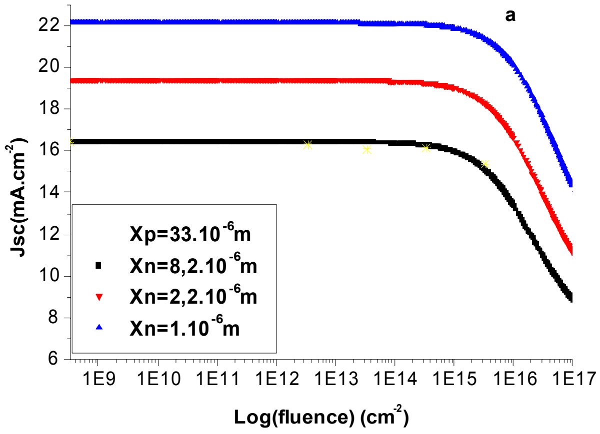
Cell	$\tau_{0n}(s)$	$\tau_{0p}(s)$	$k\sigma_n(\text{cm}^{-1})$	$k\sigma_p(\text{cm}^{-1})$
InGaP (*n+/p*)	$3.44\cdot10^{-8}$	$7.2\cdot10^{-12}$	$1.2\cdot10^{-14}$	$8.6\cdot10^{-13}$

The knowledge of J_{sc0} and V_{oc0} under given illumination, before irradiation is also necessary in order to derive the minority carrier lifetimes τ_{0n}, τ_{0p} in the base and emitter. Once the initial values of the minority carrier lifetimes are determined, one inject them into calculation. The knowledge of J_{scj} and V_{ocj} under given illumination and amount of irradiation φ_j allow it to deduce the values of τ_{jn}, τ_{jp} and hence $k\sigma_n$, $k\sigma_p$.

Often some authors fits experimental data to the values normalized prior irradiation [3, 4]. In our case we calculate the absolute theoretical data as shown in Fig. 1, a and b where the absolute experimental [5] (with yellow star (*) symbol) and the theoretical data of V_{oc}, J_{sc} are represented.

From the parameters τ_{0n}, $k\sigma_n$ (in emitter region), and τ_{0p}, $k\sigma_p$ (in base region) (see Table 2) we derive the calculated values of V_{oc} and J_{sc}. We add that these values extracted from our analysis are different of the values determined by other authors [3, 4] because of the relationship between two carriers lifetime τ_{0n} and τ_{0p}.

Once the degradation of *n+/p* InGaP is calculated, we proceed to study the parameters effects on the degradation of V_{oc} and J_{sc} [6].



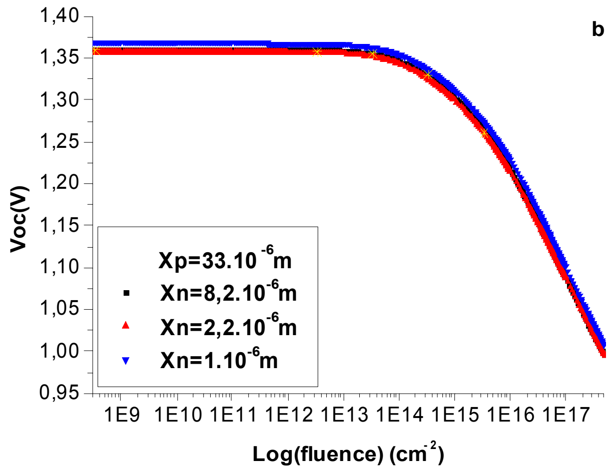


Fig. 1. *Variation (a) of the short circuit current, J_{sc}, and (b) of the open circuit voltage, V_{oc}, under 1 AM0 illumination, versus the fluence of 1 MeV electron irradiation, calculated for different values, X_n, of emitter thickness*

Table 2

Parameters of InGaP solar cells

InGaP-*n*+/*p*	Emitter thickness X_n $(1\cdot10^{-6}$ m)	Base thickness X_p $(1\cdot10^{-5}$ m)	Emitter doping N_d $(1\cdot10^{18}$ cm$^{-3})$	Base doping N_a $(1\cdot10^{17}$ cm$^{-3})$	Recombination velocity S_p $(1\cdot10^{5}$ cm·s$^{-1})$
Solar cell parameters	8.2 2.2 1.0	3.3 2 1	4.5 1.5 0.85	4 2 1	5 1 0.5

In the present work, we interest to the effects of parameters as the emitter thickness and doping (X_n, N_d) and base thickness and doping (X_p, N_a) and the front surface recombination velocity, S_p. We show in Fig. 1-5 respectively the variation of the short circuit current, J_{sc}, and open circuit voltage, V_{oc}, under 1 AM0 illumination, (the AM0 spectrum is the relevant one for satellite and space-vehicle applications), versus the fluence of 1 MeV electron irradiation, calculated for different values of the emitter and base thickness and doping level and of the front surface recombination velocities.

The effect of the variation of the thickness

For the studied cell InGaP-$n+/p$, we vary only each of the emitter thickness, X_n, and the base thickness, X_p, the other parameters being fixed at the values of Table 2. The curves of J_{sc}, short-circuit current and the open circuit voltage, V_{oc}, obtained are represented in Fig. 1, 2.

We observe an important reduction in J_{sc} with the increase values of the emitter thickness, X_n. On the contrary J_{sc} increases but slightly with increasing values of the bases thickness, X_p.

Indeed, when the emitter thickness, X_n, will be big, enough carriers don't reach the base region, what causes a reduction of the spectral response and therefore an attenuation of the value of J_{sc}.

At high fluence of irradiation (Fig. 2, *a*), we note a fast decrease of the curves representing the cells of which the thickness X_p is large.

Not indeed of surprise for the V_{oc} parameter, it doesn't vary practically at the time of the variation of the X_n and X_p (in the Fig. 1, *b* and Fig. 2, *b*; the three representative curves are nearly confounded).

The effect of the variation of the level doping

The effect of the variation of the level doping of two regions, emitter and base, is illustrated in Fig. 3, 4.

The Fig. 3, *b* and Fig. 4, *b* show that the effect of the doping remains weak on the variation of the V_{oc} parameter.

The contribution of the two regions to the short circuit current, J_{sc}, is shown in Fig. 3, *a* and Fig. 4, *a*. This contribution takes place in opposite sense, i.e., the J_{sc} increases rapidly when the base is well doped by the quantity N_a whereas the emitter is doped weakly by the quantity N_d.

Moreover, at high fluence of irradiation, to see Fig. 3, *b* and Fig. 4, *a*, J_{sc} resists to the irradiations when the cell ($n+/p$) is doped weakly by the acceptors N_a, on the other hand V_{oc} resists well to the irradiations when the junction ($n+/p$) is doped weakly by the donors N_d.

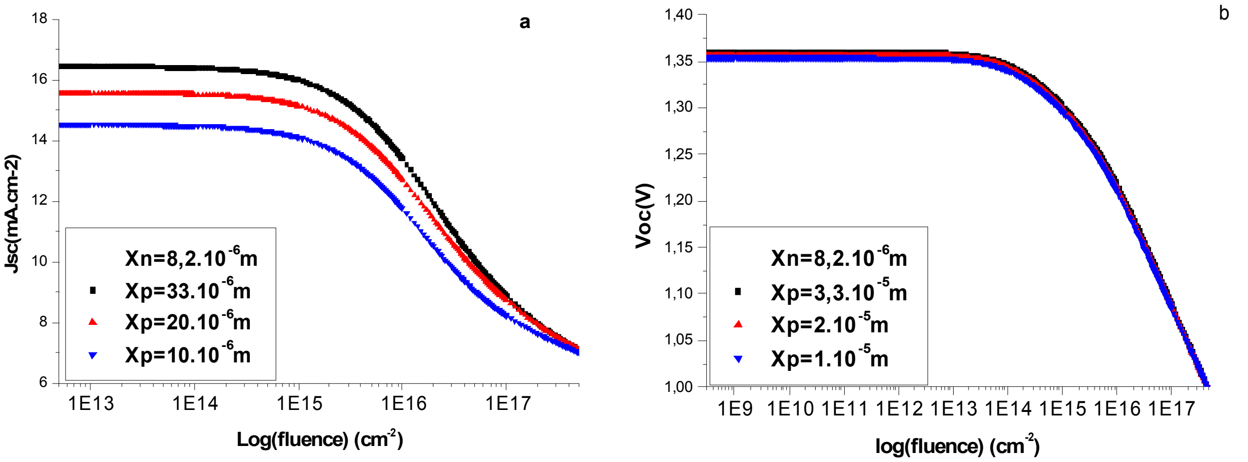


Fig. 2. *Variation (a) of the short circuit current, J_{sc}, and (b) of the open circuit voltage, V_{oc}, under 1 AM0 illumination, versus the fluence of 1MeV electron irradiation, calculated for different values, X_p, of base thickness*

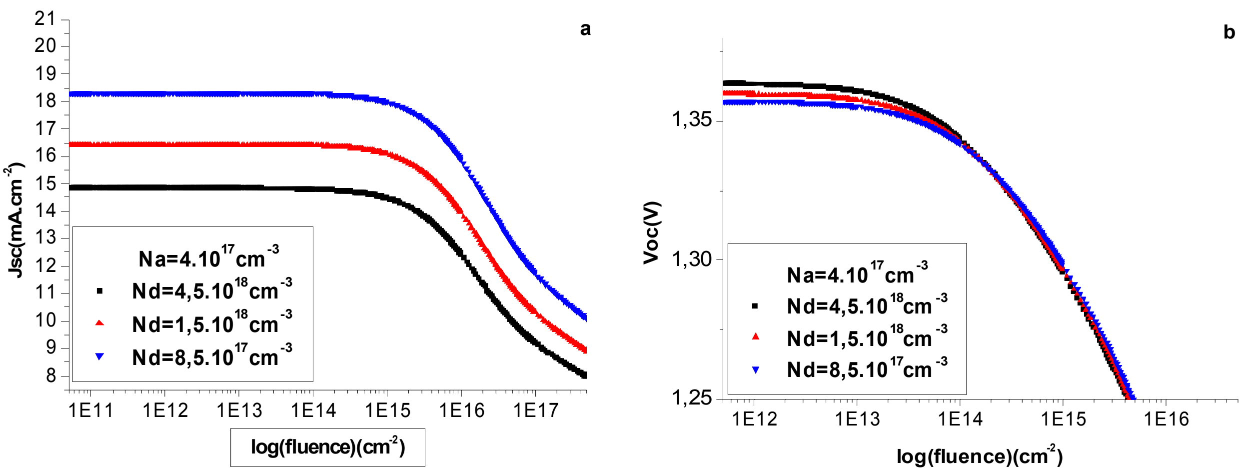


Fig. 3. *Variation (a) of the short circuit current, J_{sc}, and (b) of the open circuit voltage, V_{oc}, under 1 AM0 illumination, versus the fluence of 1 MeV electron irradiation, calculated for different values N_d of the emitter doping level*

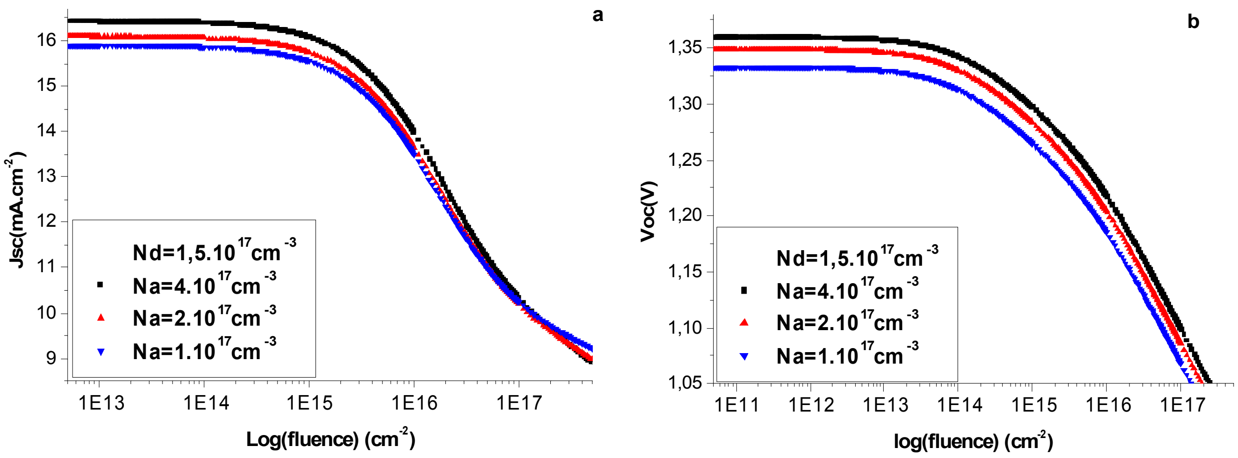


Fig. 4. *Variation (a) of the short circuit current, J_{sc}, and (b) of the open circuit voltage, V_{oc}, under 1 AM0 illumination, versus the fluence of 1 MeV electron irradiation, calculated for different values, N_a, of the base doping level*

The effect of the variation of the front surface recombination velocities

The Fig. 5 shows a not very significant effect of the front surface recombination velocities, S_p, on the characteristics J_{sc} and V_{oc} especially at low fluence of irradiation but at high fluence of irradiation, we can note a very significant effect of the S_p on the irradiation resistance of the J_{sc} and V_{oc} parameters, i.e., more the S_p decreases and more the J_{sc} and V_{oc} increase.

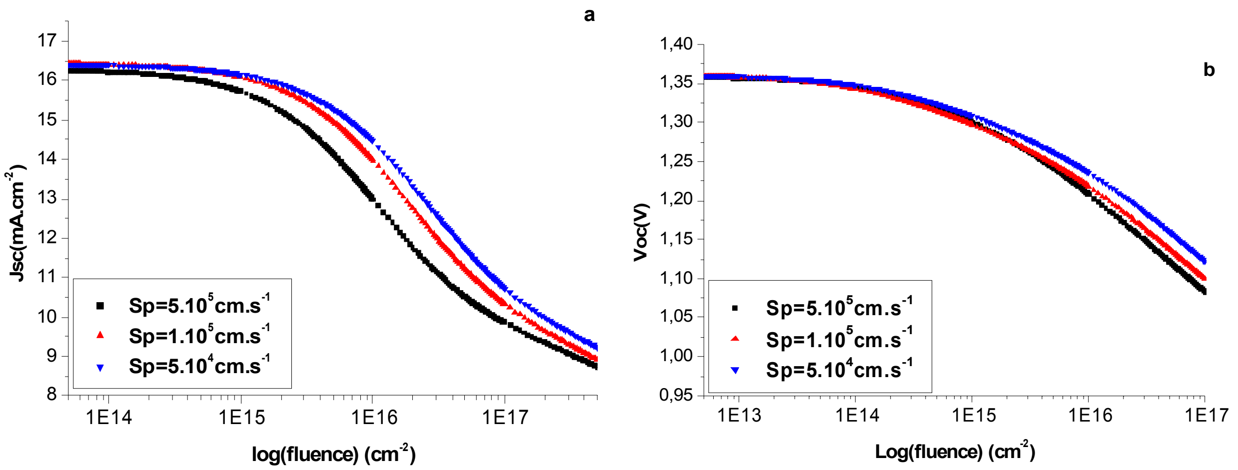


Fig. 5. *Variation (a) of the short circuit current, J_{sc}, and (b) of the open circuit voltage, V_{oc}, under 1 AM0 illumination, versus the fluence of 1MeV electron irradiation, calculated for different values, S_p, of front surface recombination velocities*

Conclusion

In this study, we have shown that the short circuit current, J_{sc}, is sensitive to variations of he emitter thickness, base thickness, emitter doping, base doping and the front surface recombination velocities.
At high irradiation of the $n+/p$ InGaP solar cell and when the level of doping of the donors, N_d, is large then that of the acceptors, N_a, is low, we note a resistance of the two characteristics J_{sc} and V_{oc} to the electron irradiations. Finally, the front surface recombination velocities, S_p, has a profound effect on the short circuit current, J_{sc}, especially at high fluence irradiation.

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