NEW APPROCH TO DETERMINE THE ACCURATE MINORITY CARRIER LIFETIME

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In the recent years, considerable research has been done on multijunction (MJ) solar cell. A monolithic MJ solar cell is composed of several junctions connected in series, all of which should be closely current matched for efficient photovoltaic device operation. The most successful implementation of this device is the InGaP/GaAs/Ge triple junction cell, attaining efficiencies in excess of 29 % AM0. The degradation of the cell characteristics under the high energy electron and proton irradiation depends on the semiconductor material and the specific solar cell structure. High energy particles lead to displacement damage and deep recombination centres reducing the minority carrier lifetime. In the present work, we present a new method, which allows to get exact value of the minority carrier lifetime and to apply this to p+/n InGaP solar cell material.

I.Introduction

Previous studies of the degradation of space solar cells have been based on experimental data acquired in space, completed by simulations made with accelerators. These technique consist in the calculating of the cell parameters, Isc, short circuit current; Voc, open circuit voltage, Pm, the maximum power for specific values of the minority carrier lifetimes τ_n and τ_p in the base and emitter, after these lifetimes have been determined versus the fluence of irradiation, φ [1].

The only difficulty lies in the determination of these lifetimes prior and after irradiation ($\tau_{0n,}$ τ_n) and ($\tau_{0p,}$ τ_p). Here, we proposed a method, justified theoretically and experimentally, allowing to deduce τ_{0n} versus τ_{0p} and τ_n versus τ_p and φ. Contrary to precedent proposed approach, which (τ_{0n}, τ_{0p}) and respectively (τ_n, τ_p) are determined separately [2]. The validity of this method is illustrated in the case of the degradation of the p+/n InGaP cells [3]. Finally a comparison of the two approaches would be studied.

II.Principle of calculation

We assume, for simplicity, no shadowing effect on the illuminated surface, i.e. the illuminated and unilluminated cell areas A, to be equal [4]. The open-circuit voltage is the voltage for which the current $I(V)$, furnished by the solar cell for voltage V, difference between the generated current, I_{ph}, and the dark current $I_{dark}(V)$ [5]

$$I(V) = I_{ph} - I_{dark}(V) \quad (1)$$

is zero, that is

$$I_{dark}(V_{oc}) = I_{ph}. \quad (2)$$

As to I_{ph}, it is the short-circuit current I_{sc} under illumination, assumed equal to the photocurrent

$$I_{sc} = I_{ph} \quad (3)$$

in such way that

$$I_{dark}(V_{oc}) = I_{sc}. \quad (4)$$

the quantities V_{OC} and I_{SC} are therefore calculated using well-known standard expressions, continuity equation and Poisson equation with boundary conditions, which can be found in text books [6].

The forward current in the dark $I_{dark}(V)$ of a junction is the sum of diffusion current $I_d(V)$ and of recombination current $I_{rec}(V)$

$$I_{dark}(V) = I_d(V) + I_{rec}(V) \quad (5)$$

$$I_{dark}(V) = I_{j1}\ [e^{\beta V} - 1] + I_{j2}\ [e^{\beta V/2} - 1] \quad (6)$$

where:

$$\beta = e/k_B.T; \quad (7)$$

the subscript *J* take the value 0 prior irradiation and 1,2,….after irradiation;

I_{j1} and I_{j2} are saturation currents of diffusion and recombination in the dark and given by the following expressions [7]

$$I_{j1} = A.\left[\frac{en_i^2\sqrt{D_n}}{N_A\sqrt{\tau_{jn}}} + \frac{en_i^2\sqrt{D_p}}{N_D\sqrt{\tau_{jp}}}\right] \quad (8)$$

$$I_{j2} = \frac{eAn_i w}{\sqrt{\tau_{jn}\tau_{jp}}} \quad (9)$$

In these expressions e is the electron charge, A is the area cell, n_i is the intrinsic carrier concentration, $D_{n,p}$ are the electron, hole diffusion coefficients at the absolute temperature T, $\tau_{jn,jp}$ are the minority carrier lifetime in the p, n regions, $N_{A,D}$ are the acceptor, donor doping on each side of the junction and W is the width of the space charge region.
From equations (4), (6), (8) and (9) we deduce the relationship between τ_{jn} and τ_{jp}

$$\tau_{jn} = \left[\frac{a_j.r_n.\sqrt{\tau_{jp}} + b_j}{I_{scj}.\sqrt{\tau_{jp}} - a_j r_p}\right]^2 \quad (10)$$

Where a_j ,b_j , r_n and r_p are given by:

$$a_j = A.e.n_i^2\left[\exp(\beta.V_{ocj}) - 1\right] \quad (11)$$

$$b_j = A.e.n_i.w.\left[\exp\frac{\beta.V_{ocj}}{2} - 1\right] \quad (12)$$

$$r_n = \frac{\sqrt{D_n}}{N_A} \quad (13)$$

$$r_p = \frac{\sqrt{D_p}}{N_D} \quad (14)$$

Recently, the fluence dependences of I_{SCj} and V_{OCj} could be calculated when the minority carrier lifetimes $\tau_{jn,jp}$ associated with the defects produced by the irradiation in the n and p regions of the cell and The value of $K\sigma$ determined experimentally by electroluminescence [8], are know. Then $\tau_{jn,jp}$ can be expressed as:

$$\frac{1}{\tau_j} = \frac{1}{\tau_0} + K\sigma\, v\varphi_j \quad (15)$$

where $K\sigma$ is product of the introduction rate of recombination centers, K, times their cross section, σ , for capturing a minority carrier and v is the carrier velocity.
Contrary to old method [2], the value of τ_{0p} is first adjusted to fit the value of I_{SCj} prior to irradiation, I_{SC0}, with the experimental value provided by the manufacturer, then we rewrite (10) with the fitted value τ_{0p} as:

$$\tau_{0n} = \left[\frac{a_0.r_n.\sqrt{\tau_{0p}} + b_0}{I_{sc0}.\sqrt{\tau_{0p}} - a_0.r_{0p}}\right]^2 \quad (16)$$

After the determination of τ_{0p} and τ_{0n}, before irradiation, then one injects them into the program. The $K\sigma_n$ and $K\sigma_p$ values would be determined, for a data of an amount of irradiation φ_j, while serving as the two expressions below:

$$\frac{1}{\tau_{jn}} = \frac{1}{\tau_0} + K\sigma_n v_n\varphi_j \quad (17)$$

$$\frac{1}{\tau_{jp}} = \frac{1}{\tau_0} + K\sigma_p v_p\varphi_j \quad (18)$$

(17)

Once these parameters are given with precision, we could predict the degradation of a cell for any amount of irradiation.

III. Degradation of InGaP cells.

The parameters of the studied cell are listed in table I below.
It is possible to calculate, and hence predict, the degradation of InGaP solar cell, when the thickness and doping respectively of the emitter and base are given.
The knowledge of J_{sc0} and V_{oc0} under given illumination, prior irradiation is also necessary in order to derive the minority carrier lifetimes 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_{sci} and V_{oci} under given illumination and amount of irradiation φ_j allow it to deduce the values of τ_{jn}, τ_{jp} and hence $k_{\sigma n}$, $k_{\sigma p}$. Previously some authors fits experimental data to the values normalized before irradiation [9,10]. In our case we calculate the absolute theoretical data as shown in Figures 1; 2; 3 where

the absolute experimental and the theoretical data of V_{oc}, J_{sc} and P_m.are represented.

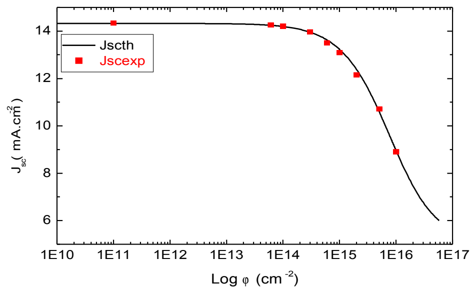

Figure 1: Variation of the short circuit current under 1 AMO illumination, versus the fluence of 1 MeV electron irradiation.

From the parameters τ_{on}, $k_{\sigma n}$ (emitter), and τ_{op}, $k_{\sigma p}$ (base) (see Table II) we derive the calculated values of V_{oc}, J_{sc} and P_m. These values extracted from our analysis are different of the values determinate by other authors [2] because before we don't take account of the dependence of two carriers lifetime τ_{on} and τ_{op}.

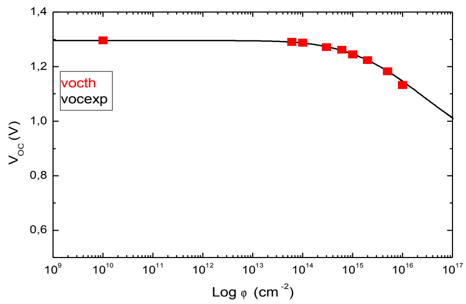

Figure 2 : Variation of the open circuit voltage versus the fluence of 1 MeV electron irradiation.

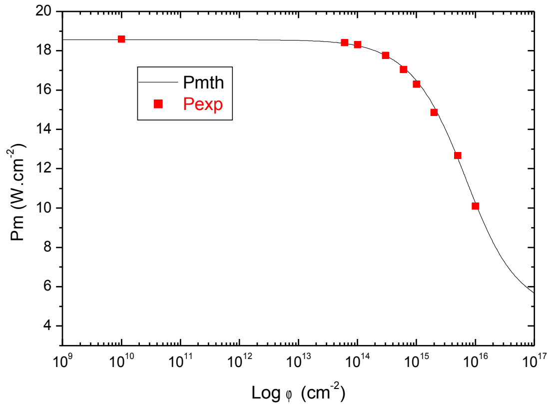

Figure 3: Variation of the maximum power versus the fluence of 1 MeV electron irradiation

IV. Conclusion

We have shown that it is possible to calculate, and hence predict, the degradation of InGaP solar cell, not only by the knowledge the thickness and doping of the emitter and base, but also by taking account of the dependence of two carriers lifetime τ_{on} and τ_{op}.

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InGaP(p+/n)	Emitter thickness ($1x10^{-6}$ m)	Base thickness ($1x10^{-6}$ m)	Emitter doping levels (cm^{-3})	Base doping levels (cm^{-3})	Surface recombination velocity ($cm.s^{-1}$)
Solar cells Parameters	0.2	1	$1x10^{16}$	$2x10^{18}$	$1x10^{6}$

***Table I**: parameters of InGaP solar cells*

Cell	τ_{on} (s^{-1})	τ_{op} (s^{-1})	$K\sigma_n$(cm^{-1})	$K\sigma_p$(cm^{-1})
InGaP	$2.2x10^{-12}$	$5.26x10^{-11}$	$2.9x10^{-12}$	$4.4x10^{-12}$

***Table II**: calculated parameters of InGaP cells*