The Influence of Radiation on the Solar Cell Efficiency

H.Šamić and S.Makham

Abstract—**The use of a solar cell in space requires the knowledge of its behavior under high-energy partial radiation. This radiation in space produces defects in semiconductor that cause a reduction in solar cell power output. In this paper we present the method for predicting the behavior of a solar cell for satellite applications. Modeling has been performed for several types of GaAs and GaInP single cells and results are compared with experimental data obtained for electron and proton irradiations.**

Index Terms—**Solar cells, GaAs, GaInP, degradation, radiation defects**

INTRODUCTION

AS worldwide energy demand increases, conventional energy resources will be exhausted in the not-too-distant future. Therefore, the solar cell is the major candidate for obtaining energy from sun, since it can provide nearly permanent power at low operating cost and almost free of pollution.

Solar cells at present furnish the most important long-duration power supply for satellites and space vehicles and have also been successfully employed in terrestrial applications.

The evaluation of solar cell degradation in space is very important now that multijonction (MJ) cells are used to fill the need for increasing power in satellites. Materials, mostly III-V semiconductors and many of their ternary alloys are used to produce multijonction cells. The study of solar cell degradation has been long standing for Si but is new for GaInP and other alloys. It is well known that the diffusion length(1) in Si and GaAs and the minority lifetime will increase as the temperature increases. The increase in minority-carrier diffusion length causes an increase in short-circuit current Jsc. However, open-circuit voltage V_{oc} will rapidly decrease because of the exponential dependence of the saturation current on temperature. For satellite and deep space missions, the knowledge of solar cells behavior under electron and proton irradiations present in space, and assessing the expected useful life of the space solar cell power plant is very important.

The high-energy particles introduce non-radiative recombination centers as result of the displacements of atoms induced by their collisions with these particles. The recombination centers (2) reduce the minority carrier lifetime and the collection of the electrons and holes generated by light absorption. This reduction causes the decrease of the short-circuit current J_{sc} , open-circuit voltage V_{oc} and finally maximum power P_m.

In this paper the degradation of GaAs and GaInP single solar cells, from the characteristic of the defects introduced by electron and proton irradiation is reported.

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RADIATION EFFECTS

The way to evaluate the degradation induced by given fluence φ of irradiation consists of computing the I-V characteristics of the cell using values of the minority lifetime τ in the emitter and base taking account the concentrations N of the non-radiative centers introduced by irradiation:

$$N = k\varphi \tag{1}$$

where k is introduction rate of the defects that act as recombination centers and

$$\frac{1}{\tau} = \frac{1}{\tau_0} + k v_{th} \varphi \sigma \tag{2}$$

τ_o is the value of the lifetime prior to irradiation called BOL (for beginning of life), v_{th} the thermal velocity of the carriers and σ the cross-section for minority carrier capture on the irradiation induced recombination centers. The photocurrent will decrease with decreasing diffusion lengths of carriers L. Since diffusion length is equal to $(D_\tau)^{1/2}$ it is important to determinate degradation parameters k and σ . The determination of the k and σ is complicated because several different defects (3) are usually created by irradiation. Until recently was used the concept of relative damage coefficient (RDC) or equivalent fluence (4-5). In order to reduce the number of irradiations tests, a RDC coefficient relates the fluence φ at a given energy E which produce the same degradation as fluence φ_0 at standard energy E_o. According this concept the degradations follows the empirical law:

$$\frac{P_m}{P_{m0}} = 1 - C\ln(1+\frac{\varphi}{\varphi_0}) \quad (3)$$

where $\frac{P_m}{P_{m0}}$ is normalized maximum power after irradiation, C and φ_0 are empirical constants, whose values are different for electron and proton irradiations and for each parameter (V_{oc}, I_{sc} and P_m) they are specific to given cell and given type of irradiation.

In this paper we used a new approach (6) based on equivalence between two particles, electron and proton. Systematic studies, combining measurements electroluminescence, time resolved photoluminescence (TRLP) and deep level transient spectroscopy (DLTS) performed on GaAs and GaInP junctions (7-8) gave as the concentrations and the introduction rates of the native and irradiation induced defects in each material.

We proposed that the degradation of one cell under the irradiation fluence φ_i and energy Ei is the same as the degradation under the irradiation fluence φ_j and energy E_j, if the nature and concentrations of non-radiative centers produced by irradiations is the same, that means $N_i = N_j$. This concept is valid (3) in the cases of GaAs and GaInP but not for Si cells, because the defects created by electrons and protons are the same, since they result directly from the transmission of energy to the primary knock-on atom and the displaced atoms are separated by an average large distance. Also, the natures and concentrations of the defects introduced by irradiation in these two materials do not depend on the nature and concentration of the impurities and native defects in materials. That means, if the introduction rates k and capture cross-section σ of recombination centers in Gas are known for 1MeV electrons, we could determine these parameters for the protons different energies.

Using SRIM program and already known values of introduction rate k=0,1cm^{-1} for GaAs cell under 1 MeV electrons and energy loss per particle $En_l = 1.4x10^2$ eVcm^{-1} we determined (9) the introduction rates k for recombination centers introduced by protons different energies. (Fig.1)

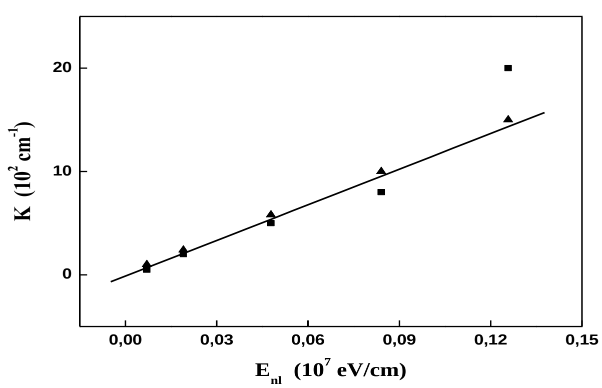

Fig. 1. Variation of the introduction rate of the recombination centers in the base (■) and in the emitter (▲) versus energy loss per proton for GaAs cell.

The same as for GaAs cell, we applied principle electron - proton equivalence on the GaInP cell using date for 1MeV electron published by NRL(10) for Enl (1MeV) =3,17x10^{-5} MeVcm^2/g and k ≈ 0.17 cm^{-1} (7) to obtained introduction rate of recombination centers introduced by protons irradiation (Fig.2)

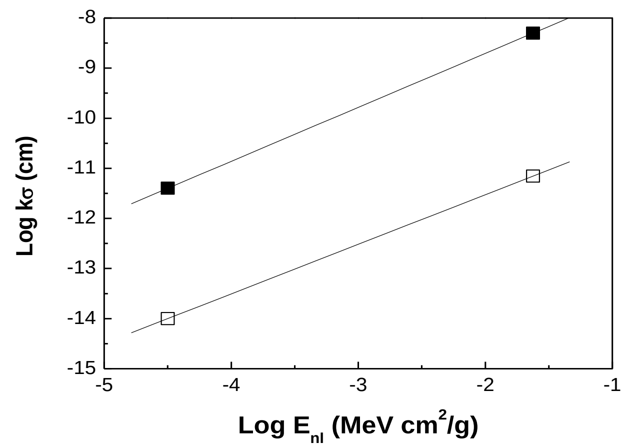

Fig.2.Variation of the degradation parameters $k_n\sigma_n$ (■) and $k_p\sigma_p$ (□) versus energy loss per electrons and protons in atomic collisions for GaInP cell NRL.

Once the k σ values are known for each material, it is possible to deduce the variations of V_{oc}, J_{sc} and P_m versus the fluence of irradiation.

MODELLIZATION OF THE DEGRADATION

Our modeling procedure consists to use the classical equations given in textbooks (11), describing the I-V characteristic of a solar cell under illumination. The short circuit current Jsc is sum of the three components, the photocurrents J generated in the emitter (e), the base (b) and the space charge region (z):

$$J_{SC} = J_e + J_z + J_b = J_{SC}(d_w, d_e, w, d_b, \phi, \alpha, \beta, S_e) \quad (4)$$

Where d_b, d_e and d_w are the thickness of the base, emitter and window, respectively, w is thickness of the depletion region, α and β are absorption coefficients of the cell material and of the window and S_e is recombination velocity at the emitter interface. The open circuit voltage V_{oc} is given by the following expression:

$$V_{oc} = \frac{2k_bT}{q}\ln\left(\frac{J_{sc}}{J_R}\right) \quad (5)$$

The recombination current $J_R(w,\varphi)$ contains three terms:

$$J_R(w,\varphi) = \frac{\pi}{2} n_i k_b T w \sqrt{\frac{1}{\tau_e \tau_b V_d^2}} + q n_i w\left(\frac{1}{\tau^*_{ob}} + \frac{1}{\tau^*_{oe}} + \frac{1}{\tau^*_b} + \frac{1}{\tau^*_e}\right) \quad (6)$$

where $\tau^*_{oe,b}$ and $\tau^*_{e,b}$ are the effective lifetimes of minority carriers in the emitter and base before and after irradiation, respectively.

The maximum power Pm is obtained through the derivative of the product VJ relative to V. The photocurrent J is difference between the short circuit current and the dark current.

$$J = J_{SC} - J_R \exp\left(\frac{eV}{2k_bT}\right) \tag{7}$$

The condition that corresponds to the maximum value V_m of the voltage $\frac{d(JV)}{dV} = 0$ gives:

$$V_m = 0.9V_{OC} - 0.49 \tag{8}$$

Once V_m is known, J_m is deduced using equation (7).

Finally maximum power Pm is directly derived from the product J_mV_m. Although most of the parameters involved in the above equations, namely d_b, d_e, d_w, N_e, N_b, α, β, $D_{e,\ b}$ and v_{th} are known, but the values of the parameters corresponding to the native and irradiation induced defects are not. The concentration N_t, energy level Et and capture cross-section σ of defects have been measured by DLTS [8,12] , the lifetimes have been measured by TRPL. When it comes to the quantitative evaluation of the degradation parameters for cell material the prediction of degradation can be made for any type of cell made of this material, modifying only the emitter and base thicknesses and doping concentrations.

RESULTS AND DISCUSSION

In this study we applied this method to single GaAs cells of different origins under 1MeV electron irradiation, taking into account the calculated values $\tau_{on} = 5\text{x}10^{-12}$ s, $\tau_{op} = 5\text{x}10^{-8}$ s for carrier lifetimes and the values $k\sigma_n = 1\text{x}10^{-12}$ cm and $k\sigma_p = 1\text{x}10^{-13}$ cm determined [8] experimentally by DLTS, the other values d_b, d_e, d_w, N_e, N_b were changed for each cell. The results of modellization are given on the (Fig.3)

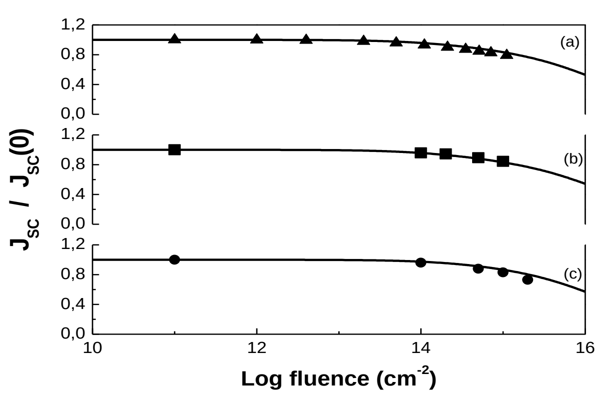

Fig. 3. Degradation of the short circuit current induced by 1 MeV electrons for EEV-Marconi(a), Tecstar(b) and CISE(c) GaAs cell and comparison with experimental data GaAs EEV-Marconi (▲),Tecstar(■) et CISE(●).

We can see when using the same degradation parameters, the same recombination velocity and the same characteristic of native defects in all cases is obtained good agreement between modeling and experimental data (Fig.4)

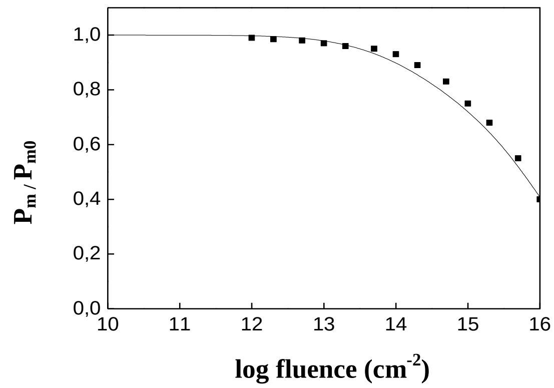

Fig4.Calculated degradation (full line) of the maximum power induced by 1 MeV electrons for NASA GaAs, and comparison with experimental data (■).

The same method was applied for GaAs cell irradiated by protons different energies and results (Fig.5) of modellization shows an excellent fit with experimental data.

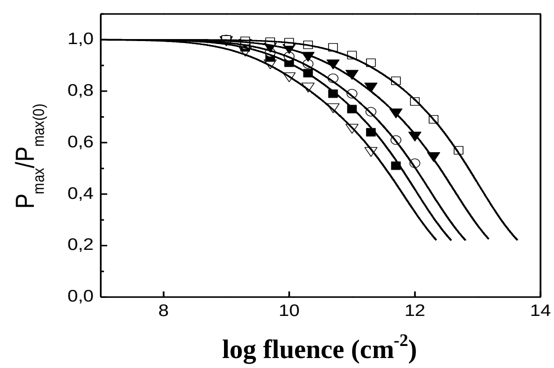

Fig. 5. Degradation (full line) of the maximum power of GaAs (ref.4) versus of the fluence φp of protons energies 300 (∇) keV, 500 (■) keV, 1(o) MeV, 3 (▼)MeV, 9.5 (□) MeV)

Until today, the defects introduced by irradiation in GaInP are not well known ,so in this case we applied the same procedure as for GaAs to calculate the degradation parameters $k\sigma_n = 4\text{x}10^{-12}$ cm , $k\sigma_p = 1\text{x}10^{-14}$ cm, and the carrier lifetimes $\tau on = 5\text{x}10^{-10}$ s, $\tau o_p = 1\text{x}10^{-9}$ s.

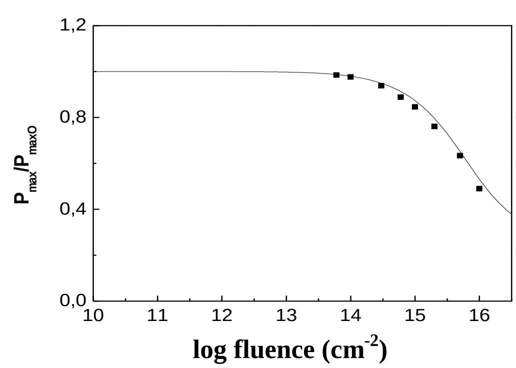

Fig. 6. Degradation (full line) of the maximum power induced by 1 MeV electrons for NRL GaInP cell and comparison with experimental data(■).

Using the same parameters and the principle of equivalence electron-proton we calculate degradation of maximum power for GaInP cell under 3 MeV protons irradiations.

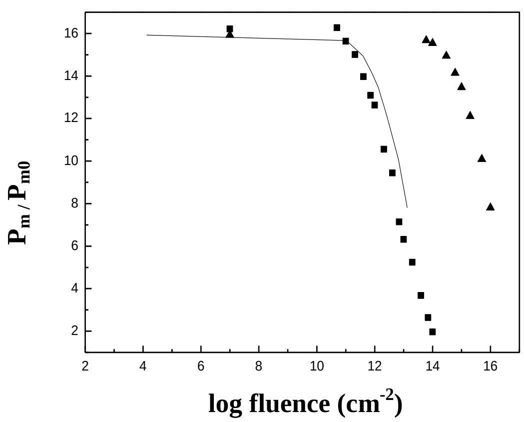

Fig.7. Variation of Pm (full line) for GaInP cell (ref.10) versus the fluence φp of protons energies 3 MeV calculated using the degradations curve of Pm under the 1MeV electron fluence φe (▲) and comparison with the experimental data (■).

Comparison between our results and experimental data shows an excellent fit is obtained in all cases.

CONCLUSION

In this paper, we presented an efficient modeling method to predict degradation of solar cells in space. Using the same degradation parameters we can account reduction of the solar cell efficiency for all types of cells produced of the same material GaAs or GaInP. The difficulty lies in the determination of the recombination velocities, minority carrier lifetimes, defect introduction rate and cross sections for minority carriers trapping on defects. Once these parameters are known for one material it is easy to predict behavior of any solar cell produced of the same material. This method can be extended on 2J and 3J solar cells(13) and also on modeling of degradation for any type of illumination spectrum and in the conditions of low temperature(14).

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