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Theoritical Modelization of Space Degradation of Multijunction Cells

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□ ABSTRACT □

The influence dependence of the short circuit and the open circuit voltage, induced by an irradiation, depends on a single parameter $\kappa\sigma$, product of the introduction rate of the defects responsible for non radiative recombination times their trapping cross section. This parameter, characteristic of a given material, can be determined experimentally, hence allowing the computation of the degradation for any type of cell or multi-junction cell. The validity of this procedure is demonstrated and illustrated in the case of the degradation of the short circuit current density of GaInP/GaAs (dual-junction) and GaInP/GaAs/Ge (triple-junction) cells.

We found that the order of the product $\kappa\sigma$ is 10^{-12} cm and 10^{-13}cm for GaAs sub-cell and GaInP sub-cell respectively .

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نمذجة نظرية لتلف الخلايا الشمسية متعددة الوصلات الثنائية والناتج عن استخداماتها الفضائية

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□ الملخّص □

إن التأثير المستحث بالتشعيع الإلكتروني على كل من كثافة تيار الدارة المقصورة وجهد الدارة المفتوحة، يتعلق بمتحول وحيد هو $K\sigma$ ، الذي يمثل جداء معدل تشكل العيوب المسؤولة عن مراكز إعادة الاتحاد غير المشعة في مقاطعها العرضية للاصطياد. هذا المتحول، الذي يميز خصائص مادة ما، يمكن أن يعين تجريبياً، وبالتالي يسمح لنا بحساب التلف لأي نوع من الخلايا الشمسية أو الخلايا الشمسية متعددة الوصلات. تم البرهان على صلاحية تطبيق هذه الطريقة من أجل حالة تلف كثافة تيار الدارة المقصورة للخلايا الشمسية من النوع GaInP/GaAs، GaInP/GaAs/Ge.

ونشير إلى أن قيمة الجداء $K\sigma$ التي وجدناها هي 10^{-12}cm و10^{-13}cm من أجل الخليتين الشمسيتين GaAs sub-cell وGaInP sub-cell على الترتيب .

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INTRODUCTION:

For years ago, modelling of solar cell degradation in space has been performed using a fully empirical method [1] developed by the Jet Propulsion Laboratory, based on data obtained from electron and proton irradiations at various energies, for each type of cell. A second method [2], proposed recently by the Naval Research Laboratory, is in essence equivalent [3]: it is based on data obtained for irradiations at only one energy and uses the fact that, to the first order, degradation is proportional to concentration of irradiation induced defects, i.e. to energy deposited by energetic particles in atomic displacements (the so-called NIEL, non ionizing energy loss). In practice, this second method reduces the number of empirical parameters, hence of irradiation tests. However, although reduced in number, these tests must still be performed for each particular type of cell.

The degradation of a cell depends directly on concentration *N* of defects which act as recombination centers, i.e. it is proportional to the product $N\sigma$ where σ is the capture cross-section for minority carriers, or equivalently to $\kappa\sigma$, where k is the introduction rate of these defects:

$$\kappa = \frac{N}{\varphi} \qquad (1)$$

Where φ is the irradiation fluency.

Hence, it is possible to calculate the degradation induced by a given fluency φ when the product $\kappa\sigma$ is known. This parameter being specific of a material, it applies to any type of cells made of a given material, i.e. remains valid whatever the geometry of the cell and the doping of the layers it contains. Because the dependence of κ versus the energy, E, of the irradiating particle can be calculated accurately, it is sufficient to determine experimentally $\kappa\sigma$ at one energy, in order to modelize the degradation for a full spectrum of energetic particles and for any type of cell.

The aim of this communication is to describe this method, explain how the degradation parameter $\kappa\sigma$ can be determined experimentally (by several independent techniques), demonstrate the validity of the method by comparing the degradation of two different GaAs/Ge cells by 1 MeV electron irradiation with the calculated modelization, and illustrate the result obtained for a GalnP/GaAs/Ge 2J cell.

PRINCIPLE OF METHOD:

We apply the theory developed in ref.4. This theory shows that, when few approximations are made in order to allow a full algebraic treatment, the degradations of the short circuit current, J_{sc}, and of the open circuit voltage, V_{oc}, are characterized by four degradation parameters, two intrinsic (ρ and η), and two defect dependent (ε and ξ), so that their fluency dependences can be written:

$$J_{sc} = \xi - \rho \log\varphi \qquad (2)$$

$$V_{oc} = \varepsilon - \mu \log\varphi \qquad (3)$$

The expressions of these parameters are given in ref.4. The degradation parameters ξ and ε allow to evaluate approximatively $\kappa\sigma$ by fitting expressions (2) or (3) with experimental data. The validity of the $\kappa\sigma$ value found in the case of GaAs and GaInP cells has been confirmed [5,6]using independent techniques of measurements (electroluminescence and the current- voltage characteristics in dark).

Here, we determine the four degradation parameters without the use of simplifying assumptions. This allows to determine accurate values of $\kappa\sigma$ by comparison with experiment. We limit the demonstration to the case of the short circuit current. For instance, with p^+/n GaAs cells, we obtained the following approximate value:

$\kappa\sigma \cong 10^{-14}$ cm [4] ,[7] in case of irradiation with 1 MeV electrons. Fitting (see Figs. 1 and 2) of the experimental data $J_{sc}(\varphi)$ with computation gives: $\kappa\sigma = 1.1\times10^{-14}$cm for a Tecstar cell and 2×10^{-14}cm for an EEV-Marconi cell, although their dimensions and doping are different.

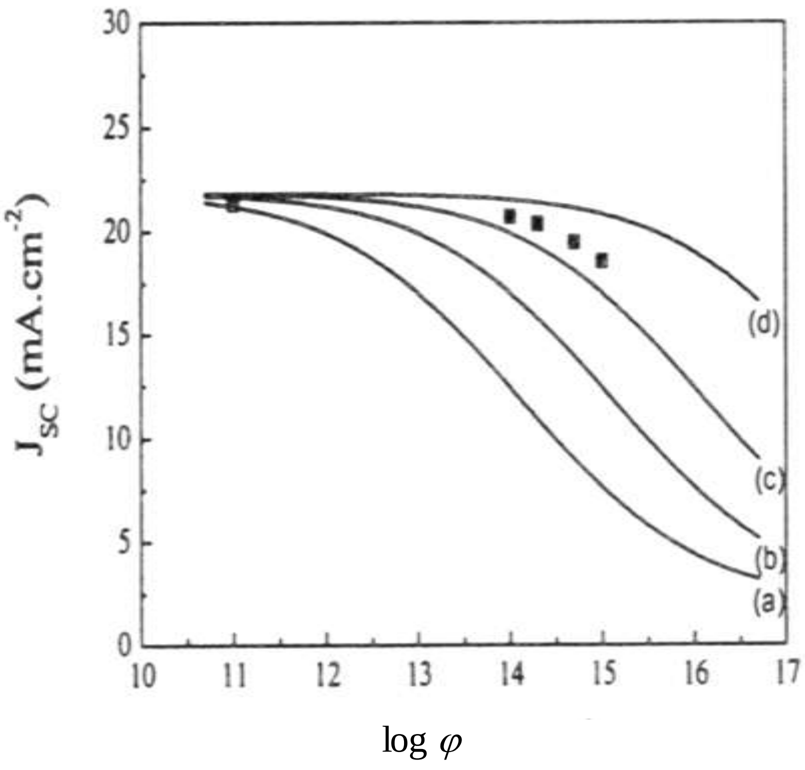

Fig. 1 Variation of the short circuit current under 1 AMO illumination, versus the fluency of 1 MeV electron irradiation, for a Tecstar cell, calculated for $\kappa\sigma$ (cm) values of 10^{-12}cm (a), 10^{-13}cm (b), 10^{-14}cm (c) and 10^{-15}cm (d). The experimental data shows that the fitting is obtained for a value of $\kappa\sigma$ close to 10^{-14}cm.

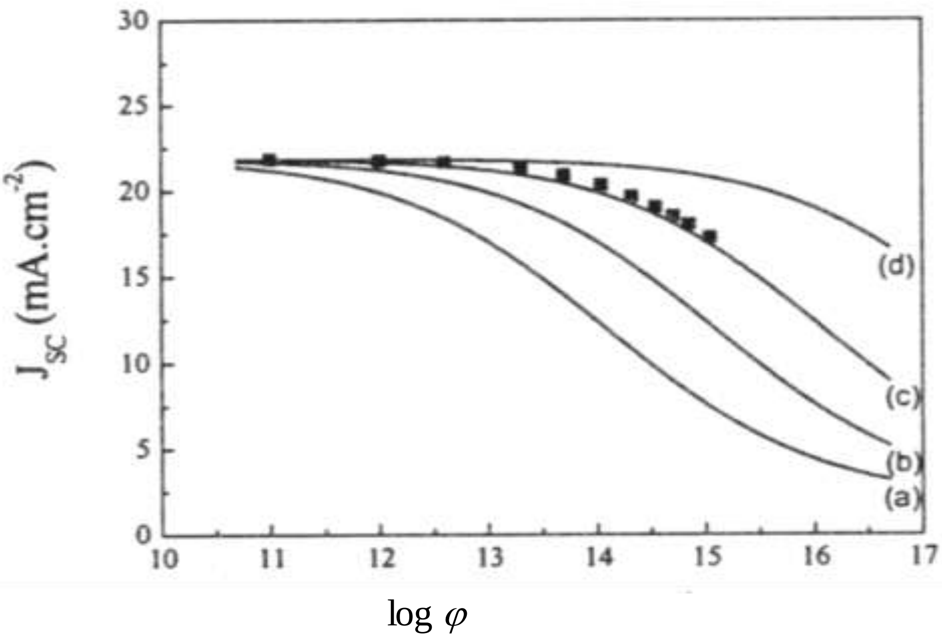

Fig.2 Variation of the short circuit current under 1 AMO illumination, versus the fluency of 1 MeV electron irradiation, for an EEV-Marconi cell, calculated for $\kappa\sigma$ (cm) values of 10^{-12}cm(a),10^{-13} cm (b), 10^{-14} cm (c) and 10^{-15} cm (d). The experimental data shows that the fitting is obtained for a value of $\kappa\sigma$ close to 10^{-14}cm.

In case of a multi-junction (MJ) cell, reconstruction of the degradation of the complete cell is made from the degradation of each individual sub-cell, calculated once the $\kappa\sigma$ values have been determined for each material composing the MJ cell. In this case, we assume that the interfaces between cells, i.e. the tunnel junctions are irradiation insensitive. This assumption is reasonable since the addition of defect states in the gap of a tunnel junction can only improve its performance.

MODELIZATION OF A MULTI-JUNCTION CELL:

We now illustrate the method using the case of GaInP/GaAs/Ge, GaInP/GaAs, cell irradiated with 1 MeV electrons. The variation of J_{sc} versus fluency has been determined for the corresponding sub-cells. The $\kappa\sigma$ values obtained by the fitting procedure are: $2.5\pm1.5\times10^{-12}$ cm, and $7\pm5\times10^{-12}$cm for the GaAs and GaInP sub-cells respectively,[4],[8] (see Figs. 3 and 4).

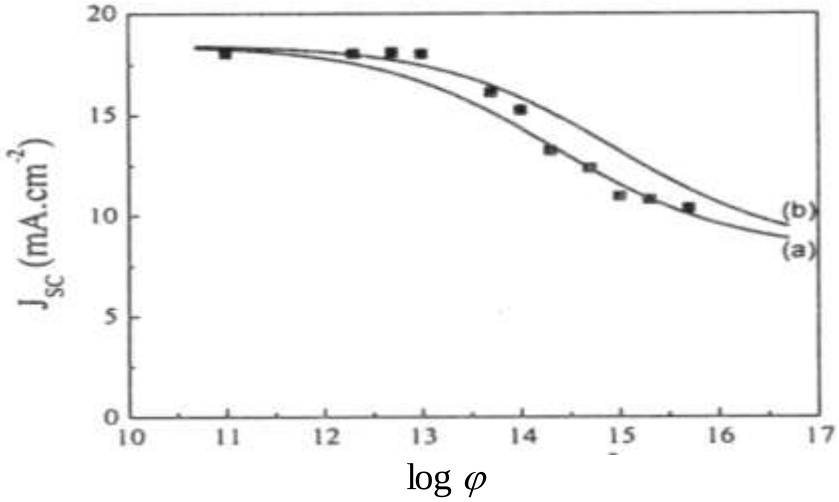

Fig. 3 Variation of the short circuit current under 1 AMO illumination, versus the fluency of 1 MeV electron irradiation, for an Emcore GaAs subcell calculated for $\kappa\sigma$ (cm) values of 4×10^{-12} cm (a) and 1×10^{-12} cm (b). The experimental data shows that the fitting is obtained for a value of $\kappa\sigma$ (cm) close to 10^{-12} cm. The reason this value is different from the one determined for a single cell is that σ has a different value in n and p materials.

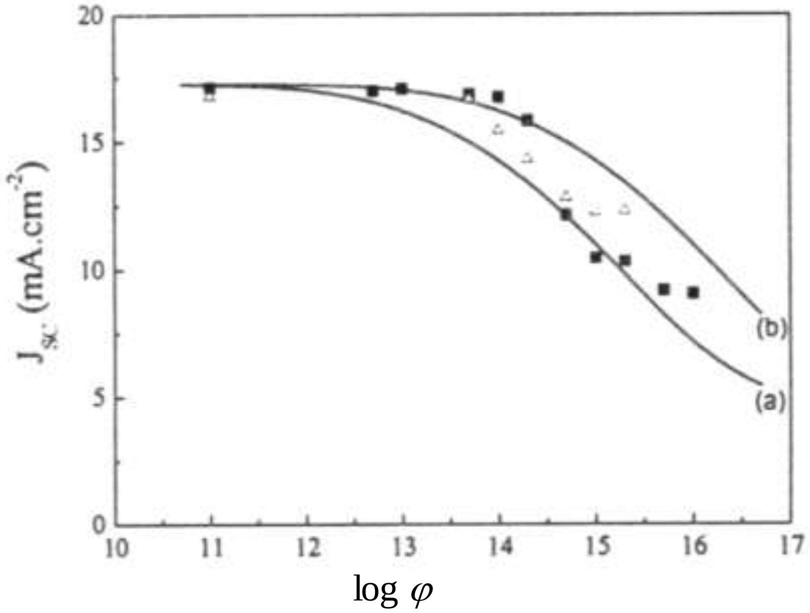

Fig. 4 Variation of the short circuit current under 1 AMO illumination, versus the fluency of 1 MeV electron irradiation, for an Emcore GaInP sub-cell calculated for $\kappa\sigma$ (cm) values of 1.7×10^{-13} cm (a) and 1.7×10^{-12} cm (b). The experimental data shows that the fitting is obtained for a value of $\kappa\sigma$ close` to 10^{-13} cm.

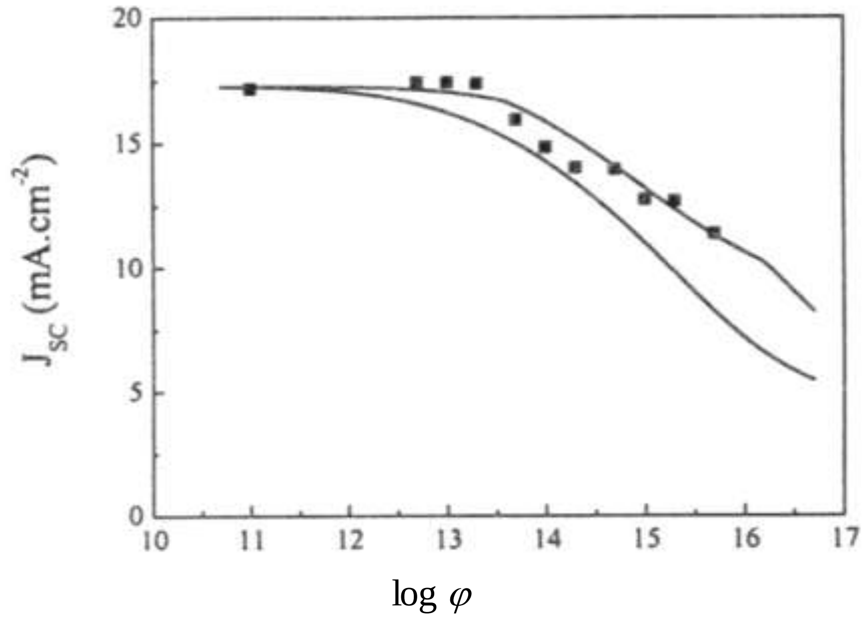

Fig. 5 Variation of the short circuit current under 1 AMO illumination, versus the fluency of 1 MeV electron irradiation, for an Emcore 2J cell. The experimental data shows that a good fitting is obtained for the $K\sigma$ values which have been determined for the two materials which compose the cell.

From the fluency dependences of J_{sc} for the GaAs and GaInP sub-cells, we construct that of the 2J cell, presented in Fig. 5. The result shows that J_{sc} is limited by that of the GaInP sub-cell for fluency lower than 10^{14}cm^{-2}. For higher fluences J_{sc} is a combination of the currents of the GaAs and GaInP sub-cells, as it is verified using spectral response measurements [6].

CONCLUSION:

We have shown that the degradation of single GaAs cells and 2J, GaInP/GaAs/Ge cells, induced by 1 MeV electron irradiation, can be quantitatively calculated without introducing any empirical parameter, when the product $K\sigma$, (defect introduction rate times their capture cross section for minority carriers) characterizing the defect which induce this degradation has been determined.

This product being characteristic of a given material, the degradation can be computed for any type of cell (different geometrical configurations, different doping concentrations, etc), including multi-junction cells since the interface between sub-cells is irradiation sensitive.

Modelization of the degradation induced by a given spectrum of energetic particles, protons and electrons, can and will therefore be calculated since the variations of the introduction rate *k*, proportional to the non ionizing energy losses, can easily be calculated versus the energy of these particles.

The experimental results have been made in the University Paris 6, LMDH, France.

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