Study of the Electrical Performance of n-GaAs sub-cells in InGaP/GaAs/Ge 3J Solar Cells under 1 MeV Electron Irradiation using Computer Simulation

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***Abstract*- A theoretical study of the electrical performance of p-on-n GaAs sub-cells under AM0, irradiated with 1 MeV electrons, has been carried out by means of computer simulation. Effects of both base and emitter carrier concentration upon radiation resistance of these devices have been researched. From analysis it is possible to determine the highest electron fluence to which the electrical parameters of the solar cell, with well-known base and emitter carrier concentrations, are reduced simultaneously in less than 20% from their non-irradiated values. Results presented in this paper are important in order to contribute to the design of radiation-hardened devices.**

I. Introduction

Devices in space are exposed to irradiation of high energy particles of the near-Earth space environment, consisting primarily of protons and/or electrons, which degrade the electrical performance of the devices [1]-[2]. Recently, monolithic multi-junction solar cells (MJSC) based on III–V technologies, particularly InGaP/GaAs/Ge triple-junction (3J), are the main power sources for spacecrafts since they have demonstrated higher conversion efficiencies and better radiation resistance compared to Si single crystalline and GaAs devices [3]-[5]. Previous studies have reported that the top InGaP and the bottom Ge sub-cells in the InGaP/GaAs/Ge 3J solar cell are subjected, at a lesser degree, to radiation degradation and consequently the radiation resistance is limited by that of the middle GaAs sub-cell [5]-[6]. Therefore, further research in GaAs sub-cells is still required with the aim of developing 3J space solar cells with improved radiation resistance.

In this work, the electrical performance of individual p-on-n GaAs sub-cells under 1 MeV electron irradiation has been analyzed by means of computer simulation. Effects of both base and emitter carrier concentration on the short-circuit current J_{SC}, open circuit voltage V_{OC}, maximum power point P_{MPP}, and fill factor FF, have been researched using radiative recombination lifetime, damage constant for minority-carrier lifetime and carrier removal rate [7]. The numerical simulations have been carried out by using the one-dimensional device modeling program PC-1D [8]. An analysis of the external quantum efficiency of the devices is shown in the full paper.

II. Simulation Setup

Numerical analysis of p-on-n GaAs structures with an area of 1 × 1 cm^2 has been performed in the optical device simulator PC-1D, for AM0 spectrum, 1 Sun conditions (0.1367 W cm^{-2}). The p-emitter (0.5 µm) was doped at levels 4 × 10^{17}, 8 × 10^{17} and 2 × 10^{18} cm^{-3}, and the n-base (3 µm) was contaminated at levels varied from 9 × 10^{15} to 2 × 10^{17} cm^{-3}. Gaussian doping profiles were considered in all cases.

III. Results And Discussion

A. Electrical parameters vs. Electron fluence

Results of the degradation in the J_{SC}, V_{OC}, P_{MPP}, and FF, after electron irradiation are shown in Fig. 1, for n-type GaAs sub-cells with a fixed emitter carrier concentration N_E = 4 × 10^{17} cm^{-3} and two different base carrier concentration: N_B = 9 × 10^{15} (filled symbols) and N_B = 2 × 10^{17} cm^{-3} (empty symbols). Values presented are normalized to the initial value obtained before irradiation.

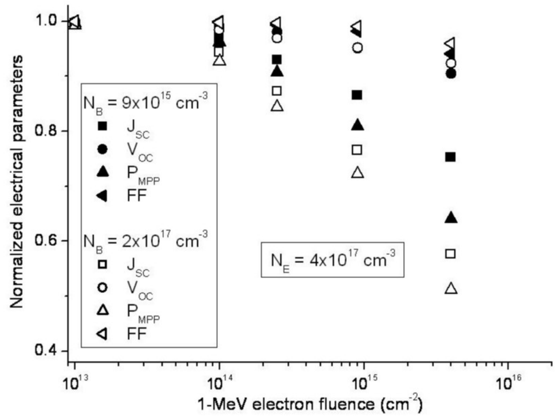


Fig. 1. Degradation of the electrical parameters of n-GaAs sub-cells exposed to electron irradiation.

It can be seen that for the two values of N_B, the most affected parameters due to the incident electrons are clearly J_{SC} and P_{MPP}. Also, in the range of studied constructive characteristics, the best radiation tolerance is found when the lowest N_B is considered. Similar results have been obtained from [9].

B. Solar cells with different resistivity

Fig. 2 shows the variation in the electrical parameters of the solar cell as a function of N_B, for two different N_E and for a given electron fluence of $\Phi = 4 \times 10^{15}$ cm^{-2}. Curves with filled symbols correspond to $N_E = 4 \times 10^{17}$ cm^{-3} whereas empty symbols correspond to $N_E = 2 \times 10^{18}$ cm^{-3}. The electrical parameters are normalized to corresponding values before irradiation. It can be seen that for J_{SC} and P_{MPP}, in the range of base carrier concentration under study, the best radiation tolerance is found when the lowest N_E is considered. Furthermore, in all cases, the magnitude most strongly affected by radiation is P_{MPP}, which is therefore the major design consideration of the electrical parameter in space solar cells.

C. Fluence limit Φ_{80}

A given solar cell, regardless of its structural characteristics, will have a satisfactory response to radiation for a specified time, during which it is possible to ensure that the electrical parameters of the device (J_{SC}, V_{OC}, P_{MPP} and FF) will be kept above 80% of their non-irradiated values. This operation time is related to electron fluence and energy. In previous work, 80% has also been chosen as the reference degradation level of P_{MPP} [6]. From an interpolation of curves similar to those presented in Fig. 1, for the entire range of N_B and N_E considered in this paper, the highest fluence has been calculated in order to prevent the $P_{MPP}(\Phi)/P_{MPP}(0)$ ratio from becoming lower than 0.8. This fluence has been named by the authors as Φ_{80} in [10]. Fig. 3 shows the overall results obtained for n-type GaAs sub-cells together with a first-order fit. From these results it can be determined the highest electron fluence to which the electrical parameters, with well-known N_B and N_E, are reduced simultaneously in less than 20% from their non-irradiated values.

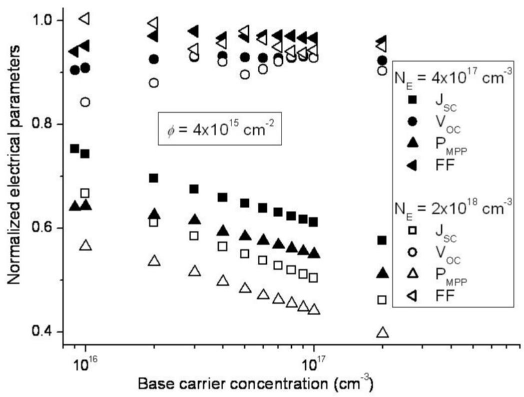
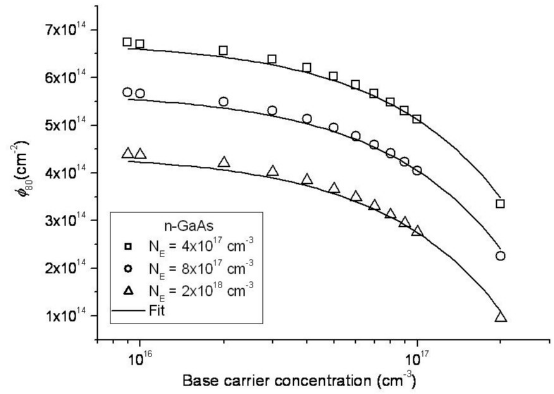


Fig. 2. Normalized electrical parameters against N_B at $\Phi = 4 \times 10^{15}$ cm^{-2}.



Fig, 3. Fluence limit $\square_{80}$ decay with increasing N_B and N_E from simulations (symbols) and fit (lines) for all studied n-GaAs sub-cells.

Additionally, the previous knowledge of the orbital location of the devices (altitude and inclination) together with the electron flux, would allow determining the maximum exposure time and the solar cell with the most suitable combination of N_B and N_E to enhance the radiation tolerance of the devices.

V. Conclusion

A computer numerical simulation tool has been used for fast and accurate study of the degradation in the electrical parameters of the n-type GaAs sub-cells in InGaP/GaAs/Ge 3J space solar cells. In particular, over 30 devices with different base and emitter carrier concentration have been analyzed, irradiated with 1 MeV electrons at fluences up to 4×10^{15} cm^{-2}. The results obtained show how radiation tolerance is a function of solar cell configuration. The maximum power point and the short-circuit current are clearly the most affected parameters due to the incident electrons. And the best performance (the highest P_{MPP}) is obtained when both the lowest base and the lowest emitter carrier concentrations are considered. Finally, the highest electron fluences have been found in order to prevent that the electrical parameters of the solar cell with well-known base and emitter carrier concentrations will be degraded less than 20% from their non-irradiated values.

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