

Solar Cell Degradation by Electron Irradiation Effect of Irradiation Fluence

H. Mazouz, A. Belghachi, F. Hadjaj

Abstract—Solar cells used in orbit are exposed to radiation environment mainly protons and high energy electrons. These particles degrade the output parameters of the solar cell. The aim of this work is to characterize the effects of electron irradiation fluence on the J (V) characteristic and output parameters of GaAs solar cell by numerical simulation. The results obtained demonstrate that the electron irradiation-induced degradation of performances of the cells concerns mainly the short circuit current

Keywords—GaAs solar cell, 1MeV electron irradiation, irradiation fluence.

I. INTRODUCTION

SPACE solar cells have been used as a power sources by satellites since 1954 [1], and played an important role in scientific research and space development applications. The objectives of research and development of space solar cells are to improve conversion efficiency, increase life time (radiation-resistance), reduce mass, cost of solar cell.

The influence of Earth's radiation belts on satellite solar cells is primarily determined by protons and high energy electrons (with the energy approximately 1MeV) [2]. GaAs solar cells are promising for space applications due to their higher theoretical and practical efficiencies [3], [4] (28.3%) [5] in comparison to silicon cells [6], [7]. An additional benefit is the fact that the GaAs solar cells are more resistant to the irradiation by energy electrons [7], [8].

The irradiation by high energy electrons introduces defects into solar cell structures. In semiconductors, radiation usually produces atomic displacements and as a result of atomic displacements, lattice defects such a vacancies, interstitials, and complex defects are generated [9]. Lattice defects that act as recombination centers or trapping centers cause a decrease in the output power of solar cells.

For space applications, the electrons irradiation fluencies ϕ vary between 10^{14} and 10^{17} e/cm² [2], [10]. The exposition of GaAs to this type of radiation generally produce three to four electron traps and one to four hole traps (Table I) [7], [10], depending on the electron fluencies and flux. Defects densities and the number of the traps increase with increasing electron fluency and flux [7].

The aim of this paper is to predict the degradation induced by high energy electrons on the photovoltaic parameters (short-circuit current, open-circuit voltage, fill factor and

efficiency) of space solar cells versus fluence.

II. NUMERICAL MODEL

In these work, numerical model is used as a mean of simulation mode of operation of a GaAs solar cell pin structure in the presence of trap levels. This modeling is based on the coupled resolution of the Poisson equation (1), the equations of continuity for electrons (2) and holes (3). Where the three dependent variables are: ψ the electrostatics potential, n and p respectively electron and hole concentrations.

$$-\nabla \cdot (\epsilon \cdot \nabla \psi) = q(p - n + N) \quad (1)$$

$$\frac{dn}{dx} = -q(G_{opt} - R_{SRH}) \quad (2)$$

$$\frac{dp}{dx} = q(G_{opt} - R_{SRH}) \quad (3)$$

R_{SRH} is the recombination rate given by the Shockley –Read –Hall. To model irradiation –induced defects, Shockley –Read –Hall recombination term is modified as follows

$$R_{RSRH} = \sum_1^n \frac{n \cdot p \cdot n_i^2}{\tau_p \cdot (n + n_t) + \tau_n \cdot (p + p_t)} \quad (4)$$

where τ_n and τ_p are electrons and holes life time. The life time varying versus the electrons irradiation fluencies ϕ as

$$\frac{1}{\tau} = \frac{1}{\tau_0} + \frac{1}{\tau_{rad}} + N_t \sigma v_{th} \quad (5)$$

where τ_0 is the native minority carrier lifetime, τ_{rad} is the radiative recombination rate, v_{th} is the carrier velocity and σ is the cross section for the capture of minority carrier by the non-radiative recombination center induced by the irradiation. The modeling of the degradation requires the knowledge of N_t (trap concentration) which associated the introduction rate k of the recombination centers and the fluency:

$$N_t = k \cdot \phi \quad (6)$$

The parameter k is the introduction rate of the non-radiative centers. It is not the total defect introduction rate: various defects are created by an irradiation and only a fraction of them behaves as recombination centers. This introduction rate depend on the material and the energy of the incident particle [11].

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TABLE I
CHARACTERISTICS OF ELECTRON AND HOLE TRAPS OBSERVED IN 1MEV
ELECTRON-IRRADIATED GAAS SOLAR CELLS

Fluency (e/cm ²)	Electron traps			Hole traps		
	Trap level (eV)	Capture cross section σ(cm ²)	Trap Concentration N _t (cm ⁻³)	Trap level (eV)	Capture cross section σ(cm ²)	Trap Concentration N _t (cm ⁻³)
10 ¹⁴	Ec-0.14	5.7 10 ⁻¹³	1.8 10 ¹³	Ev+0.71	4 10 ⁻¹³	3 10 ¹²
	Ec-0.41	2.6 10 ⁻¹³	8.2 10 ¹³			
	Ec-0.71	8.3 10 ⁻¹³	3 10 ¹⁰			
	Ec-0.90	3.5510 ⁻¹¹	8.8 10 ¹¹			
10 ¹⁵	Ec-0.41	2.6 10 ⁻¹³	2.1 10 ¹⁴	Ev+0.13	2.2 10 ⁻¹⁵	2.2 10 ¹⁴
	Ec-0.71	8.3 10 ⁻¹³	1.7 10 ¹³	Ev+0.29	2.6 10 ⁻¹³	4 10 ¹⁴
	Ec-0.90	3 10 ⁻¹¹	2.8 10 ¹⁵	Ev+0.35	6.4 10 ⁻¹⁵	8 10 ¹³
				Ev+0.71	4 10 ⁻¹³	6.4 10 ¹³
10 ¹⁶	Ec-0.41	2.6 10 ⁻¹³	8.8 10 ¹³	Ev+0.13	2.2 10 ⁻¹⁵	8.4 10 ¹⁴
	Ec-0.71	8.3 10 ⁻¹³	5 10 ¹³	Ev+0.29	2.6 10 ⁻¹³	1.6 10 ¹⁵
	Ec-0.90	3 10 ⁻¹¹	6.5 10 ¹³	Ev+0.35	6.4 10 ⁻¹⁵	1 10 ¹⁵
				Ev+0.71	4 10 ⁻¹³	2.7 10 ¹⁴

Our cell is exposed to the sunlight outside the atmosphere (AM0), so the generation of the free carriers is an optical generation G_{opt} :

$$G_{opt} = (1 - R) \cdot \alpha \cdot \exp(\alpha(-x)) \quad (7)$$

where R is the reflectivity of the front contact, $\alpha(\lambda)$ the absorption coefficient varies with the wavelength of incident light as [12]:

$$\alpha(\lambda) = K_{abs} \cdot \sqrt{\frac{1.24}{\lambda[um]} - Eg} \quad (8)$$

$$K_{abs}(GaAs) = 2.3 \cdot 10^4 \text{ cm}^{-1} \text{ eV}^{-1/2}$$

The solar cell used in this work, is an *pin* solar cell based on GaAs with 4.8μm, while the *P* type region is 0.2 μm. The parameters used in the numerical simulation are listed in Table II [13], [14].

TABLE II
SOLAR CELL PARAMETERS USED IN THIS WORK

Symbol	Value	Parameter
q	1.602e-19[C]	Elementary charge
T	300[K]	Room temperature
k	1.38e-23[J/K]	Boltzmann constant
Eg	1.43[eV]	Energy gap
ε _r	13.1	Rel. permittivity for GaAs
n _i	2e6[1/cm ³]	Intrinsic concentration for GaAs
μ _n	8800[cm ² /(V*s)]	Electron mobility for GaAs
μ _p	400[cm ² /(V*s)]	Hole mobility for GaAs
N _A	5e17[1/cm ³]	p layer doping density
N _D	5e18[1/cm ³]	n layer doping density
v _{thn}	4.4e7[cm/s]	Electron thermal velocity
v _{thp}	1.8e7[cm/s]	Hole thermal velocity
τ _n	0.1[us]	Electron life time
τ _p	0.1[us]	Hole life time
R	0.8	n/metal contact reflectivity

III. RESULTS AND DISCUSSION

The extracted J_{sc} , V_{co} , FF and η before irradiation are 38.95mA/cm²,0.980 V,0.891 and 24,840 respectively. There are fairly in agreement with standard values of GaAs [15], [16].

$J(V)$ characteristic prior to radiation and then after exposure to 1 MeV electrons at three fluence levels, 10¹⁴ e/cm², 10¹⁵ e/cm² and 10¹⁶e/cm², is shown in Fig. 1. The four most important characteristics of the GaAs solar cell based on the level of radiation are organized in Table III.

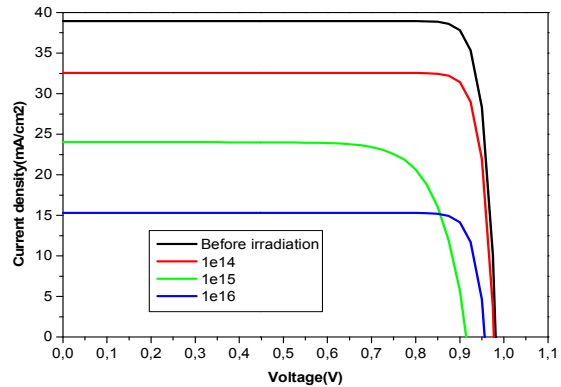


Fig. 1 I (V) characteristics as a function of fluence

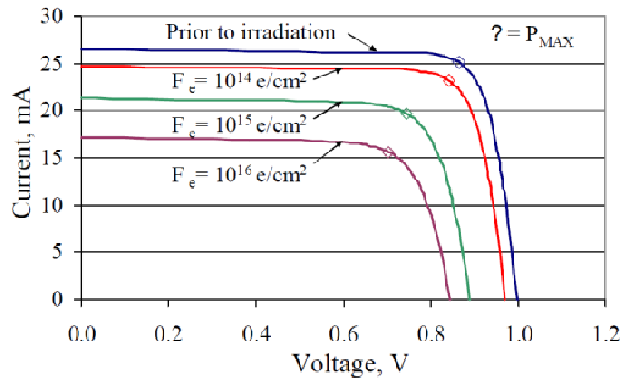


Fig. 2 I (V) characteristics as a function of fluence from [17]

TABLE III
SOLAR CELL CHARACTERISTICS

Fluence (e/cm ²)	Prior to irradiation	10 ¹⁴	10 ¹⁵	10 ¹⁶	
	Simulation	[14],[15]	Simul	Simul	Simul
J _{sc} (mA)	38.95	32.3/38.61	32.56	24.00	15.29
V _{co} (V)	0.98	1.05/1.011	0.97	0.95	0.91
FF	0.89	0.84/0.884	0.88	0.73	0.93
η%	24.84	21.1/25.51	20.64	12.35	9.54

These results are in agreement with the experimental results of Robert Y and all [18] and numerical results of Michael S [17].

It is clear that J_{sc} exhibits more sensitivity to high fluency. It decreases as the fluency of electron increase as we demonstrate in the Fig. 3.

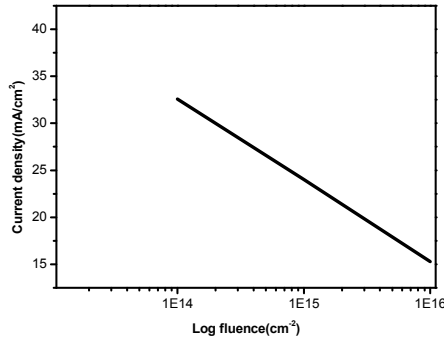


Fig. 3 Degradation induced by 1MeV electrons of the short current-circuit

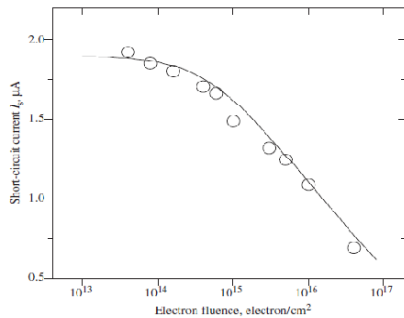


Fig. 4 The short-circuit current as a function of the irradiation fluence. Circles: experiment, solid line: simulation [19]

These results are in agreement with [19] as demonstrate Fig. 4, and other reference [20].

The degradation of $J(V)$ is due to the short-circuit current density J_{sc} . So we have to examine the dependence of J_D versus the fluence ϕ .

The short-circuit current density J_D is given by:

$$J_{sc} = q \int \frac{(\lambda)\alpha(\lambda)L}{1+\alpha(\lambda)L} \exp(-\alpha(\lambda)(d+w)) d\lambda \quad (9)$$

where W is the width of the space charge region. L is the diffusion length given by:

$$L = \sqrt{D \cdot \tau} \quad (10)$$

where D is the diffusion coefficient of the minority carriers and life time.

The effect induced by these irradiations on the electronic properties of a semiconductor material is to reduce the minority carrier lifetime τ .

Introducing notations 5 and 10 in (9) leads to:

$$J_{sc} = q \int \frac{(\lambda)\alpha(\lambda) \cdot \sqrt{\frac{D\tau_0\tau_{rad}}{\tau_0+\tau_{rad} + \tau_0\tau_{rad} N_t \sigma v_{th}}}}{1+\alpha(\lambda)L} \exp(-\alpha(\lambda)(d+w)) d\lambda \quad (11)$$

And by the introducing of the of traps concentration, we arrive at the result:

$$J_{sc} = q \int \frac{(\lambda)\alpha(\lambda) \cdot \sqrt{\frac{D\tau_0\tau_{rad}}{\tau_0+\tau_{rad} + \tau_0\tau_{rad} K\phi\sigma v_{th}}}}{1+\alpha(\lambda)L} \exp(-\alpha(\lambda)(d+w)) d\lambda \quad (12)$$

which shows that J_{sc} decreases with increase of ϕ .

IV. CONCLUSION

The radiation modeling methodology demonstrated in this work utilizes measurable trap data to predict the degradation in output parameters of pin GaAs solar cells. The simulation results show that the short circuit current is the most influenced by the electron irradiation. The agreement between experimental data and the calculated data demonstrates the validity of the method. The method will be extended to Si and GaInP cells.

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