Effect of solar cell structure on the radiation resistance of InP solar cell

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Abstract— **In this paper effects of electron irradiation-induced deep level defects have been studied on both n/p and p/n Indium phosphide solar cells with very thin emitters. The simulation results show that n/p structure offers a somewhat better short circuit current but that the p/n structure offers improved circuit voltage, not only before electron irradiation but also after 1MeV electron irradiation with 5.10^{15} fluence. The simulation shows also that n/p solar cell structure is more resistance than that of p/n structure.**

Keywords— **InP, solar cell, pn and np structure, electron irradiation, output parameters.**

I. INTRODUCTION

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Research into space solar cells has progressed rapidly over the past years. One of the fundamental objectives for developing space solar cells is to improve their high efficiency and radiation resistance. GaAs cells have shown more promise than Si cells for space applications [1, 2]. But recently, there have been reports about the radiation tolerance of InP being even better than GaAs and Si [1, 3, 4]. Also it has several advantages over Si and GaAs including high-efficiency, thin-film structure, high-temperature operation and simple cell structure.

InP solar cells are promising materials for high-efficiency space solar cells. Recently, high conversion efficiencies exceeding 29.2% (at 25c°, AM0) have been achieved with InP solar cells [5], and they have the possibility of high conversion efficiency of over 30%.

The focus of development efforts with InP cells has been on the n/p structure under AM0 conditions and little has been reported on the performance of p/n structure [6, 7, 8, 9]. Table 1 summarizes the designs, emitter and base parameters and performances of reported InP solar cells in space conditions (AM0, $135Mw/cm^2$, 25c°).As can be seen, Sharps and al [10] n/p solar cell have better Voc and Jsc as compared to the p/n one. But, Jain and al p/n solar cell [9] achieve higher efficiency in comparison with n/p solar cell, due to higher open circuit voltage (Voc) even though the short circuit current density (Jsc) is somewhat lower as compared to n/p structure.

TABLE I

DESIGNS AND PERFORMANCES OF REPORTED INP SOLAR CELL [8, 9, 10]

Group	**Vilela and al**	**Sharps and al**		**Jain and al**	
Design	pn	np	pn	np	pn
Emitter doping(cm^{-3})	2.10^{18}	5.1016		1.10^{18}	
Emitter thickness(um)	0.08	0.05		0.02	0.15
Base doping (cm^{-3})	5.10^{17}	5.1016		1.10^{17}	
Base thickness(um)	1.5	3		5	
Jph(mA/cm^2)	21.5	28.87	28.68	42.37	41.49
Vco(V)	0.803	0.848	0.814	0.941	0.997
FF	0.77	0.779	0.814	0.863	0.869
η %	10.5	14.1	13.9	25.1	26.2

In addition, it has been demonstrated that InP solar cells exhibit relatively low levels of performance degradation for both proton and electron irradiation [1, 5].

1MeV electron irradiation produce ,for p-type InP, six hole traps and five electron traps, while for n-type 16 electron and five hole traps are produced[11,12]. Instead we concentrate our attention on those traps which are dominant and for which a specific atomic structure has been proposed. That H2, H3, H4 ,H5 and E11 are due to phosphorus atom-electron collisions [11]. Trap level, capture cross section, and introduction rate of the five electron and hole traps are shown in table 2.

TABLE II
ELECTRON AND HOLE TRAPS OBSERVED BY DLTS IN ELECTRON IRRADIATED INP [11, 12]

Trap Designation		Trap level (eV)	Capture cross section σ(cm^2)	Introduction rate(cm^{-1})
p-type	H2	0.22	3 10^{-17}	0.02
	H3	0.32	6 10^{-16}	0.82
	H4	0.37	8 10^{-16}	1.2
	H5	0.52	5.5 10^{-15}	0.04
n-type	Ell	0.76	2.9 10^{-12}	0.2

Since InP solar cells are promising for space applications, the objective of this paper is twofold: (1) compare the expected performance of np and pn indium phosphide solar cells under space conditions, and (2) model the effects of 1MeV electron irradiation on InP solar cells.

II. NUMERICAL MODEL

Modeling and simulation of InP solar cells has been performed using a numerical model. The modeling is based on the coupled resolution of the Poisson equation (1), the equations of continuity for electrons (2) and holes (3) by a finite-element method .Where the three dependent variables are: ψ the electrostatics potential, n and p respectively electron and hole concentrations.

$$-\nabla.(\varepsilon.\nabla\psi) = q(p - n + N) \tag{1}$$

$$\frac{dJ_n}{dx} = -q(G_{opt} - R) \tag{2}$$

$$\frac{dJ_p}{dx} = q(G_{opt} - R) \tag{3}$$

In equations 2 and 3, R describes non-radiative recombination mechanisms such as Schockley-Read-Hall, Auger and surface recombination.

Our cell is exposed to the sunlight outside the atmosphere (AM0). AM0 corresponds to the integral power 1.35 KW/m2 and is the characteristic of sun radiation level before sun light passes through the Earth atmosphere. So the generation of the free carriers is an optical generation G_{opt}:

$$G_{opt} = (1 - R).\alpha.\phi\exp(\alpha(-x)) \tag{4}$$

Where R is the reflectivity of the front contact and α (λ) the absorption coefficient.

The materials parameters listed in Table.3 [13, 14] were used in the numerical simulation.

TABLE III
INP MATERIALS PARAMETERS USED FOR MODELING

Parameter	Symbol	Value
Elementary charge	q	1.602 10^{-19} [C]
Room temperature	T	300 [K]
Boltzmann constant	k	1.38 10^{-23}[J/K]
Gap energy	Eg	1.35[eV]
Rel. permittivity	εr	12.6
Intrinsic concentration	ni	1.2 10^{7} [cm^{-3}]
Effective density of state in conduction band	Nc	5.7 10^{17} [cm^{-3}]
Effective density of state in valence band	Nv	1.1 10^{19} [cm^{-3}]
Electron mobility	µn	5900 [cm^2/Vs]
Hole mobility	µp	150 [cm^2/Vs]
Electron thermal velocity	Vthn	3.9 10^{5} [m/s]
Hole thermal velocity	Vthp	1.7 10^{5} [m/s]
Electron life time	τn	0.73 [ns]
Hole life time	τp	151.5 [ns]
Radiative recombination coefficient	τrad	1.2·10^{-10} [cm^3/s]
Surface recombination coefficient	τs	9·10^{-31} [cm6/s]

The material and cell process parameters for the design of np structure are described in Table 4 and are same for the pn configuration except back SRV (l0^{7} cm/sec), emitter diffusion length (2um) and base diffusion length (5um).

TABLE IV
EMITTER AND BASE MATERIAL/PROCESS PARAMETERS FOR THE OPTIMAL DESIGN OF NP INP SOLAR.

Parameters	Emitter	Base
Thickness(um)	0.08	5
Doping(cm-3)	5 10^{17}	10 ^{18}
Front Sur. Rec. Vel(cm/s)	10 4	-
Back Sur. Rec. Vel (cm/s)	-	10^{5}
Electron Diffusion Length(um)	0.1	-
Hole Diffusion Length(um)	-	20

Values listed in table 4 are reported from literature [3, 15,16].

III. RESULTS AND DISCUSSIONS

The computer program was used to model the effect of 1MeV electron irradiation at 5.10^{15} electron fluence on InP solar cells. Figure 1 shows the comparison of the calculated J(V) characteristics for the np before and after electron irradiation .Fig 2 shows the comparison of the calculated J(V) characteristics for the pn before and after electron irradiation 1MeV electron irradiation.

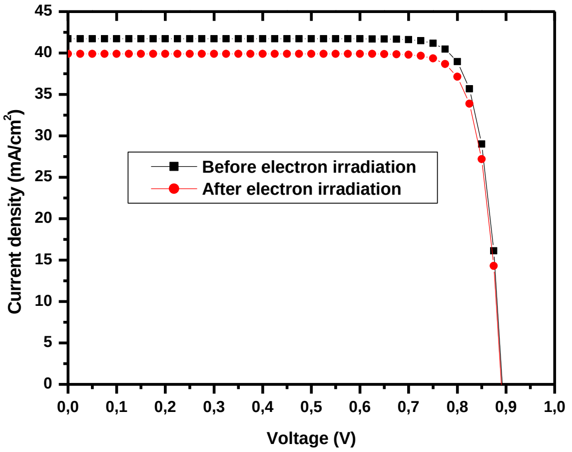

Fig.1 J (V) Characteristic of np solar cell structure before and after 1MeV electron irradiation

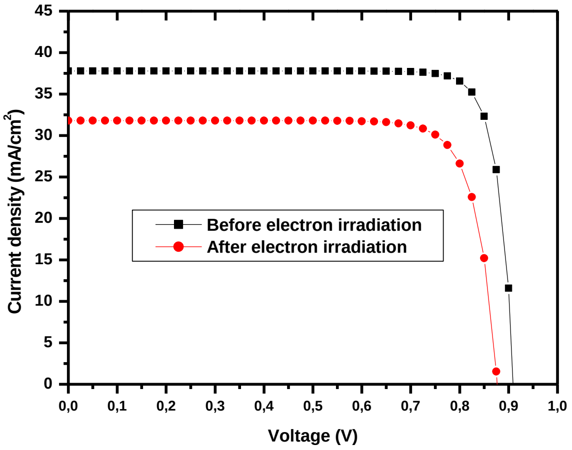

Fig 2. J (V) characteristic of pn solar cell structure before and after 1MeV electron irradiation

Table 5 describes the various cell performance parameters of the two solar cell structures np and pn before and after 1MeV electron irradiation at 5.10^{15} electron fluence.

TABLE V

Output parameters	np		pn	
	Before	After	Before	After
Jsc (mA/cm^2)	41.71	39.89	37.78	31.79
Voc (V)	0.891	0.888	0.907	0.875
FF	0.844	0.845	0.853	0.811
η%	23.24	22.19	21.66	16.73

CELL PERFORMANCE PARAMETERS BEFORE AND AFTER ELECTRON IRRADIATION

From Table 5 it is clear that, before irradiation, np solar cell structure achieve higher efficiencies compared to pn structure, due to the higher short circuit current density (Jsc) even though the short circuit current density (Jsc) is somewhat lower as compared to pn structure. Realization of high efficiency InP solar cells would help in reducing the area and mass of the solar array required to be deployed for space power applications.

It was found that the solar cell efficiencies at the degraded state for np and pn structure are 4.36% and 15.85% respectively. The effect on the other parameters is quite different. Jsc is more affected by electron irradiation in pn structure than np structure. It decreases from 41.71 to 37.78 mA/cm^2 in np structure, and from 39.89 to 31.79 mA/cm2 in pn structure. However, Voc is not affected in the np solar cell structure and it is a bit more affected in the pn one (it decreases from 0.907 to 0.875 V).

For comparison, in fig. 3 we have plotted the J (V) characteristic for np and pn solar cell structure .It is observed that the np solar cell structure is more radiation resistance at 5 10^{15} electron fluence than pn solar cell structure. Obtained results are in agreement with Ref. [9, 17].

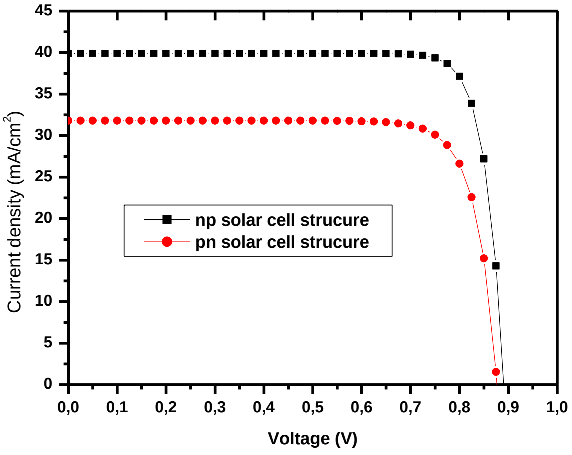

Fig 3. Comparison of the J (V) characteristic of np and pn InP solar cell structures.

A possible explanation of these differences may be due to the type and depth in the energy gap of the defects created by irradiation each solar cell structure. In the np solar cell structure, the n-InP type is the emitter, electron irradiation creates just one electron trap in this type, and it can be regarded as doping levels. For the pn structure, the p-InP type is the emitter, electron irradiation creates four hole traps trap in this type, these traps are considered as recombination centers and they are responsible of the serious degradation of Jsc and they may increase the barrier potential at the pn interface. It is well known that the open circuit voltage of a solar cell is related to the barrier built-in voltage. Hence the increase in the barrier will compensate the reduction of Voc by electron irradiation.

IV. CONCLUSION

Numerical simulation was used to compare the radiation resistance of np and pn solar cell structure. It was found that the optimum np solar cell structure was more efficient than the optimum pn solar cell structure due to a larger short current density which is in agreement with [9]. np and pn structure have nearly the same electron irradiation effect on the short current density. Present solar cell modeling predicts that not only the np InP solar cell structure is more efficient than the pn, but also it is more radiation resistance.

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