Radiation Hardness n^+-i-p^+ InP Solar Cell and Its Computer Simulation

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1. INTRODUCTION

InP solar cells have long been demonstrated to degrade less under irradiation than GaAs and Si (Yamamoto *et al*., 1984; Itoh *et al*., 1985; Yamaguchi and Ando, 1988; Weinberg *et al*., 1987). Preliminary studies on InP solar cells confirmed that room-temperature annealing and minority-carrier injection-enhanced annealing are responsible for the recovery of photovoltaic properties of degraded cells (Yamaguchi and Ando, 1988). These hint that InP solar cells have broad prospects for space applications.

In the past years, several structures of InP solar cells had been developed (Hoffman *et al.*, 1996). To further improve photovoltaic performance of InP solar cells with much higher radiation resistance, conversion efficiency and power/weight ratio, an n^+-i-p^+ sandwich-like structure InP solar cell is developed in this paper. For space applications, since the launching cost is very high, power/weight ratio of solar cells is a very important factor to be concerned. Moreover, higher EOL(end of life) efficiencies of solar cells are anticipated for space applications for it makes spacecrafts have longer lifetimes. Many structures which are now being used in satellites, *e.g.* GaAs and Si solar cells, may have high BOL (begin of life) efficiencies, but their EOL (end of life) efficiencies are too low. Current radiation-hard materials such as GaAs and InP exhibit significant degradation after only 10^{15} 1MeV electrons/cm^2. While this exposure corresponds to about 10 years at a 700km polar orbit, it is only a few days at a 3200km polar orbit. The alternative approach is based upon a structure that permits the use of material of much lower electrical quality while still attaining high efficiency operation. This structure can then be optimized for the low quality material expected after much radiation degradation. This means that the photovoltaic device efficiency will be relatively insensitive to radiation exposure until much more massive material degradation has occurred than has been previously possible. In addition, It can be expected to use the same structure to make a polycrystalline thin film version at very low cost. Furthermore, the same structure can be used with other materials as improved radiation hardened materials are developed.

2.STRUCTURE OF THE CELL

Fig.1 shows the sketch of the cell. Both of n^{+}-InP layer and p^{+}-InP layer are 0.01 μm in thickness and the doping levels of these two layers are all as high as 10^{20} cm^{-3}. The superior radiation resistance of InP strongly depends upon the carrier concentration of the cell active layer. The InP cell with higher carrier concentration substrate is more radiation resistant. The thickness of the i-layer decides the depletion width and there exists an optimum value at which the power/weight ratio of the cell is the highest. In this work, the thickness of the i-layer is taken from 0 to 1 μm for the calculation. The total thickness of the epitaxial layer is only 0.22 μm. The introduce of the i-layer is for obtaining a wider depletion region, so that a larger minority-carrier diffusion length can be obtained.

The change of short-circuit current density J_{sc} and open-circuit voltage V_{oc} of the cells as the diffusion length is in accordance with

$$J_{sc}=qgL \qquad (1)$$

$$V_{oc}=(nkt/q)ln(J_{sc}/J_0+1) \qquad (2)$$

where q is the electronic charge, g is the generation rate of electron-hole pair due to the photon, L is the minority-carrier diffusion length, n is the diode ideality factor, k is the Boltzmann constant, J_0 is the diode saturation current density. Since the efficiency of solar cells is as

$$\eta=P_m/P_{in} \qquad (3)$$

where $P_m=ff*V_{oc}*I_{sc}$ is the maximum power output of the cell and P_{in} is the incident power. The increasing of V_{oc} and I_{sc} will tremendously increase the conversion efficiencies.

3. RESULTS AND THEIR COMPARISON WITH SOME OTHER SYSTEMS

Solar cells used for spacecrafts are required as small efficiency difference as possible between BOF(begin of life) and EOL(end of life). Fig.2 shows the comparison of relative efficiencies of Si, GaAs and n^+-i-p^+ InP with the structure of Fig.1. It is clear that the decline of n^+-i-p^+ InP structure with the exposure to radiation is much slow. Fig.3 shows comparison of this work with high efficiency tandem solar cell (Brown *et al.*, 1997), InP/Si structure (Wojtczuk *et al.*, 1997) and normal InP solar cells. The slope of n^+-i-p^+ InP cell is always better even after exposures to radiation as high as 10^{18} 1MeV electrons/cm^2.

Since the launch of spacecrafts is very costly, power/weight ratio is one of the most important factors of solar cells in space applications. Some solar cell systems have high conversion efficiency, but do not have high power/weight ratio. Fig.4 gives the comparison of power output between GaAs and normal InP cells (Wojtczuk, *et al.*, 1994). It indicates that even for normal InP cells, they loss only 25% of their power output while GaAs cells loss 100% . Fig.5 is the computer simulation of AM0 efficiency of n^+-i-p^+ InP structure. It can be seen that with the increase of the thickness of the i-layer, the efficiency goes up. This comes from the increase of the depletion width. The highest efficiency point is around 2 μm with the efficiency of 24.5%, and then the curve goes down. However, as shown in Fig.6, the thickness of the i-layer with highest power/weight ratio is between 0.1 μm~0.2 μm and the ratio is as high as 130W/g (only the epitaxial layers were considered when the weight was calculated).

5. CONCLUSIONS

It can be concluded from the discussion above that the n^+-i-p^+ InP structure has the character of extreme radiation hardness. A nearly 10% AM0 efficiency can be obtained even after exposure to radiation of 10^{18} 1MeV electrons/cm^2. This results in a more flat efficiency-exposure curve. And it has as high power/weight ratio as 130W/g (the weight of epitaxial layers was considered only). It is surprising that all of these are obtained with the very simple structure shown in Fig.1.

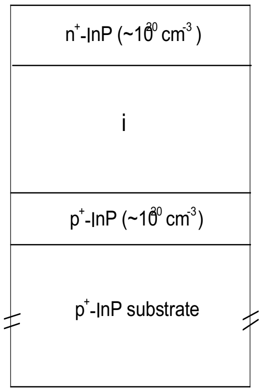

Fig.1 Sketch of the n+-i-p+ InP solar cell

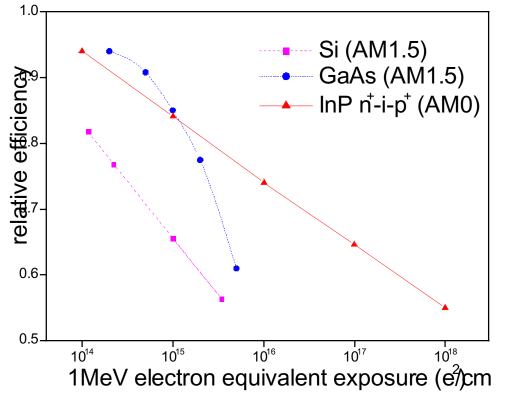

Fig.2 The comparison of relative efficiency of Si, GaA
and n+-i-p+ InP solar cells

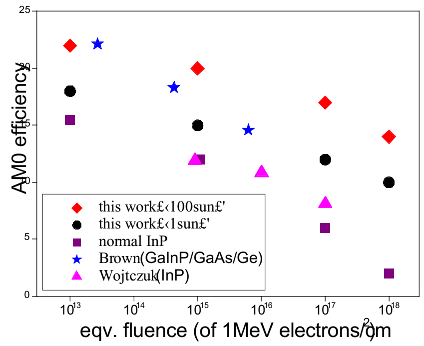

Fig.3 Comparison of radiation hardness of several structur

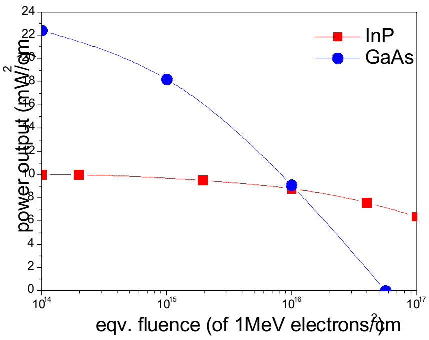

Fig.4 The influence of radiation to power outp
of GaAs and normal InP solar cells

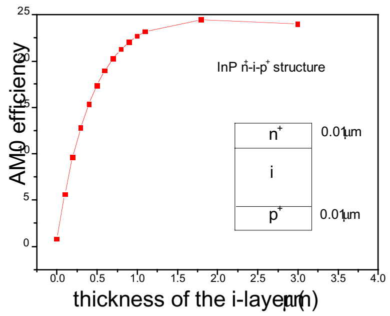

Fig.5 The relationship between AM0 efficien
of n+-i-p+ InP solar cell and
the thickness of the i-layer

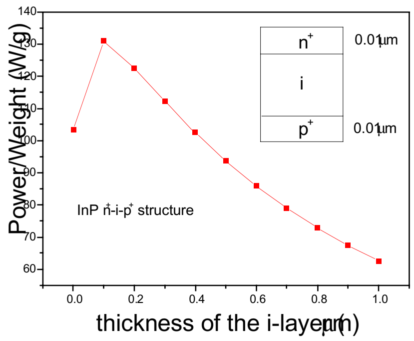

Fig.6 The relationship between power/weight ra
of n+-i-p+ InP solar cell and the
thickness of the i-layer