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Effects of Proton Irradiation on the Performance of InP/GaAs Solar Cells

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Introduction

InP solar cells are known to be more radiation resistant than either GaAs or Si [refs. 1-2]. In addition, AM0 total area efficiencies approaching 19% have been attained for InP [ref. 3]. However, the present high substrate cost presents a barrier to the eventual widespread use of InP cells in space. In addition, if cell thinning becomes desirable, their relative fragility presents a problem. For these reasons, the NASA Lewis Research Center has initiated a program, aimed at producing thin InP cells, by heteroepitaxial deposition of InP on cheaper, more durable substrates. To date, a short term feasibility study at Spire has resulted in cells processed from InP heteroepitaxially deposited on Si substrates with an intervening thin GaAs layer (InP/GaAs/Si) and cells produced from InP deposited on GaAs (InP/GaAs) [ref. 4]. As a result of this short study efficiencies of over 7 and 9% were achieved for InP/GaAs/Si and InP/GaAs respectively [ref. 4]. Although these efficiencies are low, they represent a modest and encouraging starting point for a more intensive program. Obviously, when considering economy and mechanical strength, cells processed on silicon substrates are preferred. However, although the InP/GaAs cells are not the final desirable products of this program, their properties serve to highlight several roadblocks to be overcome in producing cells with the more desirable cost and strength properties. Hence, in the present case, we concern ourselves with the properties of the InP/GaAs cells before and after irradiation by 10 MeV protons. A similar study of InP/GaAs/Si cells will be reported on at a later date.

Experimental Details

The InP/GaAs cells were produced at Spire under contract to NASA Lewis. Cell details are shown in figure one. The n^+p InP cells were processed by MOCVD on a relatively thick p-type GaAs substrate. Additional details are contained in reference 4. The cells were irradiated by 10 MeV protons, in the Lewis cyclotron, to a maximum fluence of 1.1×10^{13} cm^{-2}. Performance measurements were accomplished using an X-25 xenon lamp solar simulator and a flight calibrated InP standard cell. Spectral response measurements were performed using a filter wheel. Measurements of I_{sc} and V_{oc} were carried out at varying light intensities in order to determine the diffusion and recombination parameters of cell dark current.

Results and Discussion

Preirradiation performance parameters, averaged over 8 cells, are shown in table one. The measured values for I_{sc}, V_{oc} and efficiency shown in the table are slightly lower than those listed in reference 4. We attribute this to differences in solar simulators and to the fact that a silicon reference cell was used in reference 4 rather than the presently used InP standard. Also shown are predicted values obtained from the modelling calculations of Yamaguchi et al [ref. 5]. These latter calculations list cell parameters as a function of dislocation density. In the present case, the dislocation density of 3×10^8 cm^{-2} was obtained from the x-ray diffraction, ion channeling and cross-sectional TEM study of Pearton et al [refs. 4,6]. Referring to our predicted values, it is noted that figure eight in reference 5 lists parameters for an InP cell without front contact metallization and for a p-layer doping density of 10^{16} cm^{-3}. In the present case, the p-base doping density is 3×10^{16} cm^{-3}. Hence a correction was made to account for a small decrease in cell performance [ref. 7] An additional correction was made for the 5% front contact metallization coverage of the present cells. The low efficiencies attained are attributable to the high dislocation density caused essentially by lattice mismatch between InP and GaAs. It is noted that a reduction in dislocation density by two orders of magnitude is required to attain efficiencies over 18%. A typical preirradiation curve of the present InP/GaAs cells is shown in figure two together with a similar curve for a relatively high efficiency monolithic n^+p InP cell [ref. 8]. From the figure, the greatest difference between the two cells lies in the shunt resistance.

A plot of cell maximum power vs proton fluence is shown in figure three where it is seen that the present cells show relatively little degradation after irradiation to the highest fluence. This is further illustrated by a comparision, on a normalized basis, with similar data for monolithic n^+p cells [ref. 9]. The observed relatively high radiation resistance of the present InP/GaAs cells is attributed to the dominant effects of dislocations. In this connection it is noted that the base minority carrier diffusion length, computed from spectral response, shows a relatively small change at the highest fluence. This indicates that the effects of dislocations dominates over that of the radiation induced defects in determining minority carrier diffusion length. With regard to the remaining cell parameters, it is usually the case that I_{sc} degrades more than V_{oc} [ref. 10]. In the present case, these latter two parameters show approximately the same degradation at the highest fluence (table 2), a result which is considered to be anomalous. A further anomaly is indicated by the normalized long and short wavelength spectral response shown in figure five. It is usually the case that the highest degradation occurs in the long wavelength response, however, the opposite occurs in the present cells. The exact reason for these latter two effects is unclear at present.

The effect of dislocations is also apparent in the values obtained for the diffusion and recombination components of the dark current. These are obtained from the values of I_{sc} and V_{oc} obtained at varying light intensities. Using this data and assuming that the recombination component of dark current can be neglected at high V_{oc}, A_1, the junction ideality factor, is often obtained using the relation;

$$\ln(I_{sc} - (V_{oc}/R_{sh})) = (V_{oc}/A_1 V_T) + \ln(I_{01}) \qquad [1]$$

where $V_T = kT/q$ and I_{01} is the diffusion component of the dark reverse saturation current. However, in the present case, using relation one at high V_{oc}, it is found that $A_1 = 1.7$. This indicates that it is incorrect to neglect the recombination component at high V_{oc}. Hence to find A_1 we use:

$$\ln(\alpha) = (V_{oc}/A_1 V_T) + \ln(I_{01}) \qquad [2]$$

with

$$\alpha = I_{sc} - I_{02}\exp(V_{oc}/A_2 V_T) - V_{oc}/R_{sh} \qquad [3]$$

where I_{02} and A_2 correspond to the recombination component of dark current. These latter two quantities are evaluated from the I_{sc}-V_{oc} data at low V_{oc}. A plot of $\ln(\alpha)$ vs V_{oc} should yield a straight line from which A_1 can be evaluated. A typical plot is shown in figure six where, for this particular cell, it is found that $A_1 = 1.3$. The preirradiation parameters obtained in the present case are compared, in table three, to similar data obtained for monolithic n^+p InP and ITO/InP cells [ref. 9]. The recombination and diffusion components are noticeably higher for the InP/GaAs cells, the most noticeable difference occuring for the diffusion component. This follows from the fact that the highest concentration of dislocations occurs in the cell base at and near the InP-GaAs interface [ref. 6]. After proton irradiation we found no significant change in the recombination and diffusion components of the InP/GaAs cells. This is consistent with the dominant effect of dislocations in both the cell base and depletion regions.

Conclusion

Although the efficiencies obtained for the present cells are low, they represent a beginning which, with increased effort, should eventually result in cells with reasonably high efficiencies. It should be noted that the initial cells in the previous program which resulted in the best monolithic InP cells yielded efficiencies comparable to those obtained in the present case [refs. 3,11]. Clearly the dislocation density needs to be drastically reduced. This is evident from both the theory and the dominance of dislocations in the present cells. The challenge here is to obtain increased efficiency while, at the same time, at least, maintaining the radiation resistance exhibited by the present monolithic cells.

References

[1.] M. Yamaguchi, C. Uemura and A. Yamamoto, Japanese Journ of Appl. Physics **23**, 302, 1984.

[2.] I. Weinberg, C. K. Swartz and R. E. Hart Jr., *Proceedings 18th IEEE Photovoltaic Specialists Conf.*, 1722, 1985.

[3.] C. J. Keavney and M. B. Spitzer, Appl. Phys. Lett. **52**, 1439, 1988.

[4.] C. J. Keavney, S. M. Vernon, V. E. Haven, S. J. Wojtczuk and M. M. Al-Jassim, Appl. Phys. Lett., **54**, 1139, 1989.

[5.] M. Yamaguchi, A. Yamamoto, N. Uchida and C. Uemura, Solar Cells **19**, 85, 1986-1987.

[6.] S. J. Pearton, K. T. Short, A. T. Macrander, C. R. Abernathy, V. P. Mazzi, N. M. Haeger, M. M. Al-Jassim, S. M. Vernon and V. E. Haven, J.Appl.Phys. **65**, 1O83, 1989.

[7.] A. Yamamoto, M. Yamaguchi and C. Uemura, IEEE Trans. Electron Devices, **ED12**, 2780, 1985.

[8.] M. B. Spitzer, C. J. Keavney, S. M. Vernon and V. E. Haven, Appl. Phys. Lett. **51**, 364, 1987.

[9.] I. Weinberg, C. K. Swartz, R. E. Hart Jr. and T. J. Coutts, *20th IEEE PVSC*, 893, 1988.

[10.] I. Weinberg, C. K. Swartz, R. E. Hart Jr., S. K. Ghandhi, J. M. Borrego, K. K. Parat and M. Yamaguchi, Solar Cells **22**, 113, 1987.

[11.] M. B. Spitzer, Final Report, *Research on high efficiency radiation resistant indium phosphide solar cells*, NASA Lewis Research Center, Spire FR-60058, 1985.

TABLE I-PREIRRADIATION CELL PARAMETERS

	Jsc	Voc	FF	EFF.
	MA/CM^2	MV	%	%
MEASURED^A	26.6±.7	667±4	69±1	8.9±.1
PREDICTED^B	29.6	600	77	9.9

A AVERAGE - 8 CELLS

B N_{DIS} = 3X10^8/CM^2, P = 3X10^{16}/CM^3

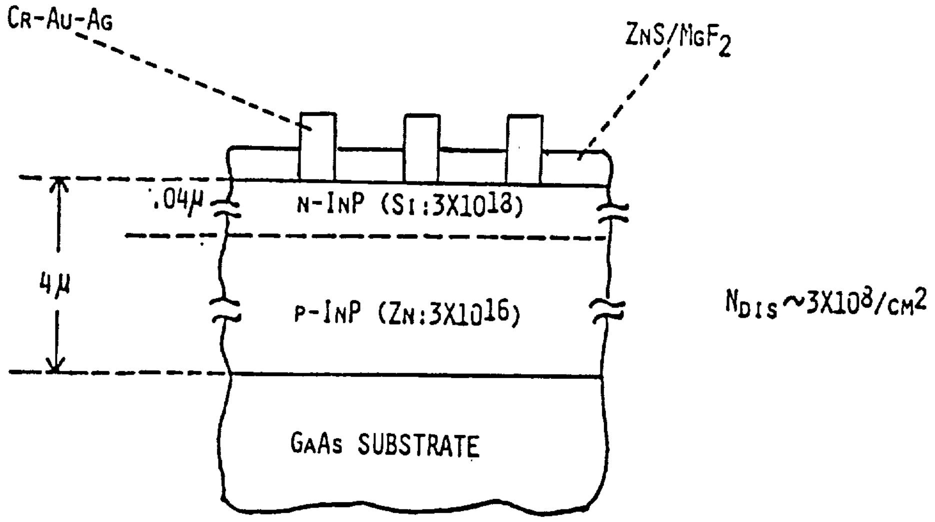
TABLE II-NORMALIZED CELL PARAMETERS AT HIGH FLUENCE

Φ = 1.1 X 10^{13}/CM^2

Jsc(Φ)/Jsc(0)	Voc(Φ)/Voc(0)	FF(Φ)/FF(0)	EFF.(Φ)/EFF.(0)
0.98	0.97	0.96	0.91

TABLE III-DIFFUSION AND RECOMBINATION PARAMETERS

CELL	A_1	A_2	J_{01} A/cm^2	J_{02} A/cm^2
ITO/InP	1.09	1.95	5.4×10^{-14}	4×10^{-9}
InP (OMCVD)	1.03	2.24	1.4×10^{-16}	4.1×10^{-9}
InP (DIFFUSED)	1.08	1.94	1.5×10^{-14}	4.1×10^{-9}
InP (DIFFUSED)	1.02	2.25	6.9×10^{-16}	2.5×10^{-3}
InP/GaAs	1.27	2.12	6.6×10^{-11}	9.5×10^{-8}



BACK CONTACT: Au-Zn

Figure 1. - Cell Details

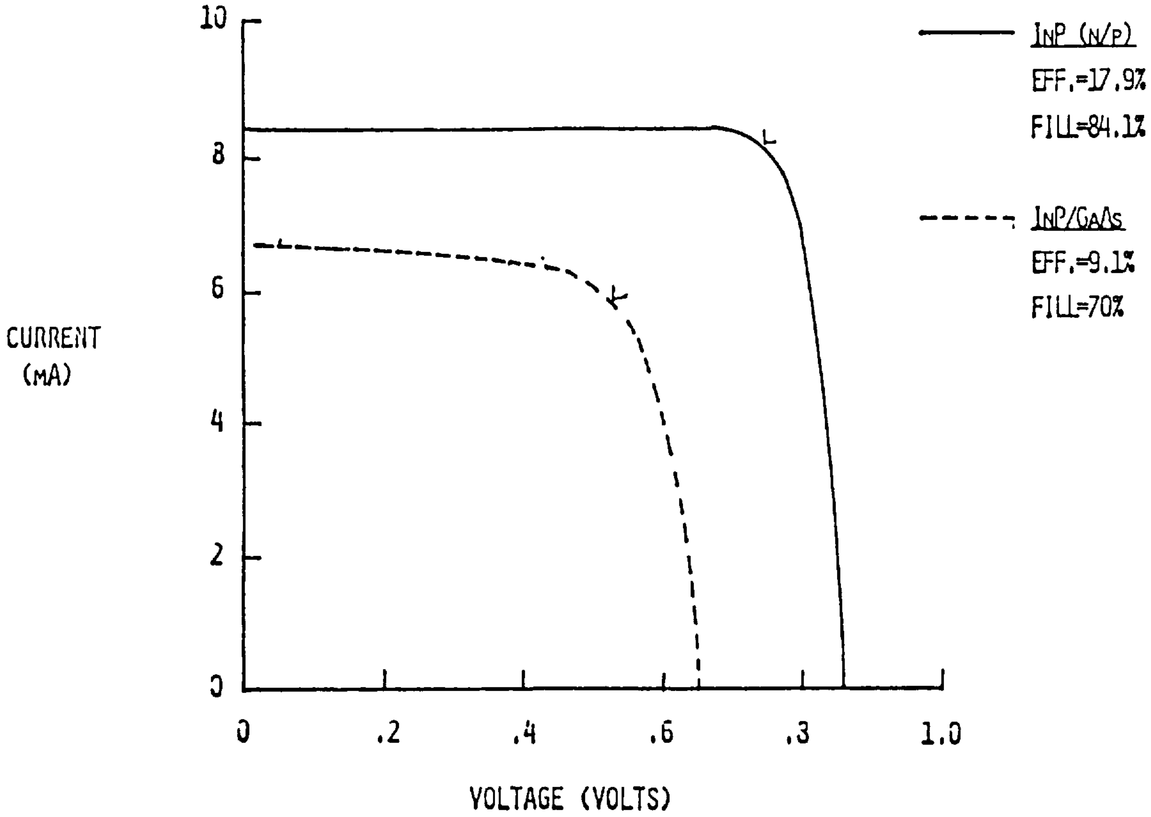


Figure 2 - Preirradiation I-V Curves

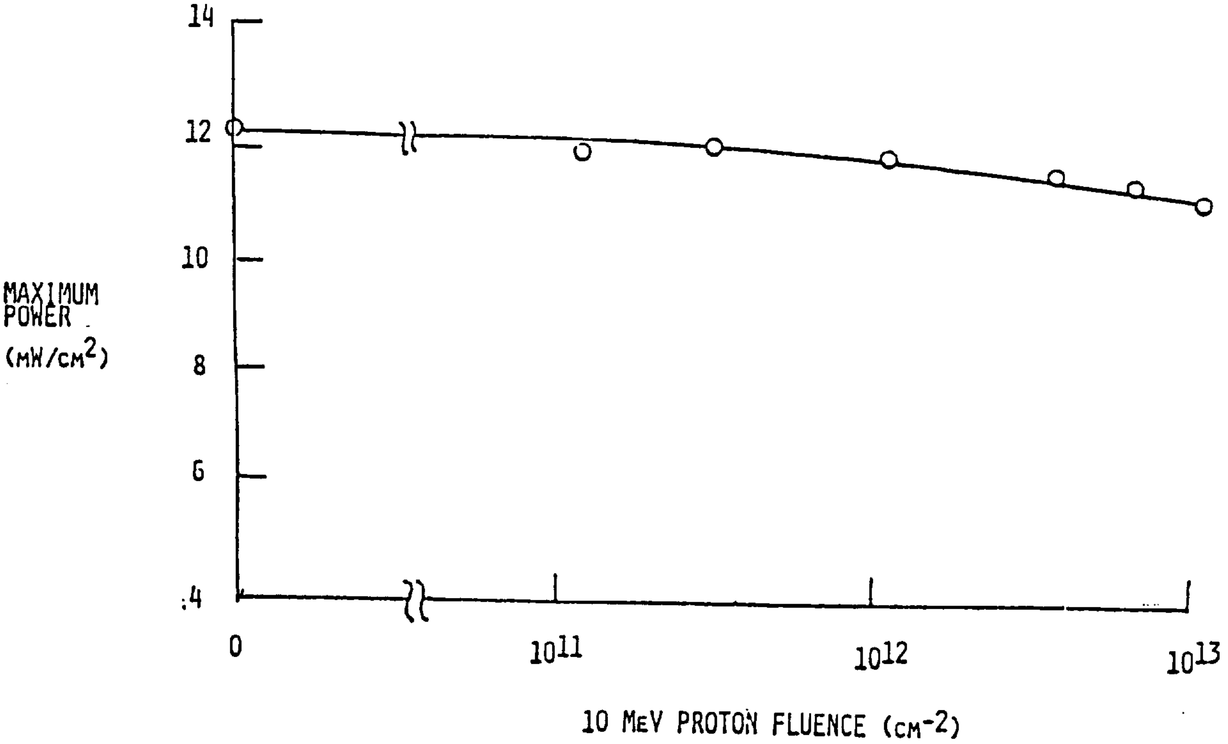


Figure 3 - Pmax After Proton Irradiations - InP/GaAs

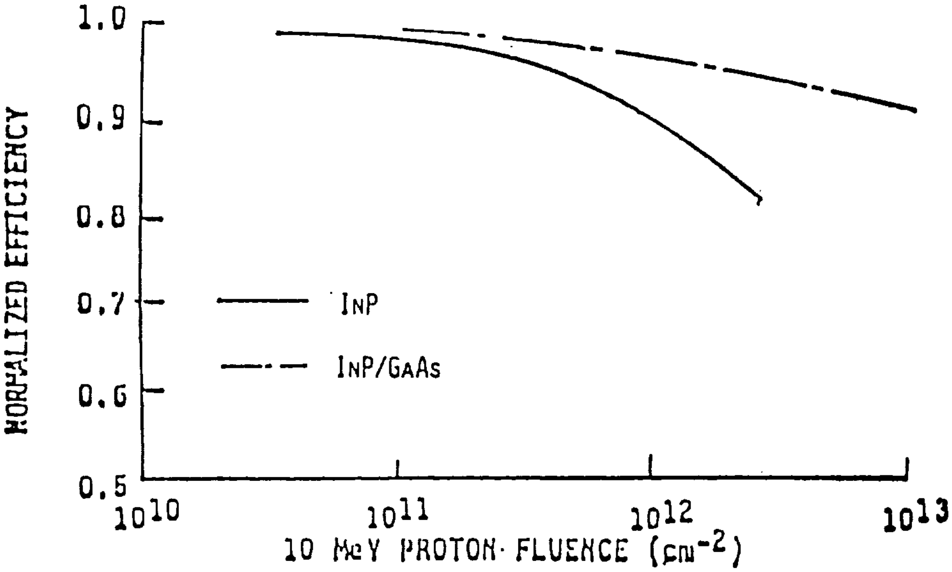


Figure 4 - Normalized Efficiencies After Proton Irradiations

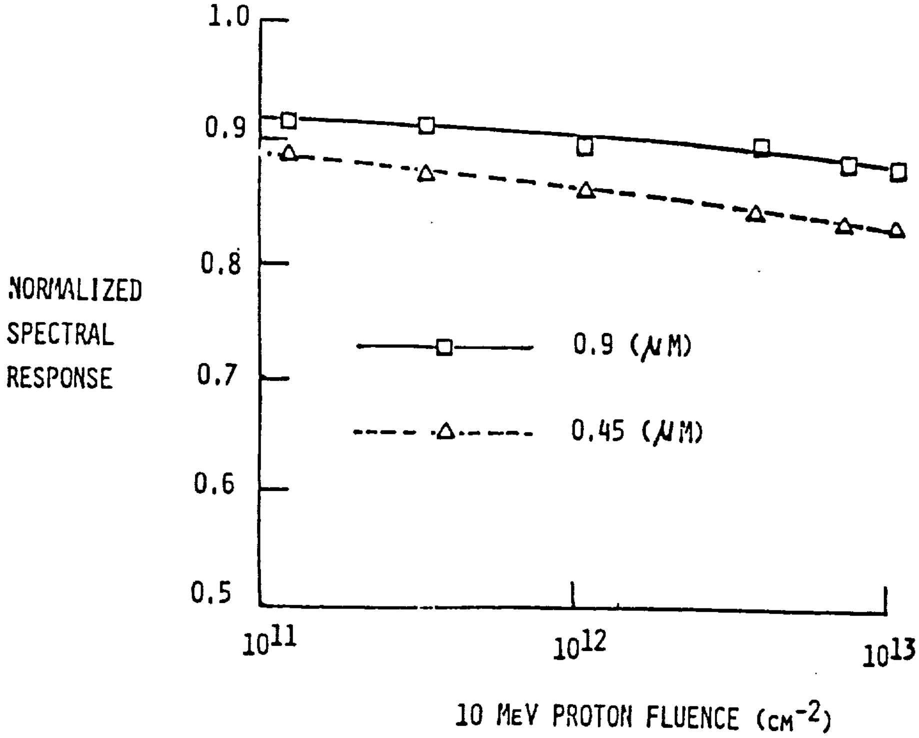


Figure 5 - Normalized Spectral Response After Proton Irradiations-InP/GaAs

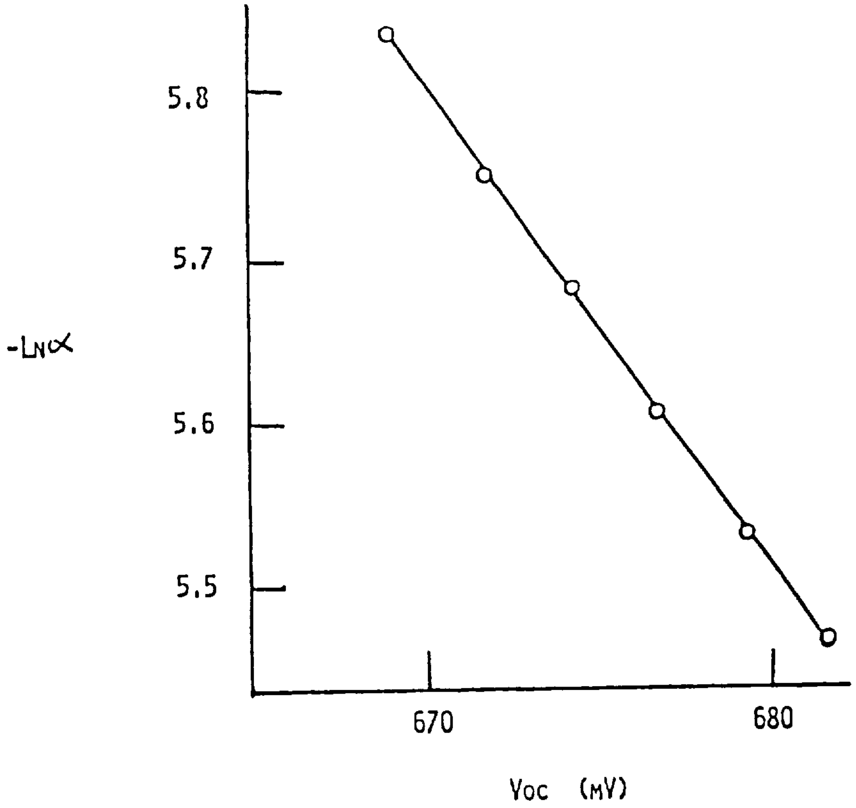


Figure 6 - Plot Used to Obtain A_1 From Variable Intensity Isc-Voc Data