N94-11383

RADIATION EFFECTS IN HETEROEPITAXIAL InP SOLAR CELLS

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ABSTRACT

Heteroepitaxial InP solar cells, with GaAs substrates, were irradiated by 0.5 and 3 MeV protons and their performance, temperature dependency and carrier removal rates determined as a function of fluence. The radiation resistance of the present cells was significantly greater than that of non-heteroepitaxial InP cells at both proton energies. A clear difference in the temperature dependency of Voc, was observed between heteroepitaxial and homoepitaxial InP cells. The analytically predicted dependence of dVoc/dT on Voc was confirmed by the fluence dependence of these quantities. Carrier removal was observed to increase with decreasing proton energy. The results obtained for performance and temperature dependency were attributed to the high dislocation densities present in the heteroepitaxial cells while the energy dependence of carrier removal was attributed to the energy dependence of proton range.

INTRODUCTION

Although air mass zero (AMO) efficiencies over 19% have been achieved for InP homojunction cells,[1] there still remains the problem of high wafer cost and relative cell fragilty. For these reasons, several groups have been conducting research programs aimed at producing InP cells heteroeplitaxially grown on cheaper, preferably stronger, substrates.[2,3,4] To date, cells have been processed using Si and GaAs as starting substrates.[2,3,4] However, in the current state of the art, lattice and thermal expansion mismatch tend to introduce performance limiting high dislocation densities. These have limited cell AMO, total area efficiencies, to 9.9% and 13.7% for heteroepitaxial InP cells, using Si and GaAs substrates respectively.[2,3,4] Our previous work on these cell types included research on the effects of 1 MeV electron and 10 MeV proton irradiations.[5,6,7] An objective of this latter work lay in determining the role of dislocations on cell performance, temperature dependency and carrier removal. In the present case, we consider the effects of lower energy proton irradiations on the properties of InP heteroepitaxial cells processed with GaAs as the starting substrate .

EXPERIMENTAL

The cells were processed by MOCVD at the Spire corporation under contract to NASA Lewis. They consisted of a heavily doped p-type GaAs substrate followed by several layers of $Ga_xIn_{1-x}As$ with lattice matching to InP occurring at x=0.47.[3,4] This is followed by deposition of n^+pp^+ InP cells. Cell details are shown in figure 1. The cells were irradiated by 0.5 and 3 MeV protons to a fluence of 10^{13} cm^{-2}. Proton ranges for these energies and for 10 MeV protons are shown in the figure. Cell base carrier concentrations, at the edge of the depletion region, were determined by C-V measurements. Pre-irradiation parameters for these cells are shown in table I. The table also includes data for an n^+p InP cell whose emitter region was processed by sulfur diffusion into p-type substrates.[8] The efficiencies of the present InP/GaAs cells are somewhat lower than the 13.7% reported for cells of a similar structure.[2,3] It is noted that the higher efficiency cells had dislocations densities as low as $3x10^7/cm^2$ while dislocations densities in the present cells were approximately an order of magnitude higher.[3,4]

RESULTS AND DISCUSSION

Cell performance:
From figures 2 and 3 it is seen that the radiation resistance of the heteroepitazial cell is significantly greater than that of the non-heteroepitaxial homojunction cell. An exception exists at the highest 0.5 MeV proton fluence where only a slight difference exists. Data for the remaining cell parameters, at the highest fluence are shown in table II. The improved radiation resistance of the InP/GaAs cell is due to a short BOL cell base diffusion length of approximately 0.4 micrometers. This is attributed to the high dislocation density present in this cell.

Temperature Depencency:
Temperature dependencies of Voc and Isc, over the measured temperature range from 25 to 75 ^oC, are shown in figures 4 and 5. The remaining parameters show the linear behavior exhibited by dVoc/dT over this temperature range. However, because of the nonlinearity exhibited by dIsc/dT at the lower temperatures, all temperature dependencies were determined at 55 ^oC. The results are shown in table III along with our previous results for InP/GaAs and homoepitaxial InP/InP cells.[6,9] Comparing the temperature dependency data for the two cell types, the only clear cut difference occurs in dVoc/dT. In the past, we have used Fan's

analytical model for a more detailed analysis of the Voc temperature dependency.[7,10] The analytical model predicts that the absolute magnitude of dVoc/dT increases with decreasing open circuit voltage. The data shown in table IV is in agreement with this prediction. The fluence dependence of dVoc/dT, shown in figure 6, indirectly confirms the prediction of the analytical model inasmuch, as seen from tables I and II, Voc decreases with increasing fluence. Aside from the fluence dependence the high dislocation densities in the heteroepitaxial cells result in reduced values of Voc and therefore higher values for the absolute magnitude of dVoc/dT. Hence, the difference in Voc temperature dependencies between the hetero- and homoepitaxial cell is attributed to the high dislocation density present in the latter cell.

Carrier Removal:
Carriers removed, in the present InP/GaAs cell, at 0.5 and 3 MeV, are shown in figure 7. Carrier removal rates R_C, where $R_C = \Delta p/\phi$, are shown in table V for the present cells together with previously obtained 10 MeV proton data for InP/GaAs and InP/InP cells.[6,9] The 10 MeV data shown in the table indicates that carrier removal in the heteroepitaxial cell is greater than that measured for the homoepitaxial cells at this proton energy. The excess carrier removal is attributed to the greater dislocation density, and hence increased defect density, present in the irradiated heteroepitaxial cells. The data also indicates that, under proton irradiation, carrier removal rates tend to increase with decreasing proton energy. From the proton ranges shown in figure 1, and plots of defects created as a function of distance, it is seen that the lower energy protons create more defects in the active cell region as compared to those created by the higher energy protons. Hence the energy dependent behavior of carrier removal is attributed to the reduction in proton range with decreasing energy.

CONCLUSION

The behavior of the present heteroepitaxial cells, at the lower proton energies, is consistent with previous results obtained for diffused junction InP cells.[8] The decreased radiation resistance observed at 0.5 MeV can be understood by noting that, compared to the higher energy irradiations, a much larger defect concentration occurs in the active InP cell region. Also, as noted in the previous section, carrier removal increases as proton energy decreases. The effects of dislocations are apparent in the increased radiation resistance of the heteroepitaxial cells, the temperature dependency of Voc, and the increased carrier removal rate observed for the InP/GaAs cells at 10 MeV. Considering that $Ga_xIn_{1-x}As$ is lattice matched to InP, the relatively low efficiency of the present InP/GaAs cells is dissapointing. The high dislocation densities occuring in these cells is probably due to mismatches occurring in the transition layers.[4] These results highlight the fact that dislocations are the principal barrier to achieving high efficiencies in heteroepitaxial InP cells. Hence future research efforts in this area would do well to focus their efforts toward reducing dislocation densities into the $10^6/cm^2$ range.

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Table I : Cell Performance at BOL

Cell	Jsc (mA/cm^2)	Voc (mV)	FF (%)	Eff. (%)
InP/GaAs	27.6±.08	697±4.4	72.8±.25	10.2±.08
InP[a]	33.7	828	81.6	16.6

a M. Yamaguchi et al, 21th PVSC ,p1198(1990)

Table II : Normalized Parameters at High Fluence

InP/GaAs; $\Phi = 10^{13}/cm^2$

Proton Energy (MeV)	Jsc (mA/cm^2)	Voc (mV)	FF (%)	Eff. (%)
3.0	0.98	0.94	0.95	0.87
0.5	0.13	0.67	0.87	0.08

Table III : Cell Temperature Coefficients at 328 K

Cell	dPm/dT (mW/cm^2K)	dVoc/dT (mV/K)	dIsc/dT (mA/cm^2K)	dFF/dT (%/K)
InP/GaAs[a]	$-(5.21\pm.27)\times10^{-2}$	$-(2.53\pm.01)$	$(1.41\pm.08)\times10^{-2}$	$-(6.56\pm.58)\times10^{-2}$
InP/GaAs[b]	$-(5.63\pm.25)\times10^{-2}$	$-(2.51\pm.01)$	$(1.99\pm.11)\times10^{-2}$	$-(7.50\pm1.97)\times10^{-2}$
InP/InP[b]	$-(5.41\pm.21)\times10^{-2}$	$-(2.07\pm.02)$	$(2.21\pm.40)\times10^{-2}$	$-(5.43\pm1.56)\times10^{-2}$

a Present Work

b I. Weinberg et al , 3rd Int'l. Conf. InP & Related Materials, p52 (1991)

Table IV : Temperature Dependency of Voc

Cell	Voc (mV)	dVoc/dT (mV/K) Measured	Calculated
InP/GaAs [a]	697±4.4	-2.52±.01	-2.82±.02
InP/GaAs [b]	700±6.0	-2.51±.02	-2.84±.03
InP/InP [b]	874±1.0	-2.07±.02	-2.27±.01

a Present Work

b I. Weinberg et al, 3[rd] Int'l. Conf. InP & Related Materials, p55(1991)

Table V : Carrier Removal Rates

Cell	InP/InP [b]	InP/GaAs [b]	InP/GaAs [a]	
Proton Energy (MeV)	10	10	3	0.5
Carrier Removal Rate (cm^{-1})	540	880	1.4×10^3	8.4×10^3

a Present Work

b I. Weinberg, et al, 3[rd] Int'l. Conf. InP & Related Materials, p55(1991)

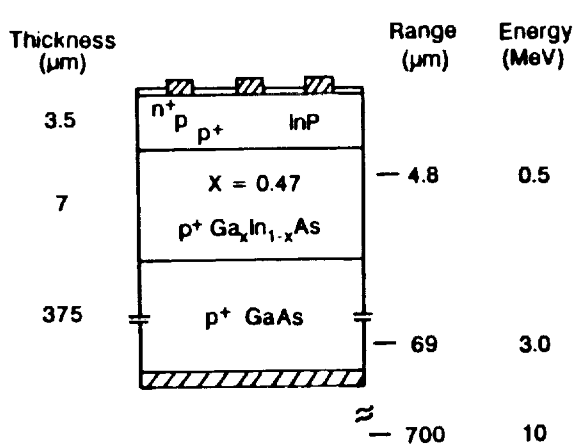

Figure 1 : Cell Details

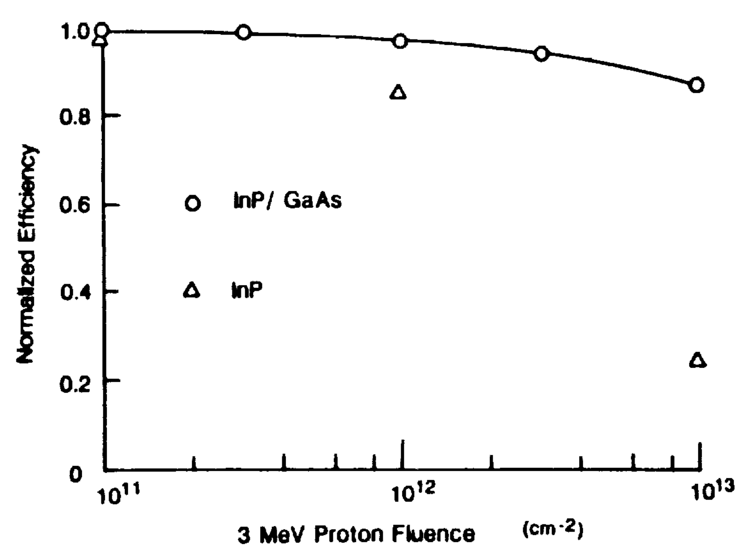

Figure 2 : Normalized Efficiencies at 3 MeV

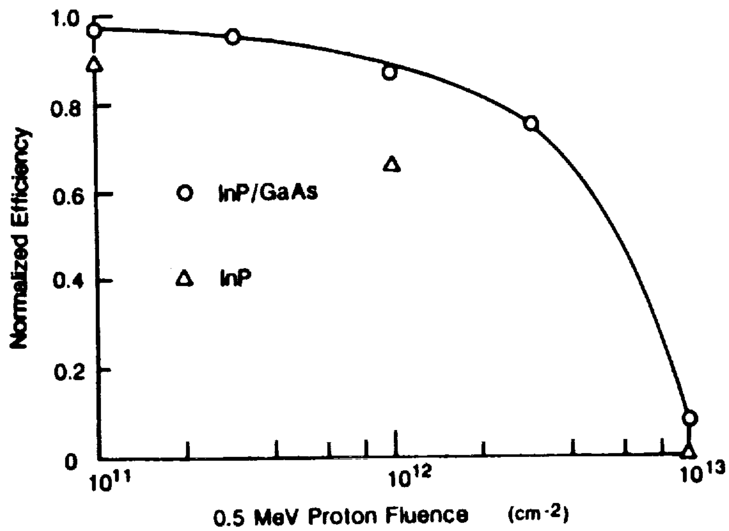

Figure 3 : Normalized Efficiencies at 0.5 MeV

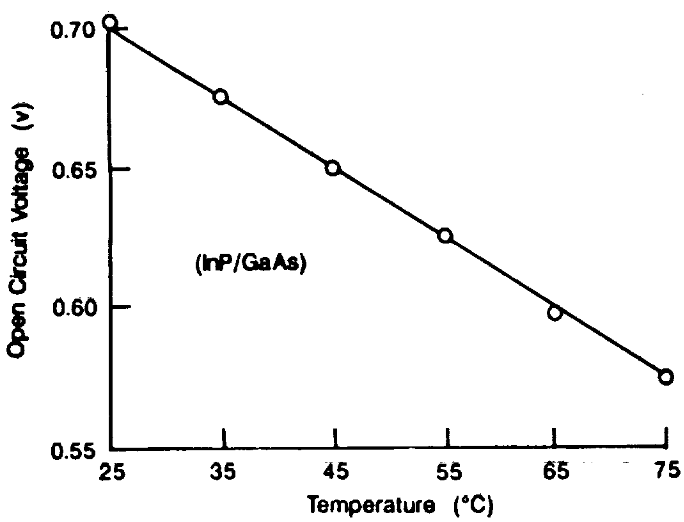

Figure 4 : Temperature Dependency of Voc

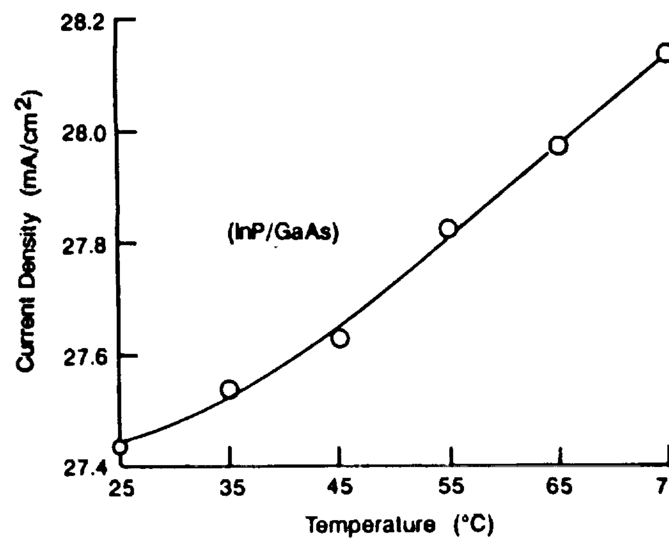

Figure 5 : Temperature Dependency of Jsc

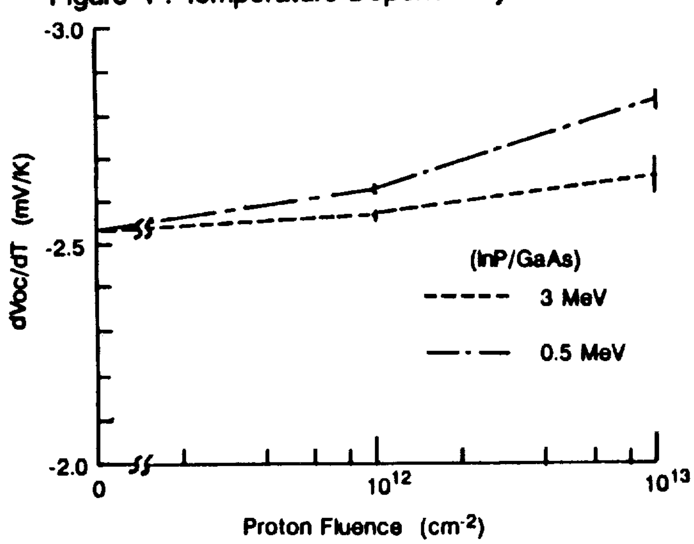

Figure 6 : Fluence Dependence of dVoc/dT

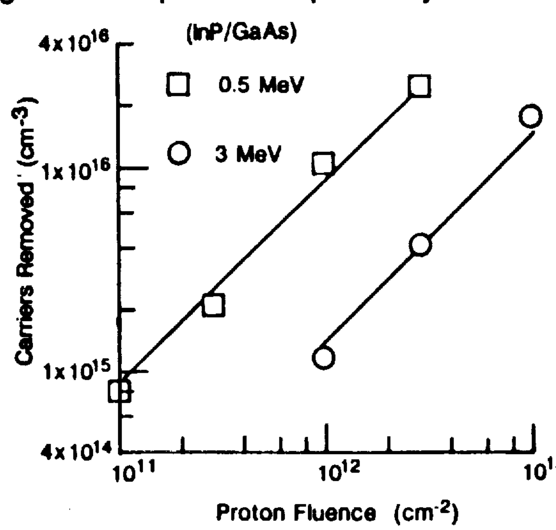

Figure 7 : Carrier Removal at 0.5 and 3.0 MeV