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EFFECT OF DISLOCATIONS ON PROPERTIES OF HETEROEPITAXIAL InP SOLAR CELLS

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ABSTRACT

The apparently unrelated phenomena of temperature dependency, carrier removal and photoluminescence are shown to be affected by the high dislocation densities present in heteroepitaxial InP solar cells. Using homoepitaxial InP cells as a baseline, it is found that the relatively high dislocation densities present in heteroepitaxial InP/GaAs cells leads to increased values of dVoc/dt and carrier removal rate and substantial decreases in photoluminescence spectral intensities. With respect to dVoc/dt, the observed effect is attributed to the tendency of dislocations to reduce Voc. Although the basic cause for the observed increased in carrier removal rate is unclear, it is speculated that the decreased photoluminescence intensity is attributable to defect levels introduced by dislocations in the heteroepitaxial cells.

INTRODUCTION

Several research programs, now underway, are aimed at producing InP solar cells from thin layers of InP epitaxially deposited on cheaper, more durable substrates (refs. 1,2,3). The motivation for this research lies in the high cost and relative fragility of InP. Efforts to date have focused on the use of Si and GaAs substrates. Although intervening lattice matching layers have been used , the lattice constant mismatch between InP and these foreign substrates introduces dislocations which tend to adversely affect cell performance. It is anticipated that the adverse effect of dislocations will eventually be minimized. However, in the present state of the art, dislocations are a dominant factor in adversely affecting cell performance and in contributing to increased radiation resistance (refs. 1,3,4). Although information exists concerning the effects of dislocations on cell performance and radiation resistance, little or nothing is known concerning their effects on such cell properties as temperature dependence, carrier removal and photoluminescence spectral intensities. The present paper is concerned with our initial results concerning the effects of dislocations on these properties.

EXPERIMENTAL DETAILS

The cells were produced by organo-metallic vapor phase epitaxy (OMVPE) at the Spire Corporation under contract to NASA Lewis. Both homoepitaxial and heteroepitaxial n+p+ cells were processed, the latter consisting of InP cells on GaAs substrates. Etch pit densities, determined by electrochemical etching, were $4X10^7$ cm^{-2} for the heteroepitaxial cells and $4X10^3$ cm^{-2} for the homoepitaxial cells. Performance parameters of both cell types are listed in table I. Temperature dependencies were determined over a range from 25 to 75°C. Over this temperature range, a pulsed Xenon arc solar simulator was used to determine cell performance. Carrier concentrations were determined by capacitance-voltage (C-V) measurements after irradiation by 10 MeV protons in the Lewis cyclotron. Photoluminescence (PL) spectra were obtained at 11 and 298K. The PL spectrometer covered the wavelength range from 850 to 3000 nm while the excitation wavelength was 514 nm.

RESULTS AND DISCUSSION

Temperature Dependencies

The temperature dependency of Voc, from 25 to 75°C is shown in fig.1. With the exception of Isc (fig.2) all of the parameters shown in table I were linear over this temperature range. The non-linear behavior of Isc is consistent with our previous data obtained over a much wider temperature range (ref. 5). A summary of temperature dependencies at 328 K is shown in table II. This temperature was chosen to avoid the non linearity in Isc. In addition, it falls within the temperature range of several space orbits of interest. As seen from the table, the temperature dependencies of all parameters, except Voc, are equal within the standard deviations. Clearly, dVoc/dT is greater for the heteroepitaxial cell.

The temperature dependency of Voc can be discussed using the relation (ref. 6),

$$dVoc/dT = ((Voc-Eg(T))/T) - 3k/q - \alpha T(T+2\beta)/(T+\beta)^2 + (kT/qIsc)(dIsc/dT) \qquad (1)$$

where Eg(T) is the bandgap at temperature T, k is the Boltzmann constant, while α and β are constants in the expression

$$Eg(T) = Eg(0) - \alpha T^2/(T+\beta) \qquad (2)$$

Eg(0) is the bandgap at 0 K (1.421 eV) and $\alpha = 6.63X10^{-4}$ ev/K with $\beta =$ 552 K (ref. 5). Values calculated for dVoc/dT, at 328 K, are shown in table III where it is seen that the measured and calculated values differ by 9.7 and 13% for the homoepitaxial and heteroepitaxial cells respectively. Despite this, equation 3 is useful in correlating values of Voc with its temperature coefficient. Detailed calculations indicate that the first term in equation 3 is dominant. Hence cells with higher values of Voc should have smaller values for dVoc/dT. The data of table III is in agreement with this prediction. Furthermore, since increased dislocation densities result in smaller values of Voc (ref.7) the data, and equation 1, tend to support the conclusion that increased dislocation densities result in higher values of dVoc/dT.

Carrier Removal

Carrier removal, after 10 MeV proton irradiations, is shown in fig.3. The carrier removal rate is obtained using the relation,

$$\Delta p = R_c \phi \qquad (3)$$

where the Δp are carriers removed at the fluence ϕ and Rc is the carrier removal rate. From (3) a slope of one is indicated for the plot shown in the figure. Since this is indeed the case, Rc can be determined from points on the straight lines of fig.3. The results shown in table IV indicate that the cell with the highest dislocation density has the highest carrier removal rate. Although the increased carrier removal is correlated with the increased dislocation density, the basic mechanism responsible for this effect is unclear at present.

Photoluminescence

The photoluminescence spectrum of an unirradiated InP/GaAs cell, at 11 K, is shown in fig.4. The peaks at 1.382 eV and 1.419 eV are attributed to the conduction band to acceptor and interband radiative transitions respectively. The remaining peak is the so called phonon replica of the conduction band-acceptor peak. Except for additional structure in the interband peak, the peak positions and slope of the homoepitaxial cell are similar to those shown in fig.4. The relative intensities, at 11 K, for each spectral component, except the phonon replica, are shown in fig.5. It is readily seen that the intensities for each component of the heteroepitaxial cell are at least an order of magnitude less than the spectral intensities for the homoepitaxial cell. The room temperature peaks of fig.6 confirm the tendency for the cell with greatly increased dislocation density to exhibit a considerably reduced photoluminescence intensity. The decreased intensity for the heteroepitaxial cell can be attributed to the presence of additional transitions outside the range of the spectrometer and/or to additional non-radiative transitions, both effects attributed to the effects of dislocations. In either case, it is assumed that the undetectable transitions are to defects caused by the increased presence of dislocations in the heteroepitaxial cells. It is noted that we have been unable to find evidence, in the literature, for the presence of additional defects,due to dislocations in p-type InP. However, for n-type InP, DLTS measurements indicate the presence of defects attributable to the presence of dislocations (refs. 8,9). Lacking such evidence for the p-type base of the InP/GaAs cell we tentatively assume the presence of additional defects due to the high dislocation density in this cell.

CONCLUSION

The present data indicates that large differences in dislocation density lead to increased values of dVoc/dT and carrier removal rate together with a drastic decrease in photoluminescence intensity. Considering the limited data set, it is perhaps premature to overgeneralize concerning the effects of dislocations on these quantities. On the other hand, the present data set tends to indicate that the increased value of dVoc/dT is due to the tendency of dislocations to reduce minority carrier diffusion length and thus Voc. Considering photoluminescence, it is speculated that the decreased intensity in the heteroepitaxial cells is due primarily to defects associated with the increased dislocation density. However, the basic cause of the increased carrier removal rate is relatively unclear at present.

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TABLE I. CELL PARAMETERS AT 298K

CELL TYPE	NUMBER OF CELLS	Jsc mA/cm^2	Voc (mV)	FF (%)	EFFICIENCY %
InP/InP	4	32.3±0.1	0.874±.001	83.3±1.4	17.1±0.3
InP/GaAs	4	28±0.2	0.7±.006	69.8±3.9	10±0.6

TABLE II. CELL TEMPERATURE COEFFICIENTS AT 328K

CELL	dP_M/dT mW/cm^2K	dVoc/dT mV/K	dIsc/dT mA/cm^2K	dFF/dT %/K
InP/InP	$-(5.46\pm.21)X10^{-2}$	-2.07±.02	$+(2.21\pm.4)X10^{-2}$	-5.43 ± 1.56 $X10^{-2}$
InP/GaAs	$-(5.63\pm.25)X10^{-2}$	-2.51±.01	$+(1.99\pm.11)X10^{-2}$	-7.5 ± 1.97 $X10^{-2}$

TABLE III. CALCULATED AND MEASURED VALUES OF dVOC/dT

CELL	EPD cm^{-2}	Voc mV	Voc/dT(mv/K)	
			MEASURED	CALCULATED
InP/InP	$4 X 10^3$	874±1	-2.07±.02	-2.27±.01
InP/GaAs	$4 X 10^7$	700±6	-2.51±.02	-2.84±03

TABLE IV. CARRIER REMOVAL RATES AFTER 10 MeV PROTON IRRADIATION

CELL	REMOVAL RATE cm^{-1}	EPD cm^{-2}
InP/GaAs	8.8×10^2	4×10^7
InP/InP	5×10^2	4×10^3

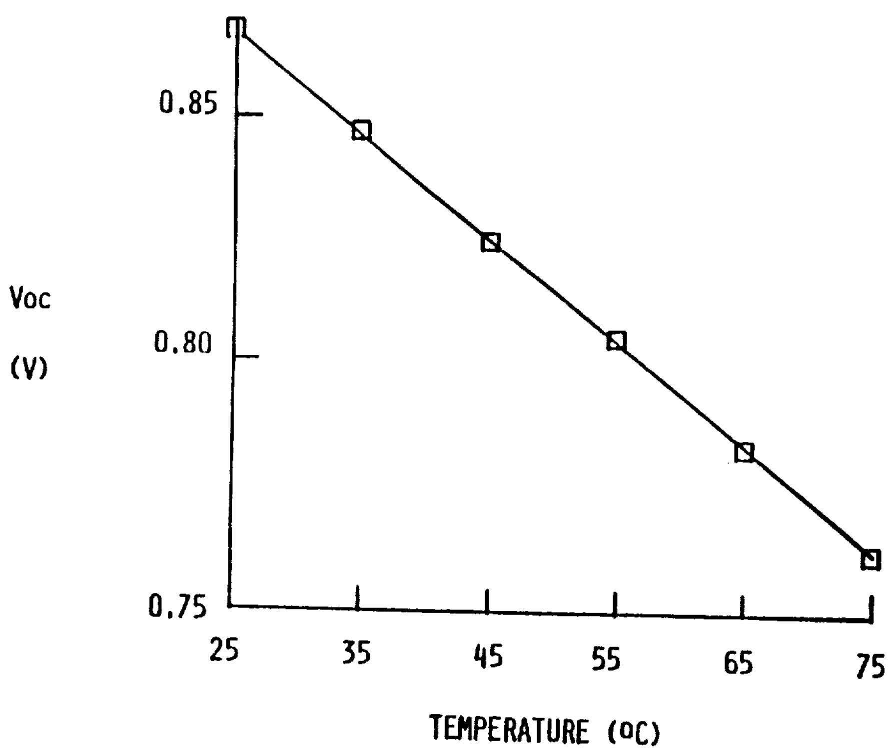

FIGURE 1 - TEMPERATURE DEPENDENCE OF OPEN CIRCUIT VOLTAGE (InP/InP CELL)

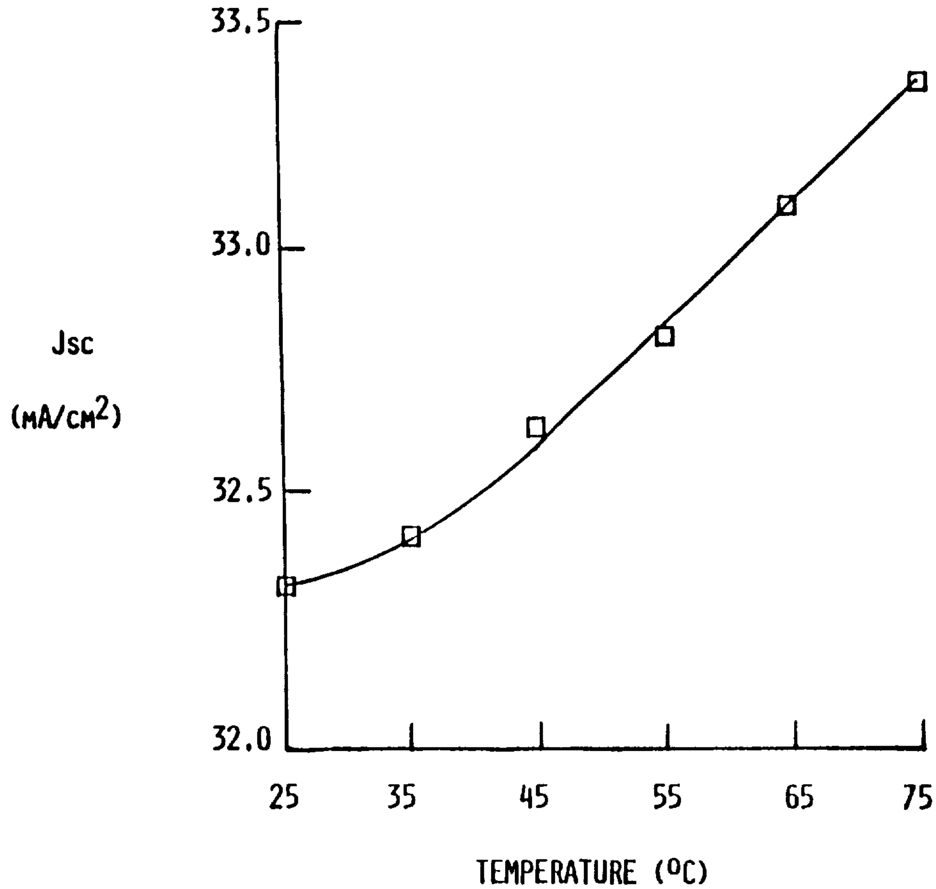

FIGURE 2 - TEMPERATURE DEPENDENCE OF SHORT CIRCUIT CURRENT (InP/InP CELL)

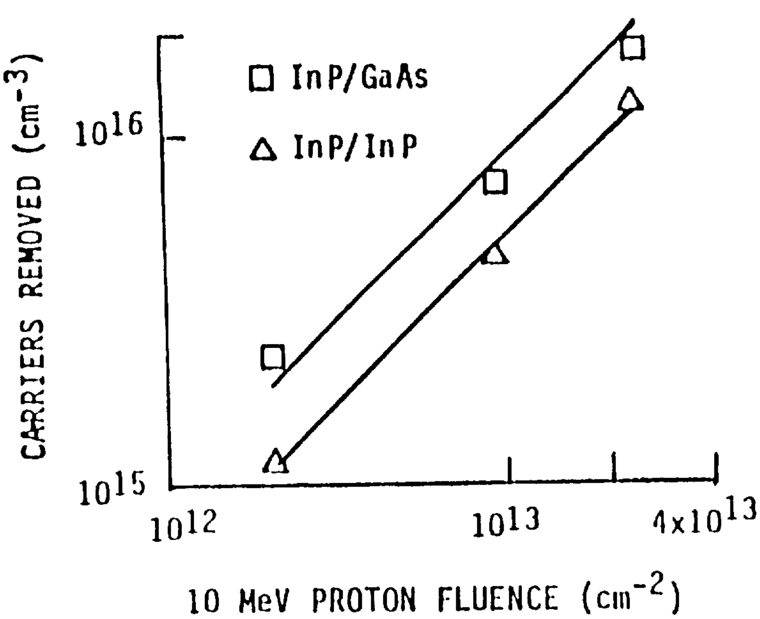

FIGURE 3 - CARRIER REMOVAL BY 10 MeV PROTONS

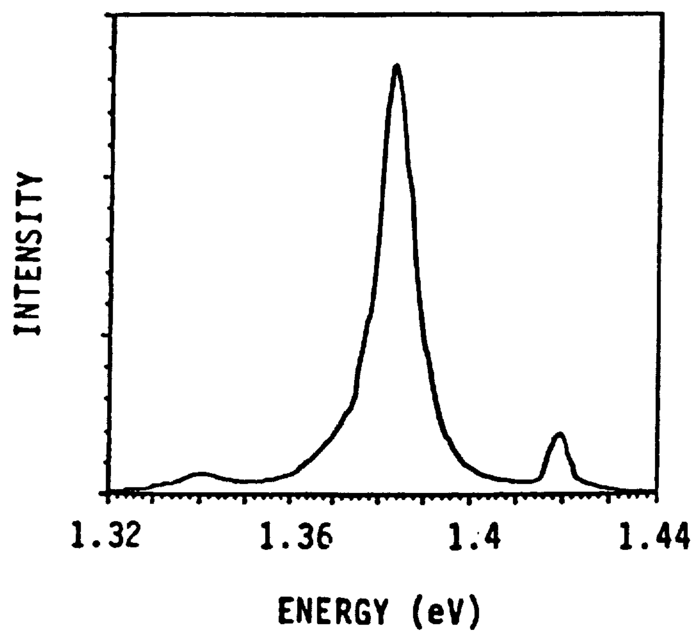

FIGURE 4 - PHOTOLUMINESCENCE AT 11 K
(InP/GaAs CELL)

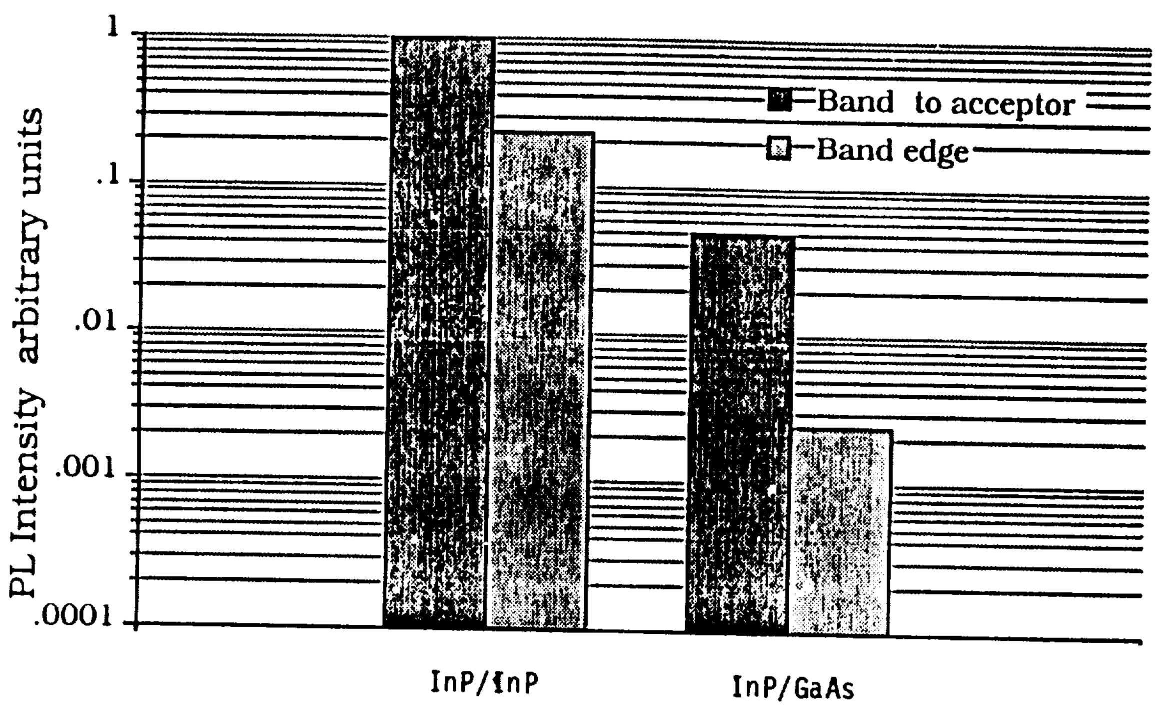

FIGURE 5 - RELATIVE INTENSITIES AT 11 K

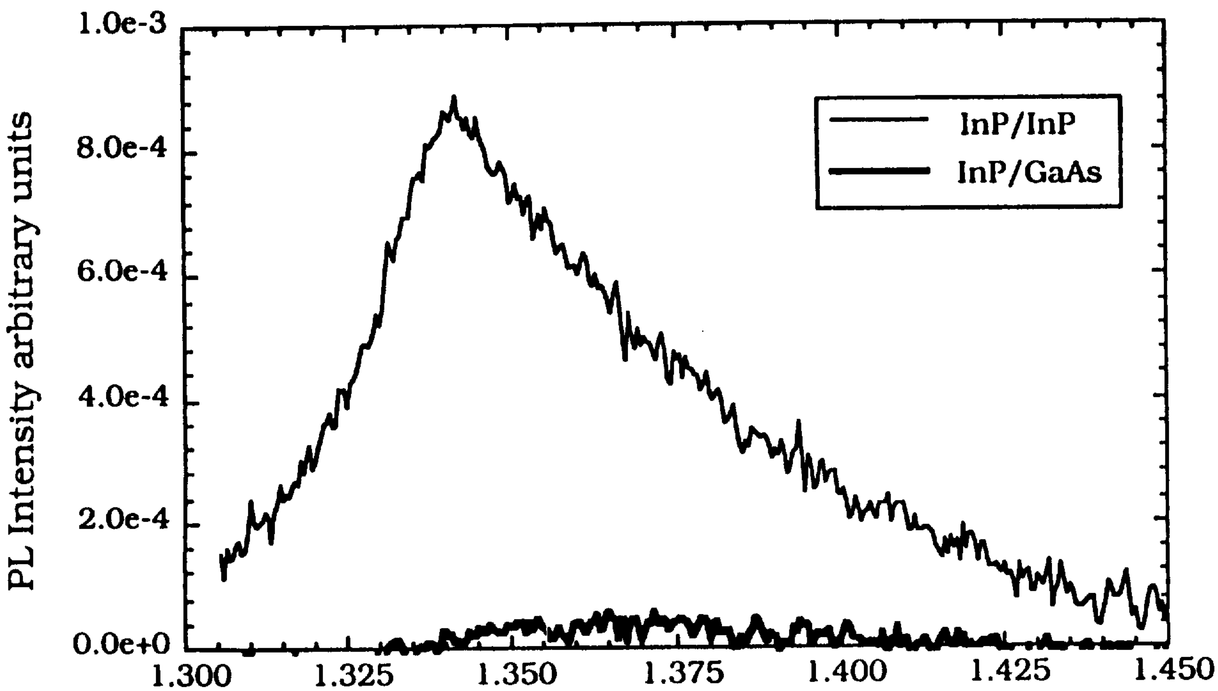

FIGURE 6 - ROOM TEMPERATURE PHOTOLUMINESCENCE