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Effect of Dislocations on the Open-Circuit Voltage, Short-Circuit Current and Efficiency of Heteroepitaxial Indium Phosphide Solar Cells

(NASA-TM-103762) EFFECT OF DISLOCATIONS ON THE OPEN-CIRCUIT VOLTAGE, SHORT-CIRCUIT CURRENT AND EFFICIENCY OF HETEROEPITAXIAL INDIUM PHOSPHIDE SOLAR CELLS (NASA) 7 p CSCL 09C G3/33
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Experimental Details

A batch of eight indium phosphide heteroepitaxial solar cells on gallium arsenide substrates was provided by the Spire Corporation under contract to NASA Lewis Research Center. The cells considered in the present investigation were grown by MOCVD. The n^+p cell structure as shown in figure 1 had emitter and base thicknesses of 40 nm and 3 μm and doping concentration of $2x10^{18}$ cm^{-3} and $3x10^{16}$ cm^{-3} respectively. The buffer layer was 1μm thick and had a doping concentration of $1x10^{18}$ cm^{-3}. These cells had a two layer ZnS/MgF_2 antireflection coating. The cell size was 0.5 by 0.5cm and the front grid coverage was 5 percent. Cells were measured at NASA Lewis under simulated AMO spectrum (137.2 mW/cm^2, 25 °C) using a calibrated reference InP cell. The average values of the short circuit current, open circuit voltage, and efficiency for the eight cells are 6.654 mA, 0.6666 V and 8.92 percent respectively.

Approach, Results and Discussion

Experimentally measured heteroepitaxial solar cell I-V results were simulated using the PC-1D computer program. The preliminary modeling results are described elsewhere (ref. 11). Figure 2 shows the calculated I-V characteristics of the heteroepitaxial InP solar cell. Hole diffusion length, electron diffusion length and front surface recombination velocity of 16 nm, 0.42 μm and 10^7 cm/sec respectively have been used in these calculations. Also shown in figure 2 are the measured short-circuit current, maximum power and open-circuit voltage points by circle. These are the average values of the

velocities of 10^7, 10^6 and 10^5 cm/sec. From these results it is clear that the short-circuit current, open-circuit voltage and efficiency improves significantly with the decrease in dislocation density and results tend to saturate for dislocation density around 10^4 cm^{-2}. From the efficiency versus dislocation density plots it is clear that the cells in excess of 18 percent AMO efficiency could be fabricated if the number of dislocations could be controlled. Dislocations act as recombination centers for minority carriers and reduce the cell short circuit current, while the increase in leakage current reduces the cell open-circuit voltage. The reduction in cell current and voltage is responsible for the low efficiencies observed in current heteroepitaxial cells having a large number of dislocations. The heteroepitaxial InP solar cells grown on silicon wafers with intermediate GaAs buffer layers have shown experimentally measured average dislocation density in the 3-$8x10^8$ cm^{-2} range (ref. 6), which is responsible for lower efficiencies (7.1 percent AMO) of these cells (ref. 4). Unfortunately no experimental data of the dislocation density are available for the heteropitaxial InP cells grown on GaAs wafers. From the calculations it is observed that the dislocation density should be around 10^8 cm^{-2} for such cells.

From figures 3 to 5 it is observed that the reduction in emitter thickness and front surface recombination velocity has an appreciable effect on the cell short-circuit current and efficiency. The open-circuit voltage almost remains unaffected by the above change. From the results plotted in figures 3 to 5, it is observed that the effect of surface recombination velocity on the cell short-circuit current and efficiency becomes less pronounced as the emitter thickness reduces. It should be noted that improved cell current and efficiency results are

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References

1. Yamaguchi, M.; et al.: Electron Irradiation Damage in Radiation-Resistant InP Solar Cells. Jpn. J. Appl. Phys., vol. 23 no. 3, Mar. 1984, pp. 302-307.
2. Wienberg, I.; Swartz, C. K.; and Hart, R. E.: Potential for Use of InP Solar Cells in the Space Radiation Environment. 18th IEEE Photovoltaic Specialists Conference, IEEE, 1985, pp. 1722-1724.
3. Spitzer, M. B.; et al.: A Review of Indium Phosphide Space Solar Cell Fabrication Technology. 21st IEEE Photovoltaic Specialists Conference, Vol. 1, IEEE, 1990, pp. 196-206.
4. Keavney, C. J.; et al.: Fabrication of n^+/p InP Solar Cells on Silicon Substrates. Appl. Phys. Lett., vol. 54, no. 12, Mar. 20, 1989, pp. 1139-1141.
5. Keavney, C. J.; Haven, V. E.; and Vernon, S. M.: Surface Recombination and High Efficiency in InP Solar Cells. Proceedings 2nd International Conference on Indium Phosphide and Related Materials, April 23-25, 1990, Denver, USA, pp. 435-438.
6. Pearton, S. J.; et al.: Characterization of InP/GaAs/Si Structures Grown by Atmospheric Pressure Metalorganic Chemical Vapor Deposition. J. Appl. Phys., vol. 65, no. 3, Feb. 1, 1989, pp. 1083-1088.
7. Yamaguchi, M.; Yamamoto, A.; and Itoh, Y.: Effect of Dislocations on the Efficiency of Thin-Film GaAs Solar Cells on Si Substrates. J. Appl. Phys., vol. 59, no. 5, Mar. 1, 1986, pp. 1751-1753.
8. Yamaguchi, M.; et al.: A New Approach for Thin Film InP Solar Cells. Solar Cells, vol. 19, Nov. 1986, pp. 85-96.
9. Sugo, M.; et al.: Heteroepitaxial Growth and Characterization of InP on Si Substrates. J. Appl. Phys., vol. 68, no. 2, July 15, 1990, pp. 540-547.
10. Basore, P. A.; Rover, D. T.; and Smith, A. W.: PC-1D Version 2: Enhanced Numerical Solar Cell Modeling. 20th IEEE Photovoltaic Specialists Conference, Vol. 1, IEEE 1988, pp. 389-396.
11. Jain, R. K.; and Flood, D. J.: Estimation of Minortity Carrier Diffusion Lengths in InP/GaAs Solar Cells. Proceedings 2nd International Conference on Indium Phosphide and Related Materials, April 23-25, 1990, Denver, USA, pp. 439-446. (Also, NASA TM-103213).

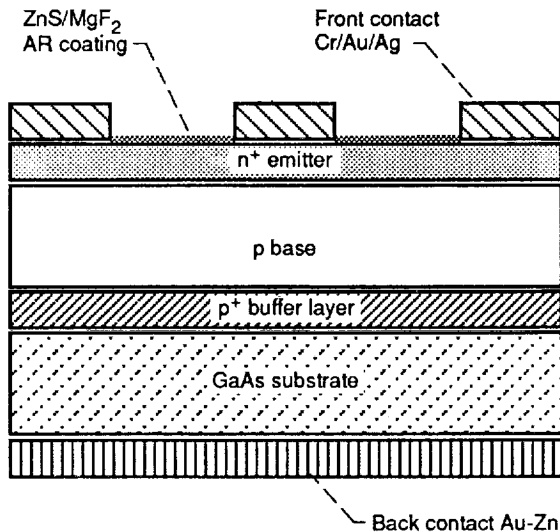

Figure 1.—Structure of a heteroepitaxial indium phosphide solar cell.

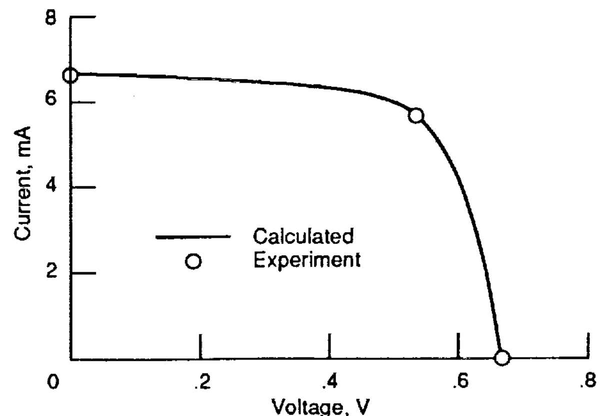

Figure 2.—Comparison of calculated and average measured I-V results.

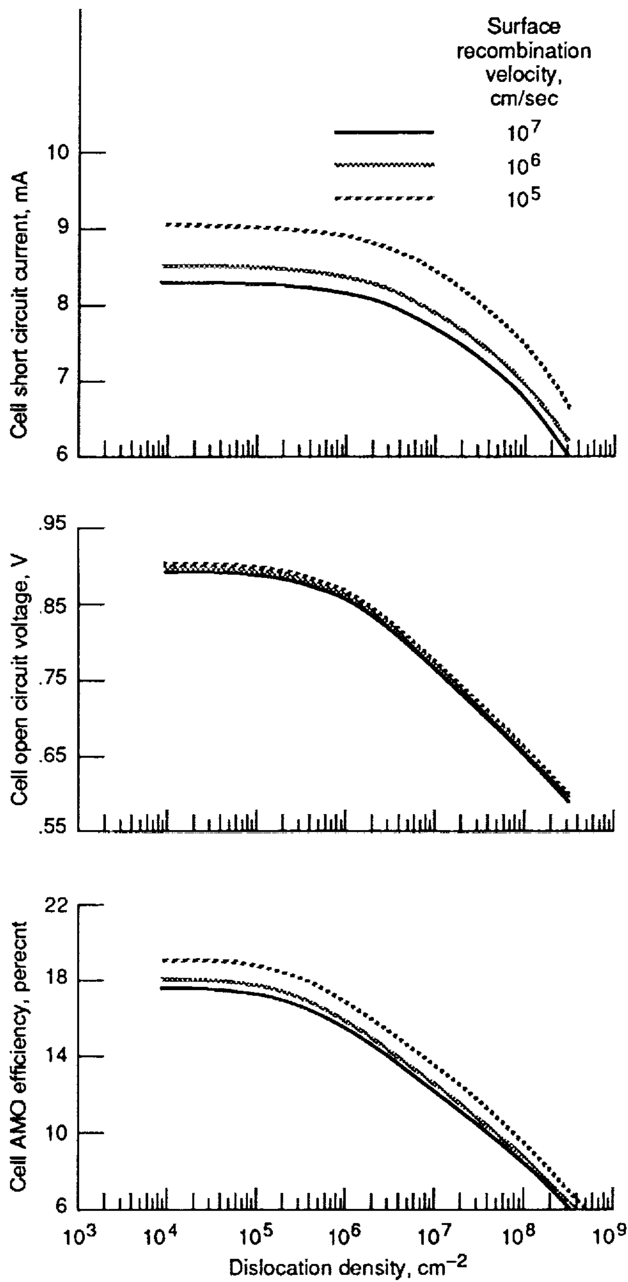

Figure 3.—Variation of heteroepitaxial indium phosphide solar cell short-circuit current (a), open-circuit voltage (b), and AMO efficiency (c) versus dislocation density as a function of surface recombination velocity. (Emitter thickness 40 nm)

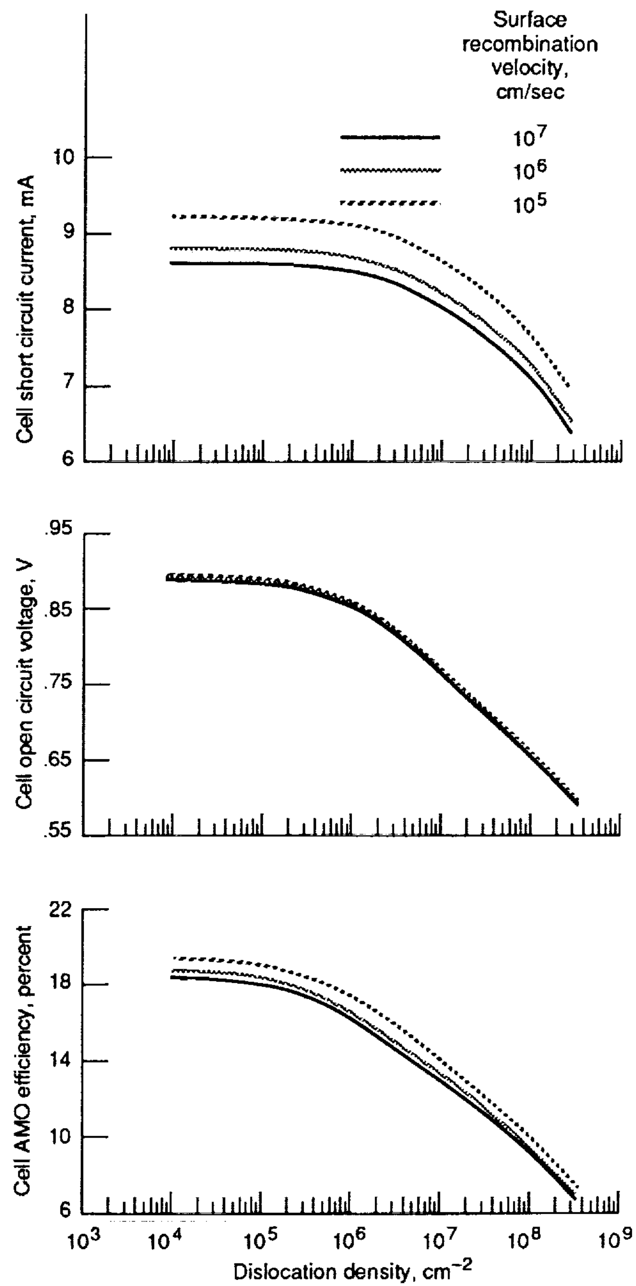

Figure 4.—Variation of heteroepitaxial indium phosphide solar cell short-circuit current (a), open-circuit voltage (b), and AMO efficiency (c) versus dislocation density as a function of surface recombination velocity. (Emitter thickness 30 num)

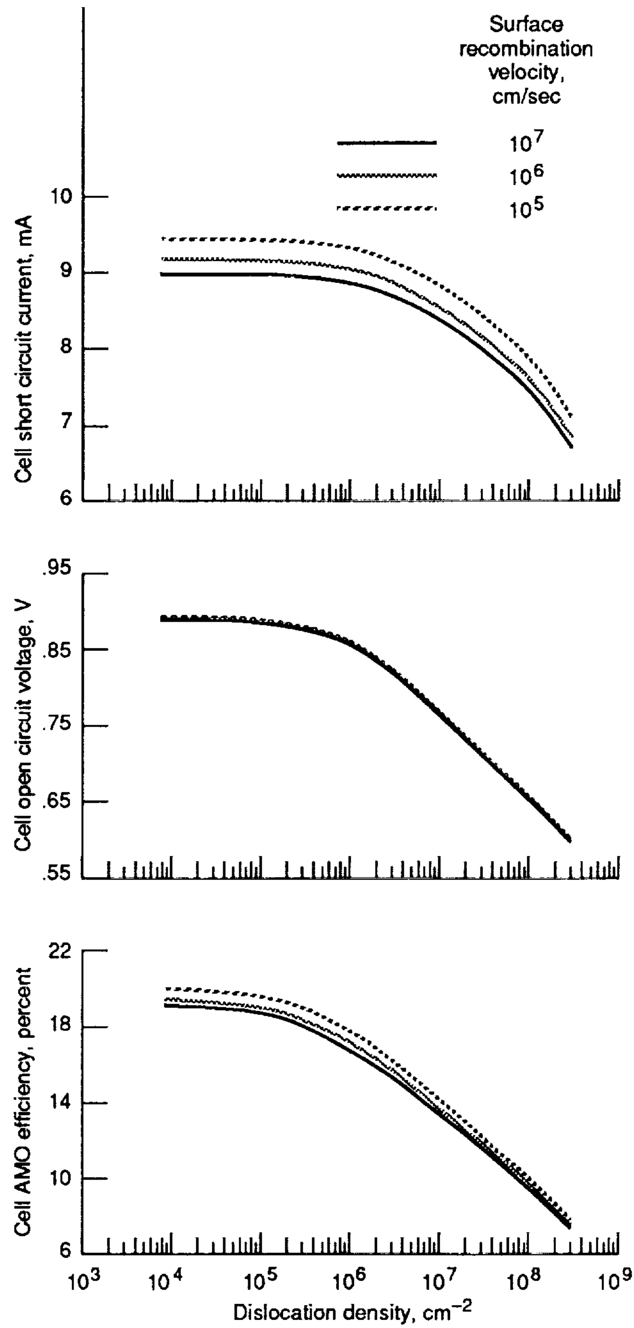

Figure 5.—Variation of heteroepitaxial indium phosphide solar cell short-circuit current (a), open-circuit voltage (b), and AMO efficiency (c) versus dislocation density as a function of surface recombination velocity. (Emitter thickness 20 nm)

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16. Abstract

Excellent radiation resistance of indium phosphide solar cells makes them a promising candidate for space power applications, but the present high cost of starting substrates may inhibit their large scale use. Thin film indium phosphide cells grown on Si or GaAs substrates have exhibited low efficiencies, because of the generation and propagation of large number of dislocations. Dislocation densities have been calculated and its influence on the open circuit voltage, short circuit current and efficiency of heteroepitaxial indium phosphide cells has been studied using the PC-1D. Dislocations act as predominant recombination centers and are required to be controlled by proper transition layers and improved growth techniques. It is shown that heteroepitaxial grown cells could achieve efficiencies in excess of 18 percent AM0 by controlling the number of dislocations. The effect of emitter thickness and surface recombination velocity on the cell performance parameters versus dislocation density plots is also studied.

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