N87-26444

SOLAR CELLS IN BULK InP USING AN OPEN TUBE DIFFUSION PROCESS*

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This paper describes a simple open tube diffusion technique for the fabrication of N+P junction solar cells. Large area (>0.25 cm^2) solar cells have been made by this process with a photovoltaic conversion efficiency of 15.2% under simulated AMO illumination. An ideality factor is 1.04 and a saturation current density of 9.6 x 10^{-16} A/cm^2 have been observed for these cells. These are the lowest (best) values reported to date for diffussed structures in bulk InP.

INTRODUCTION

At the present time there is large interest in the use of indium phosphide on solar cells for space applications. Besides being a direct band gap material with an energy gap of 1.34eV which is close to the one required for maximum efficiency under AMI illumination, it offers the possibility of low surface recombination velocity if properly passivated (ref. 1) and it has shown less degradation to gamma ray radiation than Si or GaAs cells of comparable junction depths (ref. 2).

InP solar cells previous reported had been fabricated by either epitaxial growth or by thermal diffusion in a closed box system (ref. 3, 4). In this paper we describe the fabrication and photovoltaic characteristics of n+p InP solar cells using a simple open tube diffusion process. Advantages of this technique are its case of implementation and potential for low cost.

DEVICE FABRICATION

The p-type InP substrates used for the fabrication were pre-polished LEC grown** 2" diameter wafers (100) misorientated 2° towards (110) and doped with Zn to a concentration of 5-6 x 10^{16} cm^{-3}. After degreasing the slices were etched in order to remove any residual poslishing damage. Before loading in the evaporator, the wafers were etched in 10% H_3PO_4 to remove any surface damage. A gallium sulphide (99.99% purity) film was evaporated onto the frontside which was used as the source for sulphur doping. To prevent degradation of the InP surface during diffusion the InP substrate was coated on top and back with a 0.5 um thick film of SiO_2. The silicon dioxide film was deposited on the wafer in a CVD reactor by the pyrolysis of silane and oxygen in an argon ambient. During the SiO_2 deposition the samples were held at 325°C. The sulphur diffusions were carried out for 20 to 60 minutes at 700°C in an open tube furnace with nitrogen gas flowing in order to prevent back diffusion of air. After diffusion the SiO_2 and Ga_2S_3 films were removed and a back ohmic contact

* Work performed under NASA-Lewis Grant No. NAG-3-604.
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made by evaporating a film of Au - 5% Zn and alloying it at 420°C in forming gas. The non-optimized top metallic grid was defined photolithographically and electroplated Au was used as the contact metal for the top n+ layer. The active area of the cell was delineated by a second photolithography step and it was mesa etched using a solution of iodic acid. The total area of the cell was 0.313 cm^2 which after substracting the area of the top metallic grid gives 0.265 as the active area of the cell. Since the refractive index of InP is approximately 3.5, the optimum values of the refractive index of a single layer AR coating is 1.9 which makes SiO a suitable choice for this purpose. An SiO layer of approximately 750 Å was evaporated over the whole cell to serve as an AR coating. No attempts were made to passivate the top n+ surface of the cell. A schematic diagram of the cell structure is shown in Fig. 1.

ELECTRICAL AND PHOTOVOLTAIC CHARACTERISTICS

Electrical characterization of the finished cells involved measurement of their photovoltaic performance of large area cells, their quantum efficiency as a function of wavelength and ln I vs V. Small area diodes were used for diagnostic purposes specially for determining the doping concentrations and doping profile in the vicinity of the junction. The photovoltaic performance of the large area solar cells was measured under simulated AM1 conditions in our laboratory and under simulated AM0 at NASA* and it is summarized in Table I using the active area of the cell. The short circuit is larger under AM0 conditions than under AM1 illumination but the fill factor and efficiency remain the same. Figure 2 shows the ln I vs V characteristics of a large area cell. For low forward biases the forward characteristics are determined by recombination in the depletion layer. At larger currents the ln I vs V characteristics are linear and show an ideality factor of n = 1.04 and saturation current density of $J_o = 9.6 \times 10^{-16}$ A/cm^2. The very low value of the saturation current density is responsible for the high open circuit voltage observed. The value of the ideality factor close to 1 indicates that the forward current characteristics are dominated by recombination in the neutral regions and not in the depletion layer of the junction which indicates a clean junction. The high value of the fill factor is a consequence of the ideality factor being close to 1 and that the top n+ layer is heavily doped so the series resistance is low even for the shallow junction used

Figure 3 shows the external quantum efficiency as a function of wavelength for typical AR and a non-AR coated cell. For the non-AR coated cell the quantum efficiency remains essentially constant for 500 nm to 850 nm where the efficiency drops very sharply and it is essentially zero at 920 nm which corresponds to the energy gap of InP.

The external quantum efficiency of the AR coated cell shows that the efficiency improves between 550 nm and 900 nm. This increase in efficiency is responsible for an increase of 37% in the short circuit current between AR coated and non-AR coated cells.

* The AM0 measurements were performed by Dr. I. Weinberg of NASA Lewis Research Center, Cleveland, Ohio.

COMPUTER SIMULATION

In our measurements the internal quantum efficiency η int was obtained from the measured external quantum efficiency η ext through the equation:

$$\eta \text{ int} = \eta \text{ ext}/(1-R) \qquad (1)$$

where R is the reflection coefficient. This internal quantum efficiency was compared to a computer simulation in order to determine important cell parameters. The internal quantum efficiency at short wavelengths is determined mainly by the junction depth and the top surface recombination velocity. The hole diffusion length in the top n+ layer does not appear to affect the quantum efficiency as long as the diffusion length is longer than the junction depth. At long wavelengths the internal quantum efficiency depends upon the depletion layer width and the electron diffusion length in the p-region.

Figure 4 shows the comparison between a computer simulation and the measured internal quantum efficiency of one of the non AR coated cells. The same figure shows that the values of the parameters for a good match were junction depth of 0.06 μm top surface recombination velocity of 2×10^6 cm/sec, depletion layer width of 0.26 μm and electron diffusion length of 2.5 μm. Of the above parameters the depletion layer width was determined by measuring the depletion layer capacitance of small area diodes.

CONCLUSION

We have demonstrated an open tube diffusion technique for fabricating high efficiency n+p InP solar cells. Detailed evaluation of the electrical and photovoltaic characteristics of the cells shows that the fabrication techniques used give a clean junction with an ideality factor close to 1 and a very low value of the saturation current density. Comparison of the measured and simulated spectral response as a function of wavelength allowed the determination of important device and material parameters.

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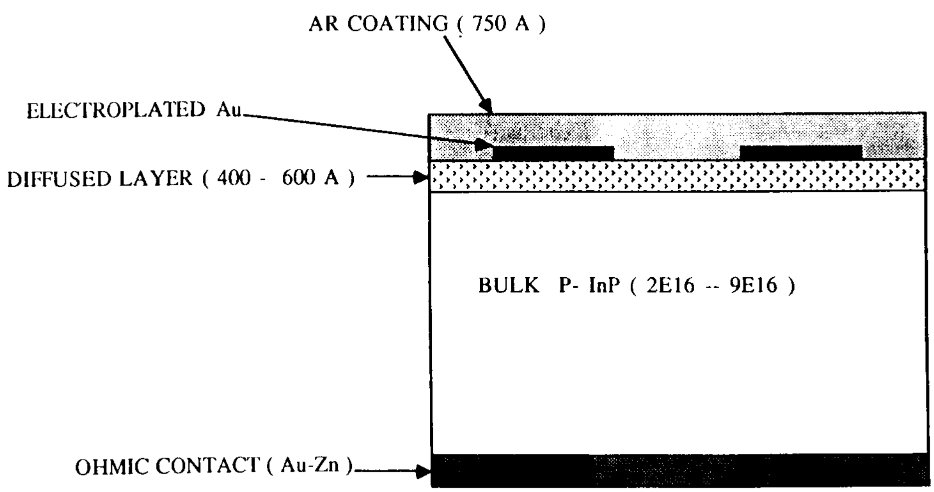
TABLE I

Photovoltaic Performance of Bulk n+p InP Cells.

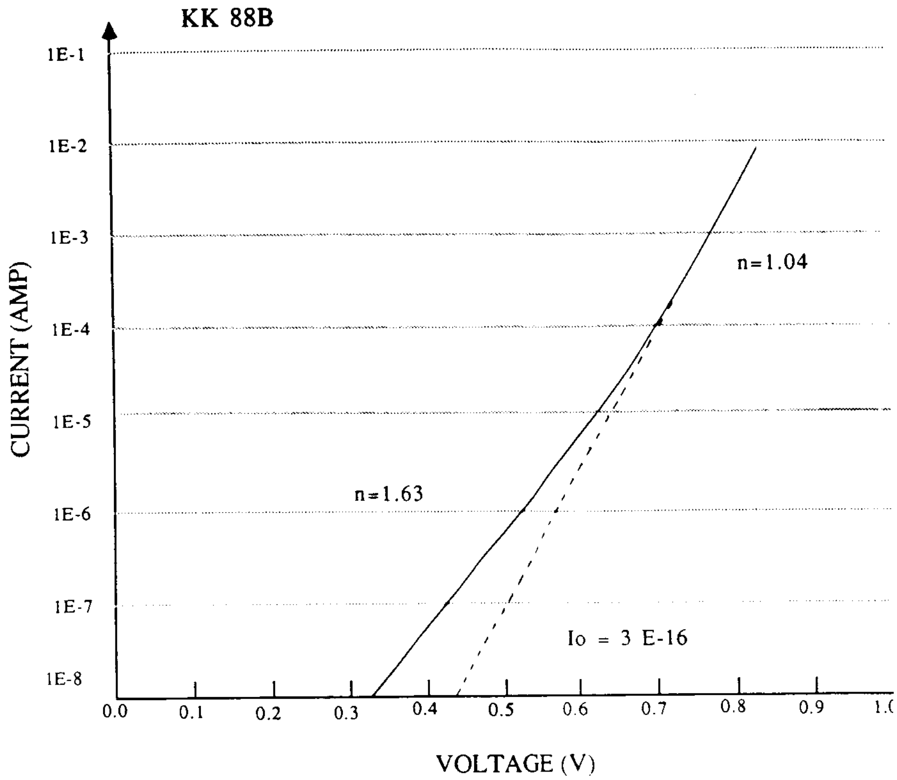
	J_{sc} (mA/cm^2)	V_{oc} V	FF -	Eff. (%)
AM - 1	24.7	0.800	0.815	16.3
AM-0 (NASA)	31.01	0.815	0.826	15.2

DEVICE STRUCTURE



* MESA ETCH DEFINED * DEVICE AREA 0.313 CM^2

Fig. 1 - Schematic Diagram of Solar Cell Structure



AREA = 0.313 cm^2

Jo = 9.58 E-16 A /cm^2

Fig. 2 - lnI vs V characteristics of large area solar cell

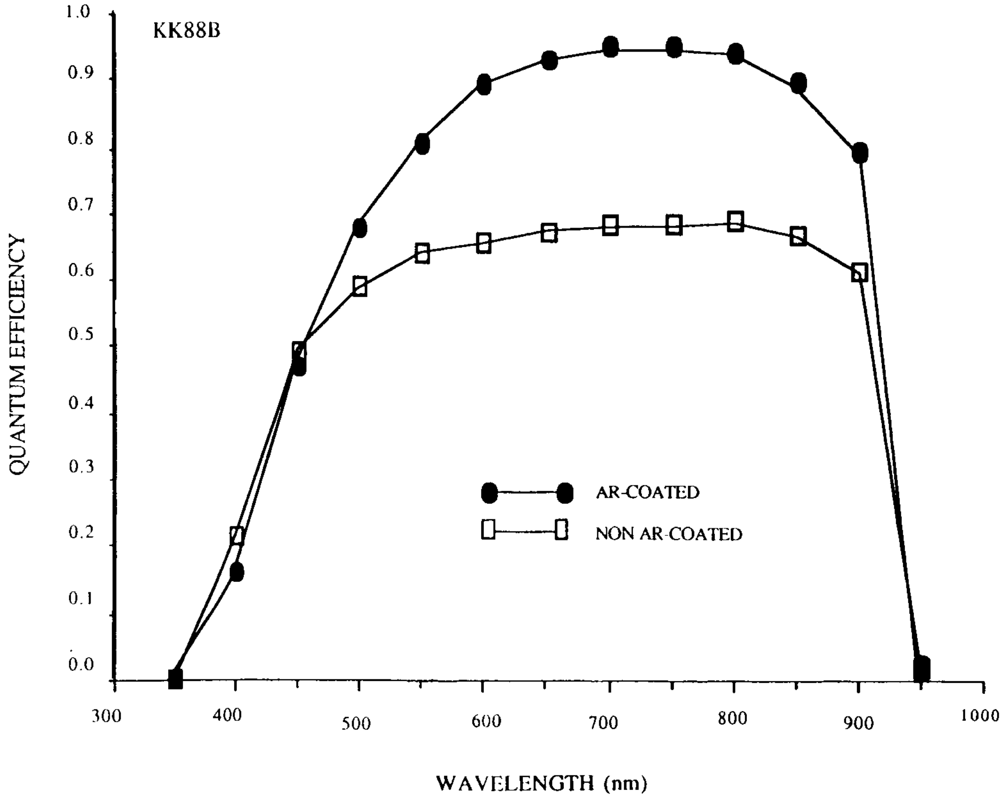


Fig. 3 - Quantum efficiency as a function of wavelength for n+p InP cells.

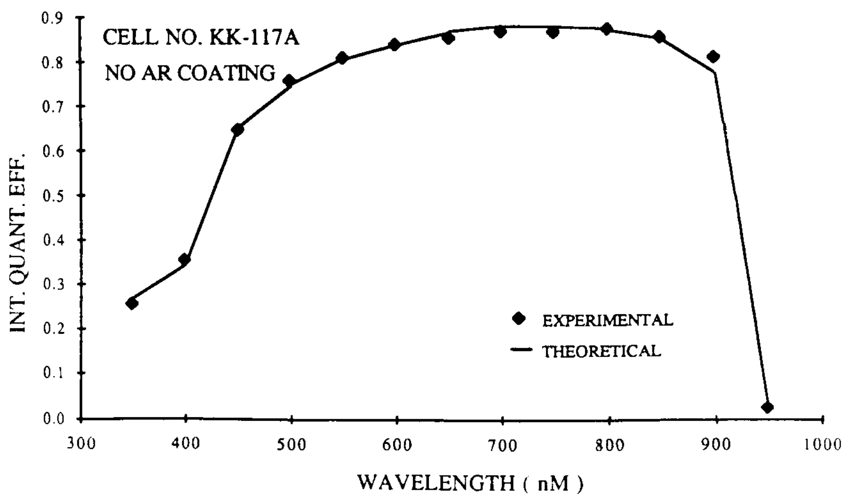


Fig. 4 - Comparison between measured and simulated internal quantum efficency for a non AR coated InP cell.