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HIGH-EFFICIENCY AlGaAs-GaAs CASSEGRAINIAN CONCENTRATOR CELLS*

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AlGaAs-GaAs heteroface space concentrator solar cells have been fabricated by metalorganic chemical vapor deposition. AMO efficiencies as high as 21.1% have been observed both for p-n and np structures under concentration (90-100X) at 25°C. Both cell structures are characterized by high quantum efficiencies and their performances are close to those predicted by a realistic computer model. In agreement with the computer model, the n-p cell exhibits a higher short-circuit current density.

INTRODUCTION

GaAs solar cells are becoming increasingly important for space applications. An attractive approach is offered by the concentrator space cell (Ref. 1), which has the potential for reaching efficiencies higher than those predicted for one-sun space solar cells (Ref. 2).

A concentrator cell will operate at a temperature of approximately 80°C; however, the predicted efficiency is still higher than for one-sun cells operating at 25°C. In this work, we are studying heteroface AlGaAs-GaAs p-n and n-p small-area concentrator solar cells grown by metalorganic chemical vapor deposition (MOCVD). The cells are intended for use in a miniaturized Cassegrainian concentrator assembly operating at approximately 100 suns, AMO. The cell has a circular configuration with 4-mm diameter active area, and the total dimensions are 5 mm x 5 mm. Cell efficiencies as high as 21.1% have been obtained under simulated 92 suns, AMO.

CELL DEVELOPMENT

The concentrator cells are designed by a realistic computer model which solves the transport equations and determines the current-voltage (I-V) characteristics. The model uses measured values of relevant parameters such as mobility, minority-carrier diffusion lengths, absorption coefficients, etc. Cells are optimized for operating conditions such as temperature and concentration. Under concentrated light, it is crucial that the emitter and grid pattern on top of the solar cell each have very low series resistance. At the same time, the internal spectral response must remain high and the obscuration must be minimized. A one-dimensional distributed resistance model incorporating dark current mechanisms such as injection and recombination is used to determine the I-V curve. Obscurations caused by the grid pattern and the AlGaAs window layer are also included in the model.

The cell structure used in the model is shown in Fig. 1. Starting from the substrate, a highly-doped buffer layer (0.5 μm) is grown to provide a smooth surface for overlying growths and also reduce recombination at the back of the cell. Next

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lie the two active layers, the base and the emitter, followed by a thin, highly-doped AlGaAs (90% Al) window layer. This layer reduces the surface recombination velocity in the emitter, and its thickness is optimized to couple with the antireflection (AR) coating to minimize the reflectance. Finally, the cell structure is terminated with a highly-doped GaAs cap layer serving as a contact layer for good ohmic contacts. This layer, which also protects the cell during processing, is selectively etched away immediately before deposition of a single-layer AR coating.

Calculations of the quantum efficiency are limited to the emitter, base, and depletion regions. Two optimized responses are shown in Fig. 2 for p-n and n-p structures, respectively, with the individual contributions from the various regions being indicated. In the p-n structure, most photons are absorbed in the p-type emitter, whereas in the n-p structure, all regions make significant contribution to the photogenerated current. Inherently lower resistivity of n-type versus p-type GaAs allows the use of a much thinner emitter in the n-p configuration. Consequently, a better radiation tolerance for n-p cells may be expected.

In addition to the quantum efficiency, the computer model finds the optimum performance. Figure 3 shows the I-V characteristics of an optimized p-n structure under 100X, AMO at 80°C. Efficiencies of 20.7% are predicted for both p-n and n-p cell structures. With the addition of gradients both in doping and in composition, even higher efficiencies are predicted, as indicated in Table I. These gradients can be added both in the base and emitter regions where they give rise to built-in fields that aid in the collection of photogenerated carriers. Over a 2% increase in efficiency is observed with the additional gradients.

For each optimized cell structure, the computer model provides doping levels and layer thicknesses. Thus far, fabrication and testing efforts have been concentrated primarily on cells without intentional gradients. The structures are grown in a horizontal rf-heated MOCVD reactor at 730°C, as described in Ref. 3. Selenium and zinc or magnesium (Ref. 4) are used as n-type and p-type dopants, respectively. An optimized grid pattern (shown in Fig. 4) is defined using conventional photolithographic techniques. Metallizations are typically deposited by evaporation to a thickness of 0.2 µm, and normally consist of Au/Ge/Ni/Au for n-type GaAs and Pd/Au for p-type GaAs. The front contact grid pattern is plated to 3-µm thickness.

Cell performances were measured both at Varian and at Sandia National Laboratories. All measurements are based on the total circular area with a 4-mm diameter. Figure 5 shows the I-V characteristics for a p-n cell under simulated concentrated light. The measurement was obtained at 28°C. The cell efficiency versus solar concentration is shown in Fig. 6, together with the theoretically-predicted behavior. The poor performance of the experimental cell at one sun may be attributed to shunt currents which become less significant at higher concentrations. However, the measured values are still below the theoretical values, which indicates that further improvements are necessary.

Cells having the n-p configuration have also been fabricated. Compared to p-n cells, these cells show larger values of short-circuit current, in agreement with the theoretical prediction. Similar behavior has been observed for large-area, 1-sun GaAs cells (Ref. 5). However, lower values of open-circuit voltage and fill factor are predicted and also experimentally observed. Therefore, the efficiencies of p-n and n-p cells are comparable. The n-p structure has a very thin emitter, which may be of importance for increased radiation hardness. Experiments will have to be conducted to assess whether the n-p cell exhibits better radiation tolerance. The addition of doping and compositional gradients, which provide built-in fields, may also improve radiation hardness by retaining good carrier collection even in damaged material.

High-efficiency cells intended for much higher concentrations have also recently been fabricated for terrestrial use. In this case, the doping levels were raised further to accommodate much higher current levels. These cells have the p-n configuration and are doped with Mg in the emitter. Efficiencies in excess of 26% have been observed at 753X (AM1.5, 100 mW/cm^2), as shown in Fig. 7.

CONCLUSIONS

Heteroface AlGaAs-GaAs cells for space concentrator applications have been demonstrated with efficiencies as high as 21.1% at 92X, AMO. Both p-n and n-p cell structures have been fabricated using MOCVD. The cells still need to be tested at temperatures up to 80°C. Similarly, the effects of intentional gradients in doping and composition must be evaluated. Radiation hardness may be increased by including gradients and using the n-p configuration.

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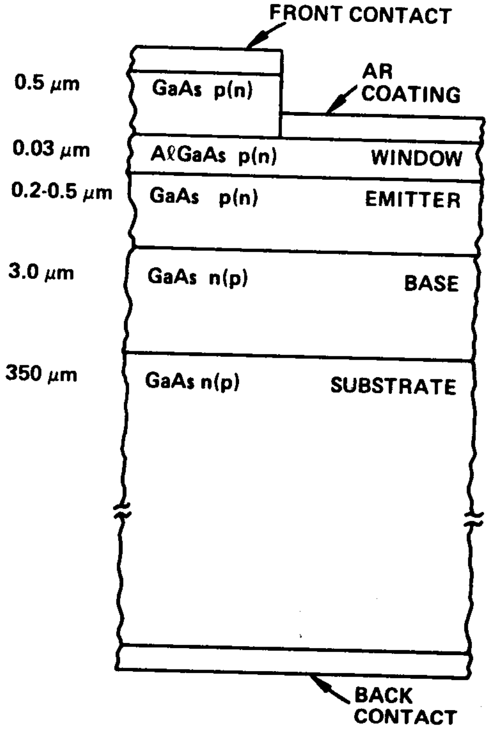
TABLE I. RESULTS OF CELLOPT OPTIMIZATION RUNS FOR CELLS OPERATING UNDER 100X, AMO AT 80°C.

E = exponential profile
L = linear profile
U = constant level of dopant or aluminum fraction

Type	Doping Profile	Aluminum Profile	Efficiency (%)
p-n	U	U	20.71
p-n	E	U	22.50
p-n	E	L	22.70
p-n	E	E	23.15
p-n	L	U	22.23
p-n	L	L	22.54
p-n	L	E	23.15
n-p	U	U	20.79
n-p	E	U	22.73
n-p	E	L	22.85
n-p	E	E	23.08
n-p	L	U	22.46
n-p	L	L	22.50
n-p	L	E	23.13



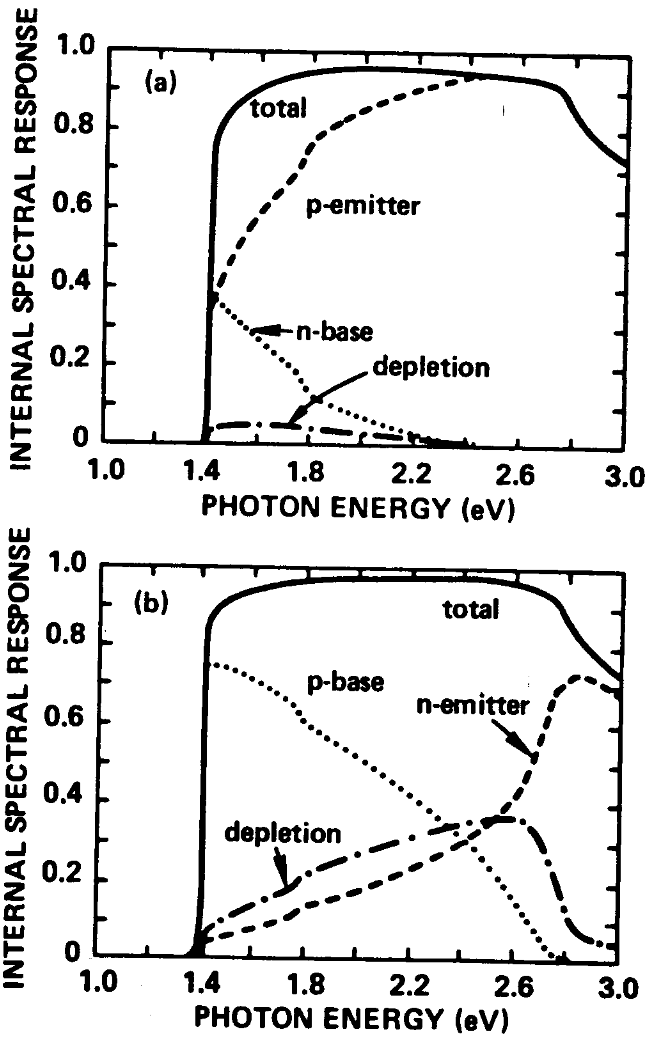


Fig. 1 Schematic solar cell structures in the computer model development.

Fig. 2 Internal spectral response versus photon energy determined by the computer modeling program for optimized (a) p-n and (b) n-p structures.

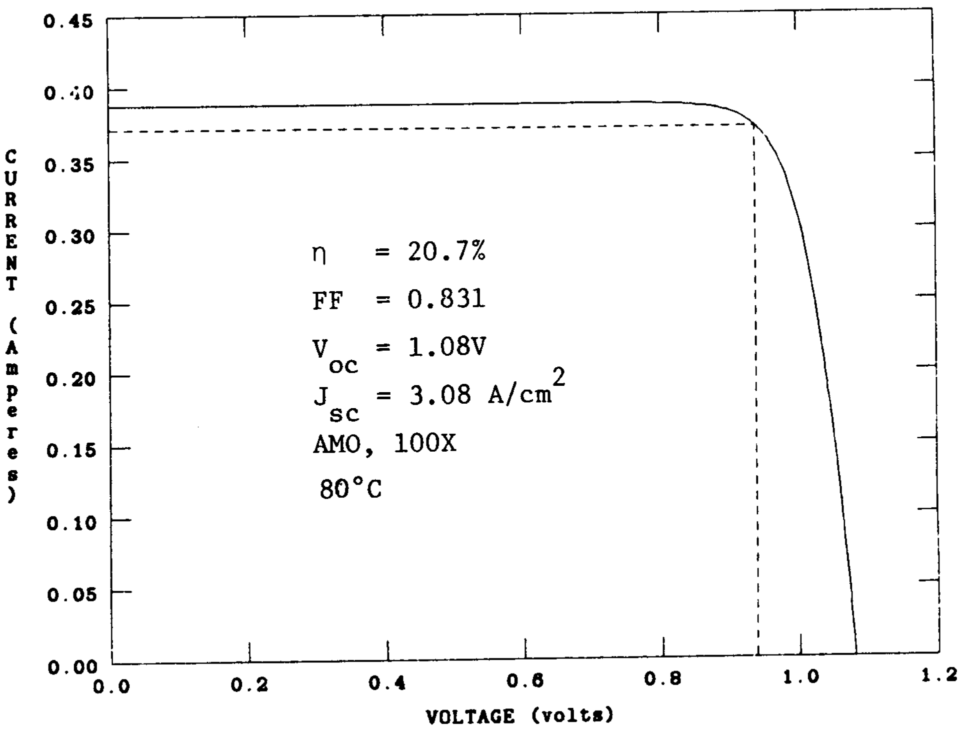


Fig. 3 Current-voltage characteristics for an optimized p-n cell as predicted by computer model. The cell operating conditions are indicated.

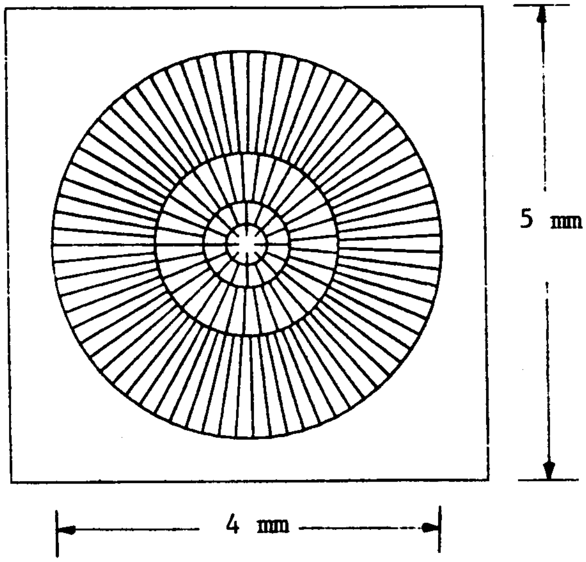


Fig. 4 Grid pattern for space concentrator cell.

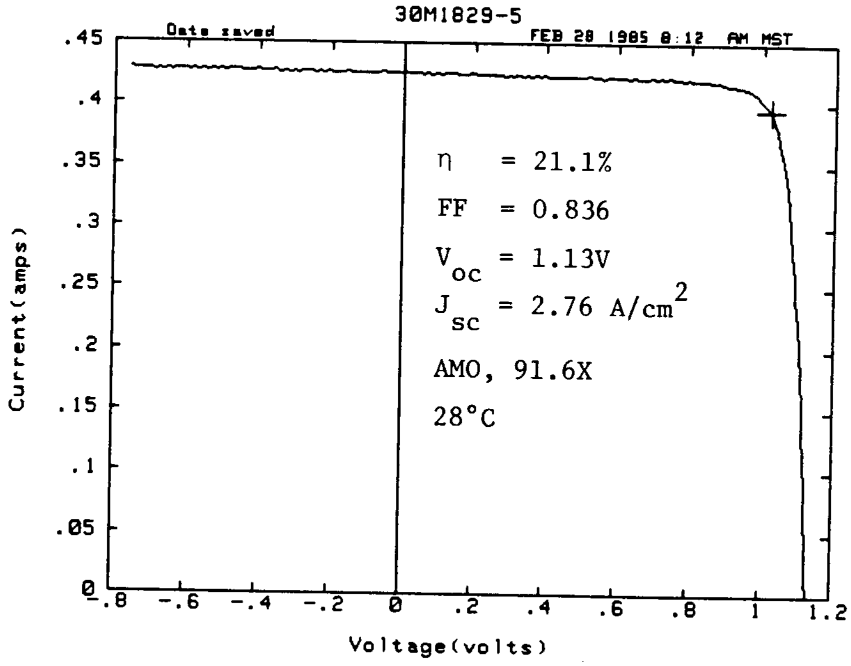


Fig. 5 Current-voltage characteristics for a p-n cell under simulated concentrated light.

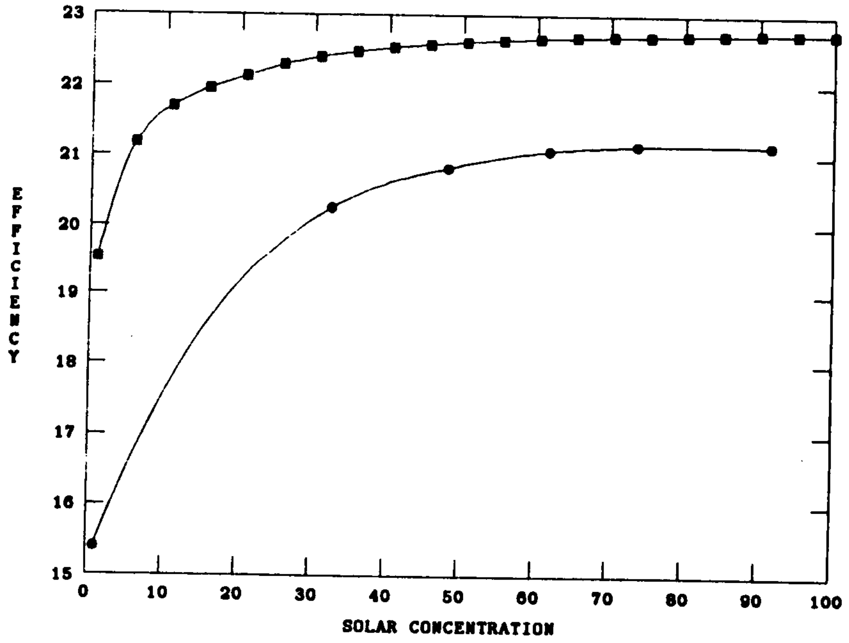


Fig. 6 Cell efficiency versus solar concentration at 28°C, AMO: computer model (■), experimental (●).

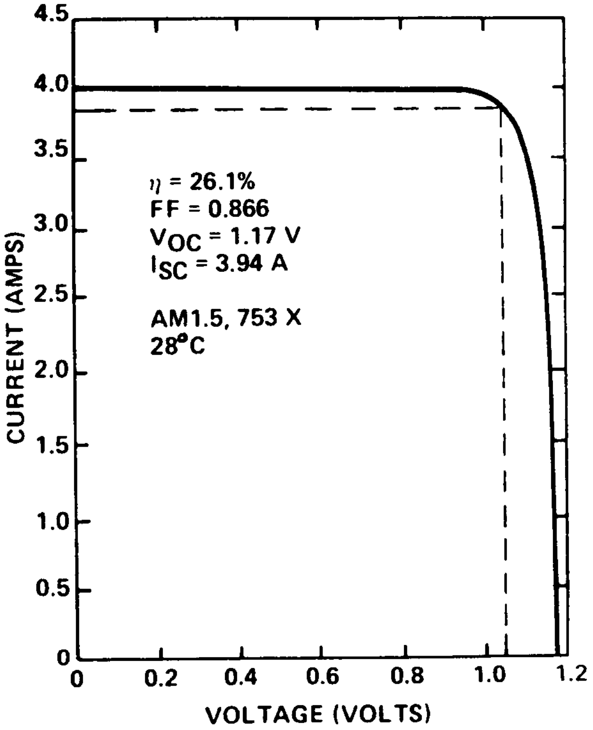


Fig. 7 Current-voltage characteristics for an experimental p-n solar cell under simulated terrestrial concentrated light.