PERFORMANCE OF GaAs CONCENTRATOR CELLS UNDER ELECTRON IRRADIATIONS FROM 0.4 TO 2.3 MeV

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ABSTRACT

Gallium Arsenide concentrator cells were irradiated with electrons with energies varying from 0.4 to 2.3 MeV and their electrical performance was measured. The cells were manufactured by Varian and they are 5x5 mm square with a 4 mm diameter illuminated area. At each of four different electron energy levels (0.4, 0.7, 1, and 2.3 MeV), there were three n/p and two p/n cells irradiated. I-V performance measurements were made prior to irradiation and at several intermediate fluence levels. The final fluence level was $3x10^{15}$ e/cm^2.

INTRODUCTION

During the past several years, the concept of concentrator arrays in space has come under intensive investigation. One of the interesting features of concentrator arrays is the potential for radiation resistance due to the shielding of the optical system. One factor which is not fully understood is the performance degradation of the concentrator cells themselves when measured at elevated sunlight levels. Previous work has presented results for GaAs, AlGaAs, InGaAs, and silicon concentrator cells irradiated with 1 MeV electrons and 37 MeV protons (1,2,3).

For this paper we are irradiating gallium arsenide concentrator cells with electrons with energies varying between 0.4 and 2.3 MeV. The ultimate purpose of this work is to provide input data for concentrator array designers, who know the shielding effects of their optical system, to aid in calculating the performance of concentrator arrays under space irradiation. With the addition of proton irradiation at a variety of energies, an initial look at damage equivalence for gallium arsenide concentrator cells can be made.

CELL DESCRIPTION

The concentrator cells irradiated during this work were GaAs with an AlGaAs window. They are 5 mm square with a 4 mm diameter illuminated area. The cells were made by Varian and are both n/p and p/n. They are OM-VPE grown with a junction depth of about half a micron. The cells were delivered to Lewis as part of a research contract with Varian Assoc. of Palo Alto California. The cells are bare with no coverglass and there was no shielding to simulate the optical concentrator.

EXPERIMENTAL DESCRIPTION

The cells were irradiated with electrons in several steps to a total fluence of $3x10^{15}$ e/cm^2. There were four different sets of cells irradiated and each set was irradiated with a different electron energy (0.4, 0.7, 1.0, and 2.3 MeV). Each set of cells consisted of 3 n/p cells and 2 p/n cells. The irradiations were done at the Westinghouse Research Center using a Van de Graff generator. During electron irradiations, the cells were bare with no coverglass attached. During electrical performance measurements, the cells were mounted in separate cell holders. The holders consisted of a small bottom metal base and a washer-like metal top with a beveled hole slightly larger than the illuminated area of the cell. These two pieces supplied both a support for the cell and and an area for the four wire electrical attachment. There was no soldering or welding of any contacts to the cells. The cells were bare except for the holders during measurements.

Electrical performance measurements were made on the unirradiated cells and at several intermediate fluence levels on the way to the final fluence of $3x10^{15}$ e/cm^2. The performance measurements consisted of the following:

1) I-V data at 25^{o}C and 1 AMO using an X-25 xenon solar simulator and a reference cell.

2) I-V data at 25^{o}C at several concentrations up to 100X AMO and above using a pulsed xenon solar simulator and the linear assumption between irradiance and short circuit current.

3) Short circuit current data at one fixed concentration at both 25^{o}C and 80^{o}C in order to set the current scale at the elevated temperature.

4) I-V data at 80^{o}C at several concentrations as in step 2 above.

During I-V measurements the cells in their holders are mounted to a temperature controlled block. The concentration level on the cell is varied by a combination of changing the distance from the light source and the use of a fresnel lens. Since the duration of the light pulse from the flash simulator is just 2 milli-seconds, there is no heating effect from the concentrated light. The elapsed time at 80°C was about 20 minutes for each cell at each fluence level.

RESULTS AND DISCUSSIONS

The initial (unirradiated) electrical characteristics for the GaAs concentrator cells at 25°C and 100X AMO are given in Table I. The Isc, Voc fill, and efficiency values are the averages for the 12 n/p cells and the 8 p/n cells which were irradiated during this work. Note that the p/n cells are slightly more efficient than the n/p cells, due mostly to a higher short-circuit current. When the cells are raised in temperature to 80°C there is a loss in power of about 6 to 7%. The efficiency values at 80°C and 100X AMO are 19.92% for the n/p cells and 20.23% for the p/n cells.

Table I Average performance of unirradiated cells at 25°C and 100X AMO.

	n/p cells	p/n cells
Isc (A/cm^2)	2.988	3.065
Voc (Volts)	1.131	1.127
Fill	0.858	0.860
Efficiency (%)	21.20	21.71

The ratios of electrical performance at several fluence levels to the unirradiated performance values are given in Tables II and III. Results for short-circuit current, open-circuit voltage, fillfactor, and maximum power are presented. Table II contains data for the n/p cells while Table III shows results for the p/n cells. All the results are for the 25°C-100X AMO case. Each Table has results for the four different electron energies which were used to irradiate the cells, (0.4, 0.7, 1.0, and 2.3 MeV).

Figures 1 and 2 show the maximum power ratio plotted as a function of electron fluence for the four different electron energies. Figure 1 is for the n/p cells while figure 2 contains the p/n cell data. Again, the results plotted are for the 25°C-100X AMO case. In all the figures which are plotted with electron fluence on the x-axis, the first measured data point is at $3x10^{13}$ e/cm^2. The point at $3x10^{12}$ is actually the unirradiated data.

There are several items of interest in the data which are evident in Tables II and III and figures 1 and 2. The degradation due to the 0.4 MeV electrons is minimal at low fluences and still quite small at $3x10^{15}$ e/cm^2. As the electron energy is increased from 0.4 towards 2.3 MeV, the

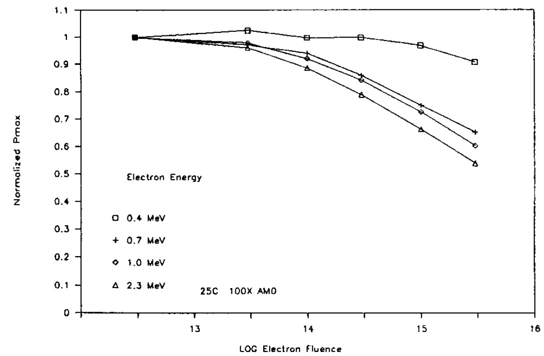

Figure 1 Normalized maximum power vs. electron fluence for n/p GaAs concentrator cells at four electron energy values.

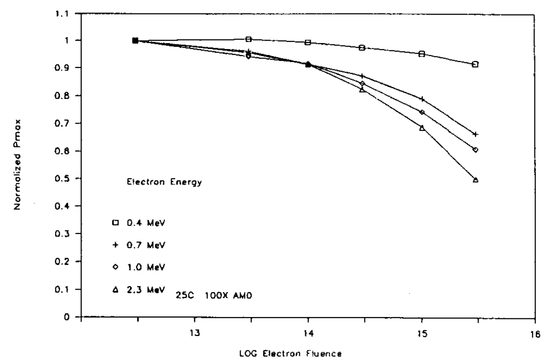

Figure 2 Normalized maximum power vs. electron fluence for p/n GaAs concentrator cells at four electron energy values.

degradation increases dramatically as seen in figures 1 and 2. This is the same trend that is observed in silicon cells (4). This leads to the conclusion, (at least for electron irradiations), that shielding by an optical concentrator that either lowers the electron flux or slows the electrons down will improve the radiation performance of the GaAs concentrator cell.

There are some small differences in the radiation resistances of the n/p and p/n cells. Figure 3 shows normalized Pmax for the 2.3 MeV electron fluences for both the n/p and p/n cells at 25°C and 100X AMO. The difference between the two curves is small and probably is due to normal fluctuations due to the small number of cells irradiated.

Table II Ratios of irradiated to initial values after several electron fluences at 25°C and 100X AMO for n/p cells.

Fluence (e/cm^2)	Isc	Voc	Fill	Pmax
	0.4 MeV electrons			
$3x10^{13}$	1.024	0.997	1.005	1.025
$1x10^{14}$	1.010	0.992	0.996	0.997
$3x10^{14}$	1.015	0.989	0.995	0.999
$1x10^{15}$	0.998	0.980	0.991	0.970
$3x10^{15}$	0.970	0.961	0.974	0.907
	0.7 MeV electrons			
$3x10^{13}$	1.004	0.983	0.986	0.973
$1x10^{14}$	0.988	0.968	0.984	0.941
$3x10^{14}$	0.930	0.950	0.972	0.858
$1x10^{15}$	0.851	0.923	0.955	0.750
$3x10^{15}$	0.774	0.896	0.940	0.652
	1.0 MeV electrons			
$3x10^{13}$	0.996	0.984	1.000	0.980
$1x10^{14}$	0.965	0.966	0.988	0.920
$3x10^{14}$	0.907	0.947	0.979	0.842
$1x10^{15}$	0.819	0.914	0.969	0.725
$3x10^{15}$	0.722	0.883	0.944	0.602
	2.3 MeV electrons			
$3x10^{13}$	0.985	0.981	0.995	0.961
$1x10^{14}$	0.944	0.962	0.976	0.886
$3x10^{14}$	0.873	0.938	0.963	0.789
$1x10^{15}$	0.774	0.910	0.940	0.662
$3x10^{15}$	0.665	0.875	0.925	0.539

Table III Ratios of irradiated to initial values after several electron fluences at 25°C and 100X AMO for p/n cells.

Fluence (e/cm^2)	Isc	Voc	Fill	Pmax
	0.4 MeV electrons			
$3x10^{13}$	0.997	1.001	1.008	1.007
$1x10^{14}$	1.000	0.998	0.996	0.994
$3x10^{14}$	0.991	0.994	0.989	0.974
$1x10^{15}$	0.975	0.988	0.989	0.953
$3x10^{15}$	0.947	0.976	0.991	0.916
	0.7 MeV electrons			
$3x10^{13}$	0.983	0.987	0.993	0.962
$1x10^{14}$	0.971	0.973	0.969	0.915
$3x10^{14}$	0.934	0.955	0.977	0.871
$1x10^{15}$	0.875	0.923	0.980	0.790
$3x10^{15}$	0.768	0.892	0.969	0.663
	1.0 MeV electrons			
$3x10^{13}$	0.968	0.984	0.991	0.944
$1x10^{14}$	0.953	0.968	0.995	0.917
$3x10^{14}$	0.914	0.941	0.982	0.845
$1x10^{15}$	0.834	0.905	0.984	0.743
$3x10^{15}$	0.715	0.875	0.974	0.609
	2.3 MeV electrons			
$3x10^{13}$	0.973	0.985	0.999	0.957
$1x10^{14}$	0.956	0.964	0.992	0.913
$3x10^{14}$	0.891	0.938	0.986	0.824
$1x10^{15}$	0.786	0.899	0.975	0.688
$3x10^{15}$	0.603	0.863	0.962	0.500

In all cases, the short-circuit current degradation was larger than that of the open-circuit voltage. Figure 4 shows the normalized values of Isc, Voc, and Pmax after $1x10^{15}$ e/cm^2 as a function of electron energy. The results are again for the 25C and 100X AMO case. At all electron energies, the degradation of current is about double that of voltage. The trend of increasing degradation with increasing electron energy is also quite evident in Figure 4.

During the course of each measurement series, results were obtained at 80°C as well as 25°C. In all cases, the degradation at 100X AMO was essentially the same when measured at the two temperatures. Figure 5 shows the comparison between the two temperatures for the p/n cells under 2.3 MeV electron irradiations. This is the "worst case" set of data and still the two curves are quite similar. It can be concluded that the power degradation is independent of the temperature at which it is measured.

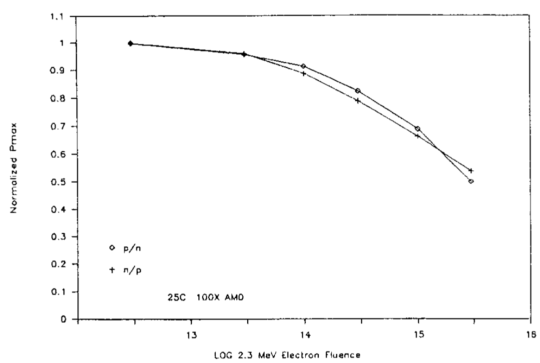

Figure 3 Comparison of normalized maximum power between n/p and p/n cells at 25C and 100X AMO (2.3 MeV electrons).

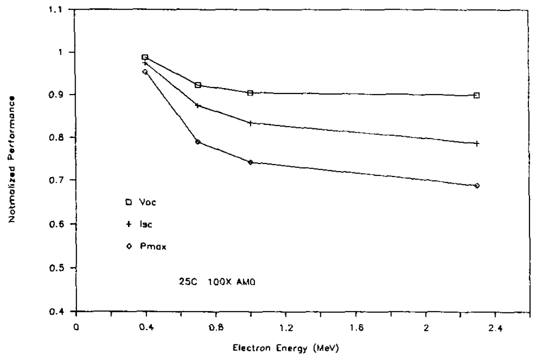

Figure 4 Performance ratios (Isc, Voc, Pmax) of p/n cells vs. electron energy after $1x10^{15}$ e/cm^2 at 25C and 100X AMO.

The Varian GaAs concentrator cells irradiated during this work were very similar to other Varian cells delivered to Lewis about two years prior to the delivery of the present cells. Radiation damage results on the "old" cells were presented previously (1,3) for 1 MeV electron irradiations. A comparison of the "old" and current cells is shown in figure 6, which plots cell efficiency vs. 1 MeV electron fluence. Note that the older cells degrade less but when plotted on an actual output scale (cell efficiency), the two curves are fairly close.

CONCLUDING REMARKS

Gallium arsenide concentrator cells made by Varian were irradiated with 0.4, 0.7, 1.0, and 2.3 MeV electrons to a total fluence of $3x10^{15}$ e/cm^2. The cells were quite small with an illuminated diameter of 4 mm. Both n/p and p/n cells were irradiated. The major results were:

1) The degradation due to electron irradiation increased dramatically with increasing electron energy. From this, one may conclude that any shielding from an optical concentrator will improve the radiation resistance of the cells.

2) The cell radiation performances were essentially the same when measured at 25^oC or 80^oC.

3) There were only minor differences in the radiation performances of the n/p and p/n cells.

4) In all cases, the degradation in current was about twice as large as the degradation in voltage.

5) The degradation of the cells in this work is fairly close to earlier data on similar cells (1.0 MeV electrons), especially when compared on an actual cell output basis.

REFERENCES

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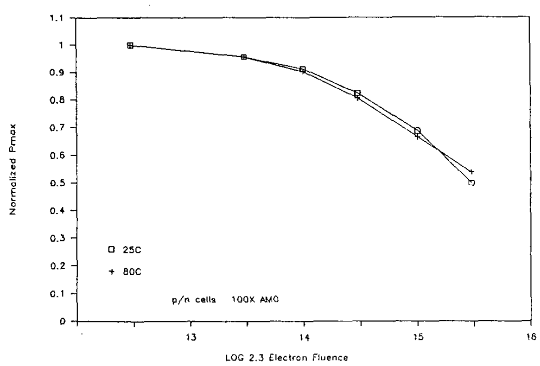

Figure 5 Normalized maximum power vs 2.3 MeV electron fluence for p/n cells at 25C and 80C.

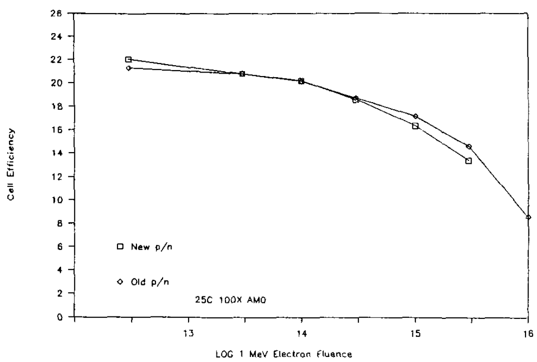

Figure 6 Comparison of current and older p/n cells at 25C and 100X AMO under 1 MeV electron irradiations.