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Performance of GaAs and Silicon Concentrator Cells Under 37 MeV Proton Irradiation

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PERFORMANCE OF GaAs AND SILICON CONCENTRATOR CELLS

UNDER 37 MeV PROTON IRRADIATION

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SUMMARY

Gallium arsenide concentrator cells from three sources and silicon concentrator cells from one source were exposed to 37 MeV protons at fluences up to 2.8×10^{12} protons per square cm. Performance data were taken after several fluences, at two temperatures (25 and 80 °C), and at concentration levels from 1 to about 150X AMO. Data at one sun and 25 °C were taken with an X-25 xenon lamp solar simulator. Data at concentration were taken using a pulsed solar simulator with the assumption of a linear relationship between short-circuit current and irradiance. The cells are 5 by 5 mm with a 4-mm diameter illuminated area.

INTRODUCTION

The use of concentrating optics for space photovoltaic power generation has been under consideration for some time. The potential advantages of concentrators include higher cell efficiency, better radiation resistance and lower cost. One possible optical design out of several is the miniature Cassegrainian concept developed by TRW (ref. 1). This design involves small gallium arsenide cells operating at a concentration level of 100 to 130X AMO. The cells are 5 by 5 mm with a 4-mm diameter illuminated area which leaves about half the cell area covered with outer bus-bar.

One of the unanswered questions involving concentrator cells is their performance degradation at concentrated light levels after electron and proton irradiation. As part of an ongoing concentrator cell program at NASA Lewis Research Center, we have irradiated several concentrator gallium arsenide cells with either 1 MeV electrons or 37 MeV protons. For comparison purposes, we also irradiated some silicon small area concentrator cells. The data for the electron irradiations were presented at the 18th PVSC (ref. 2). The results of the proton irradiations are presented here along with some comparison to the electron data.

CELL DESCRIPTION

The gallium arsenide cells used for these irradiations are from three sources, Hughes, Varian, and ASEC. All the cells are p/n with an AlGaAs window and a junction depth of 0.5 µm. The Hughes cells are LPE grown while the Varian and ASEC cells are OM-CVD. The Hughes and Varian cells were supplied to NASA Lewis as part of NASA contracts, while Lewis purchased the ASEC cells directly. The silicon cells were given to NASA Lewis for this experiment by ASEC. They are 2 Ω-cm n/p cells with a junction depth of 0.2 µm. There were two cells from each source irradiated for this work.

EXPERIMENTAL DESCRIPTION

During cell performance measurements the small area concentrator cells were individually mounted in separate cell holders. The holders consist 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 supply both a permanent support for the cell and an area for the four-wire electrical attachment. There was no soldering or welding of any contact to any cell. The Varian cells remained in their holders throughout all proton irradiations and performance measurements, while the other cells were removed from their holders for the proton irradiations. There were no cover glasses attached to the cells, nor was there any shielding by optical elements during the irradiations.

Proton irradiations using 37 MeV protons were performed at the NASA Lewis cyclotron. The cells were irradiated to a total fluence of 2.8×10^{12} protons per square centimeter, with performance measurements made at several intermediate fluence levels. The performance measurements consisted of the following:

(1) I-V data at 25 °C and 1 AMO using an X-25 xenon solar simulator and a reference cell.

(2) I-V data at 25 °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 and 80 °C in order to set the current scale at the elevated temperature.

(4) I-V data at 80 °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 ms, there is no heating effect from the concentrated light. The elapsed time at 80 °C was about 30 min for each cell. Several repeat measurements were made at 1 sun and 25 °C after the elevated temperature measurements, in order to determine if any annealing had taken place.

RESULTS AND DISCUSSIONS

All the data shown are the averages of the two cells from each source which were carried throughout the proton irradiations. Each of the gallium arsenide cell groups had at least one cell with an efficiency of over 20 percent at 100X AMO and 25 °C before irradiation. The silicon cells were near 16 percent at the same temperature and concentration. Including the cells which were irradiated with electrons (ref. 2), the average efficiency (25 °C, 100X AMO) for the three types of GaAs cells varies from 19.1 to 21.3 percent. The average efficiency for the silicon cells is 16.4 percent. The data presented here are intended to be a first look at the performance of concentrator cells after proton bombardment, and should not be used for final comparison between cell sources.

Tables I to III show the ratios of short circuit current, open circuit voltage, fill factor, and maximum power after irradiation to the unirradiated values for several fluence levels at three different measurement conditions. Table I shows data for 25 °C at 1 sun, while tables II and III show data for 100X concentration at 25 and 80 °C respectively. The ratios for short-circuit current at 25 °C are the same for both solar irradiation levels due to the linear current-irradiance assumption. Figure 1 shows the normalized P_{max} ratio versus 37 MeV proton fluence for all four cells at 25 °C and 100X.

The data indicates that all three types of GaAs cells were more resistant to 37 MeV protons than the silicon cells. At 100X AMO and 2.8×10^{12} protons per square centimeter, the maximum power degrades about 16 percent for the three GaAs cells, while the silicon cells degraded over 40 percent.

For the gallium arsenide cells, the drop in power is fairly evenly divided between voltage and current losses. The one exception to this is the ASEC cells at concentration. The dominant loss in the silicon cells is due to the current. Table IV summarizes the major loss parameter for the various cells at both AMO and at 100X. For comparison purposes, we have also included similar information for 1 MeV electrons (ref. 2). Note the silicon cell P_{max} drop is always dominated by the current loss. For the GaAs cells, there is the general trend of current loss being dominant for 1 MeV electrons to both current and voltage being important for the 37 MeV protons.

Figures 2 to 5 show the ratios of maximum power, short-circuit current, open-circuit voltage, and fill factor to the initial values as a function of proton fluence. The data are for 25 °C and 100X AMO. Each figure is for either silicon or one of the GaAs cell types. As stated above, the Varian and Hughes GaAs exhibit roughly an equal current and voltage drop while the ASEC GaAs and the silicon cells are mainly current loss. In general, the fill factor drop is quite small and does not play an important role in the power degradation.

The data discussed above has been mainly for 25 °C and 100X AMO. The cells are concentrator cells and the 100X data is the most important, however we do have data at 1 sun--25 °C and also at 100X--80 °C. Figure 6 shows P_{max} ratio versus 37 MeV proton fluence for the different cells at 25 °C and AMO. As in the 100X case of figure 1, the three GaAs cells all degrade much less than the silicon cells. However the Varian cells degrade somewhat less at one sun than the other GaAs cells. This is shown further in figures 7 and 8 which show the P_{max} ratio for both the Varian and ASEC GAAs cells at the three measurement conditions.

Note that for the ASEC cells (fig. 7) the data shows more degradation at 1 sun than at concentration which is the opposite of the Varian cells (fig. 8). It must be remembered that these are concentrator cells designed to operate at 100X and they are very small (5 by 5 mm). Because of their small size, there may be edge related shunting paths which can be changed by the proton irradiations. These would be much less important at the higher current densities at concentration. Also shown on figures 7 and 8 are data at 80 °C and 100X. For all the GaAs cells the 80 °C data shows a little more degradation than the 25 °C data. The differences are not large enough to be significant.

Performance data was also taken at 25 °C after the 30 min spent at 80 °C for measurement purposes for several cells in order to determine if there were any annealing effects. In all cases, there was no annealing due to the time spent at 80 °C.

CONCLUDING REMARKS

Gallium arsenide cells from three sources and silicon cells from one source were irradiated with 37 MeV protons to a total fluence of 2.8×10^{12} protons per square centimeter. After several different intermediate fluences performance measurements were made at both 25 and 80 °C at different irradiance levels. The major conclusions were:

1. The GaAs cells all were more radiation resistant to the 37 MeV protons than the silicon cells.

2. There was no large difference in the degradation of GaAs cell performance when measured at 25 or 80 °C.

3. There was no annealing due to the time spent (about 30 min) at 80 °C for measurements.

REFERENCES

1. R.E. Patterson, "Preliminary Concept of a 100-Kilowatt Miniaturized Cassegrainian Concentrator Solar Array," NASA CP-2314, 1983, pp. 157-162.

2. H.B. Curtis and C.K. Swartz, "Performance of GaAs and Silicon Concentrator Cells Under 1 MeV Electron Irradiation," in Eighteenth IEEE Photovoltaic Specialists Conference, Piscatawa, NJ: IEEE, 1985, pp. 356-361.

TABLE I. - RATIOS OF IRRADIATED TO INITIAL VALUES AFTER SEVERAL 37 MeV PROTON FLUENCES AT 25 °C AND AM0

Fluence, p/cm^2	I_{sc}	V_{oc}	Fill	P_{max}
Varian				
7.6×10^{10}	0.987	0.999	0.995	0.982
2.5×10^{11}	.972	.988	1.005	.966
6.5×10^{11}	.955	.970	1.002	.929
3.0×10^{12}	.924	.934	1.021	.882
Hughes				
7.6×10^{10}	0.991	0.980	0.994	0.966
2.5×10^{11}	.976	.965	.987	.930
6.2×10^{11}	.959	.946	.976	.885
2.8×10^{12}	.910	.895	.952	.776
ASEC				
7.6×10^{10}	0.980	0.993	0.991	0.964
2.5×10^{11}	.967	.973	.973	.915
6.2×10^{11}	.945	.959	.968	.878
2.8×10^{12}	.899	.911	.935	.766
Silicon				
7.6×10^{10}	0.869	0.954	0.912	0.758
2.5×10^{11}	.759	.929	.875	.617
6.2×10^{11}	.711	.895	.837	.535
2.8×10^{12}	.603	.863	.827	.431

TABLE II. - RATIOS OF IRRADIATED TO INITIAL VALUES AFTER SEVERAL 37 MeV PROTON FLUENCES AT 25 °C AND 100X

Fluence, p/cm^2	I_{sc}	V_{oc}	Fill	P_{max}
Varian				
7.6×10^{10}	0.987	0.990	1.006	0.984
2.5×10^{11}	.972	.977	.995	.947
6.5×10^{11}	.955	.964	.988	.909
3.0×10^{12}	.924	.928	.980	.841
Hughes				
7.6×10^{10}	0.991	0.989	1.008	0.987
2.5×10^{11}	.976	.978	.996	.951
6.2×10^{11}	.959	.965	1.005	.929
2.8×10^{12}	.910	.943	.981	.842
ASEC				
7.6×10^{10}	0.980	0.998	1.008	0.987
2.5×10^{11}	.967	.993	.995	.955
6.2×10^{11}	.945	.987	.990	.923
2.8×10^{12}	.899	.977	.955	.838
Silicon				
7.6×10^{10}	0.869	0.989	1.004	0.862
2.5×10^{11}	.759	.978	.994	.736
6.2×10^{11}	.711	.958	.994	.677
2.8×10^{12}	.603	.935	.993	.559

TABLE III. - RATIOS OF IRRADIATED TO INITIAL VALUES AFTER SEVERAL 37 MeV PROTON FLUENCES AT 80 °C AND 100X

Fluence, p/cm^2	I_{sc}	V_{oc}	Fill	P_{max}
Varian				
$7.6x10^{10}$	0.990	0.988	1.003	0.981
$2.5x10^{11}$	.973	.970	.988	.933
$6.5x10^{11}$	.954	.959	.986	.902
$3.0x10^{12}$	.919	.920	.967	.816
Hughes				
$7.6x10^{10}$	0.988	0.985	0.998	0.977
$2.5x10^{11}$	.972	.971	.994	.941
$6.2x10^{11}$	.949	.963	.997	.913
$2.8x10^{12}$	.900	.931	.970	.815
ASEC				
$7.6x10^{10}$	0.982	0.997	0.995	0.974
$2.5x10^{11}$	.967	.988	.980	.938
$6.2x10^{11}$	.937	.991	.976	.905
$2.8x10^{12}$	.890	.979	.945	.823
Silicon				
$7.6x10^{10}$	0.894	0.993	1.001	0.888
$2.5x10^{11}$	.796	.994	.998	.790
$6.2x10^{11}$	.756	.952	.992	.715
$2.8x10^{12}$	.662	.920	.997	.606

TABLE IV. - DOMINANT CONTRIBUTION (CURRENT/VOLTAGE) TO P_{max} LOSS FOR VARIOUS CELLS UNDER 37 MeV PROTON AND 1 MeV ELECTRON RADIATIONS AT BOTH AMO AND 100X

Cell Type	37 MeV protons		1 MeV electrons	
	AMO	100X	AMO	100X
Varian GaAs	Both	Both	Current	Both
Hughes GaAs	Both	Both	Current	Current
ASEC GaAs	Both	Current	Current	Current
Silicon	Current	Current	Current	Current

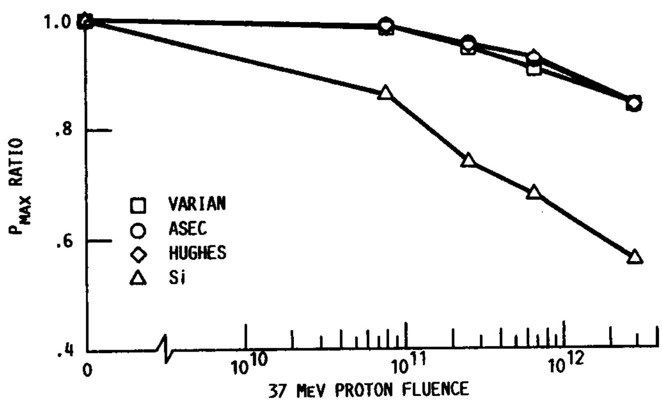

FIGURE 1. - MAXIMUM POWER RATIO VERSUS 37 MeV PROTON FLUENCE FOR FOUR DIFFERENT CELLS AT 25 °C AND 100X AMO.

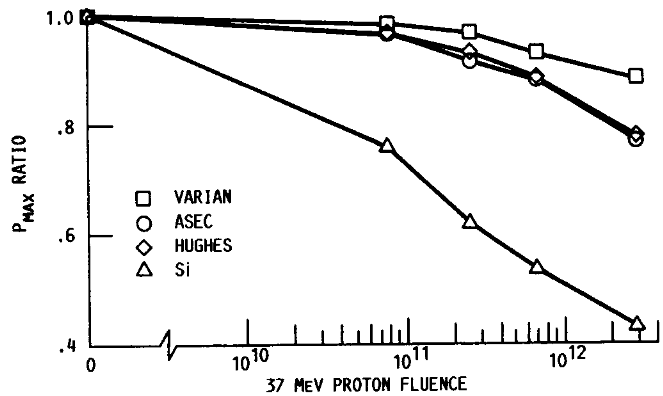

FIGURE 2. - MAXIMUM POWER RATIO VERSUS 37 MeV PROTON FLUENCE FOR FOUR DIFFERENT CELLS AT 25 °C AND ONE SUN.

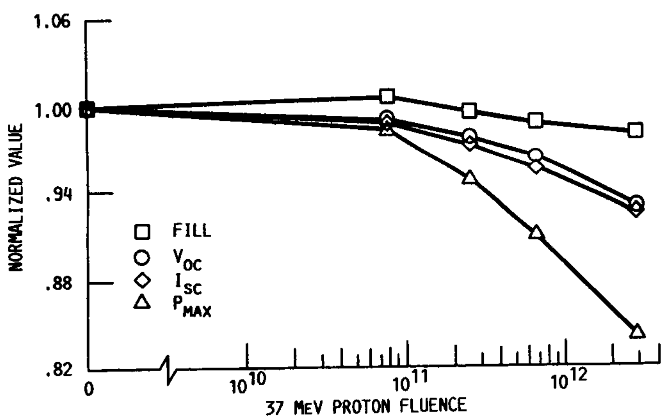

FIGURE 3. - NORMALIZED I_{SC}, V_{OC}, P_{MAX} AND FILL VERSUS 37 MeV PROTON FLUENCE FOR VARIAN GaAs CELLS AT 25 °C AND 100X AMO.

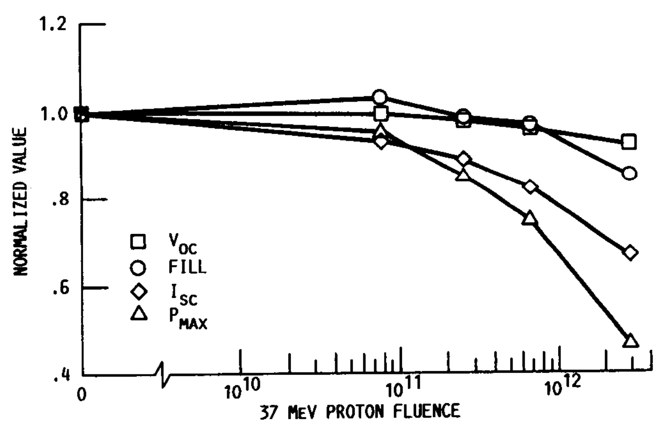

FIGURE 4. - NORMALIZED I_{SC}, V_{OC}, P_{MAX} AND FILL VERSUS 37 MeV PROTON FLUENCE FOR ASEC GaAs CELLS AT 25 °C AND 100X AMO.

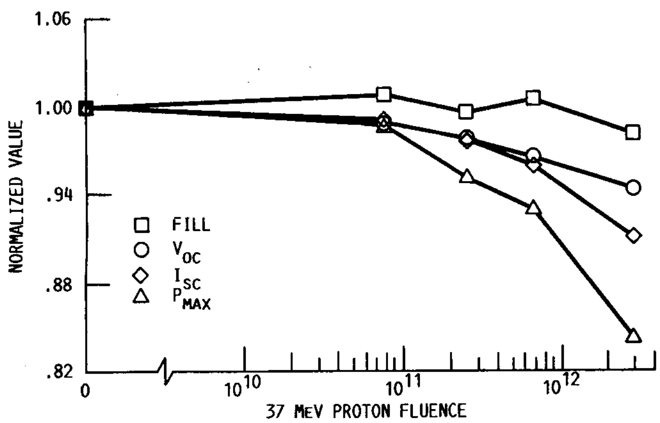

FIGURE 5. - NORMALIZE I_{SC}, V_{OC}, P_{MAX} AND FILL VERSUS 37 MEV PROTON FLUENCE FOR HUGHES GaAs CELLS AT 25 °C AND 100X AMO.

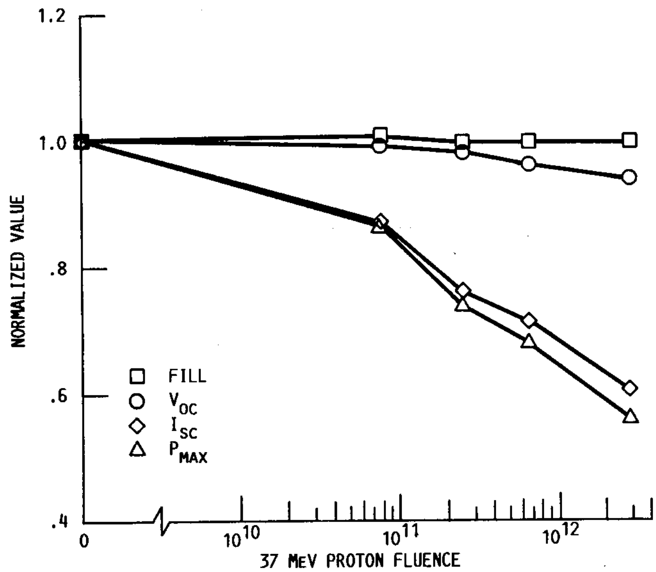

FIGURE 6. - NORMALIZED I_{SC} V_{OC}, P_{MAX} AND FILL VERSUS 37 MEV PROTON FLUENCE FOR SILICON CELLS AT 25 °C AND 100X AMO

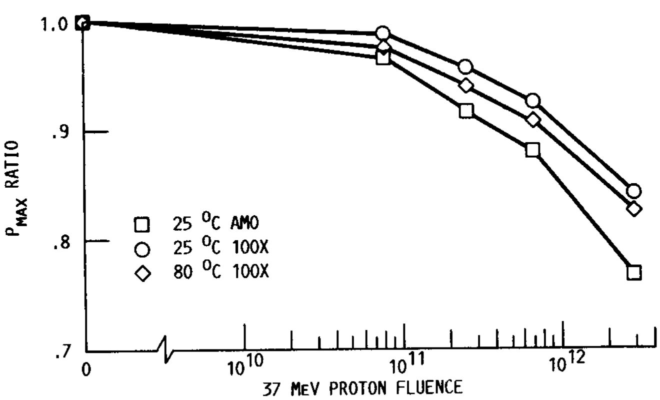

FIGURE 7. - MAXIMUM POWER RATIO VERSUS 37 MEV PROTON FLUENCE AT THREE DIFFERENT CONDITIONS FOR ASEC GaAs CELLS.

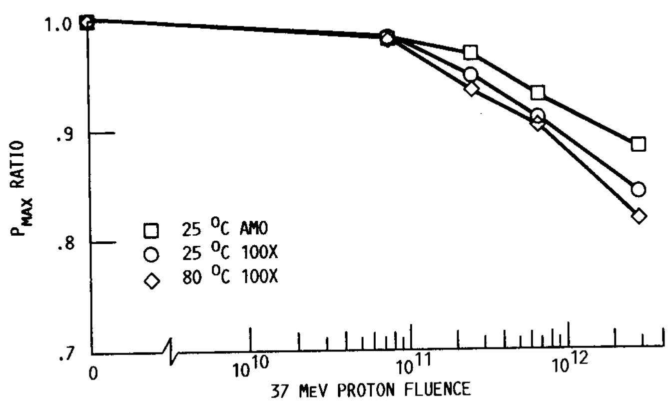

FIGURE 8. - MAXIMUM POWER RATIO VERSUS 37 MEV PROTON FLUENCE AT THREE DIFFERENT CONDITIONS FOR VARIAN GaAs CELLS.

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16. Abstract

Gallium arsenide concentrator cells from three sources and silicon concentrator cells from one source were exposed to 37 MeV protons at fluences up to 2.8×10^{12} protons per square cm. Performance data were taken after several fluences, at two temperatures (25 and 80 °C), and at concentration levels from 1 to about 150X AMO. Data at one sun and 25 °C were taken with an X-25 xenon lamp solar simulator. Data at concentration were taken using a pulsed solar simulator with the assumption of a linear relationship between short-circuit current and irradiance. The cells are 5 by 5 mm with a 4-mm diameter illuminated area.

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