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Potential for Use of Indium Phosphide Solar Cells in the Space Radiation Environment

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POTENTIAL FOR USE OF INDIUM PHOSPHIDE SOLAR CELLS IN THE SPACE RADIATION ENVIRONMENT

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SUMMARY

Indium phosphide solar cells were observed to have significantly higher radiation resistance than either GaAs or Si after exposure to 10 MeV proton irradiation. Using the present proton irradiation data and previous 1 MeV electron data together with projected efficiencies for InP, it was found that these latter cells produced more output power than either GaAs or Si after specified fluences of 10 MeV protons and 1 MeV electrons. Estimates of expected performance in a proton dominated space orbit yielded much less degradation for InP when compared to the remaining two cell types. It was concluded that, with additional development to increase efficiency, InP solar cells would perform significantly better than either GaAs or Si in the space radiation environment.

INTRODUCTION

E-2785

Recently published results indicate that indium phosphide solar cells have the potential to perform exceedingly well in the space radiation environment. This follows from the observation that the radiation resistance of InP is greater than either GaAs or Si under 1 MeV electron irradiation (ref. 1). Furthermore, significant but incomplete recovery has been observed by annealing at room temperature (ref. 2), with almost complete recovery observed after 1 MeV electron irradiation, when annealing at 100 °C (ref. 3). In addition, partial recovery is observed at room temperature due to the minority carrier injection caused by incident light (ref. 4). In the present case, we have determined the radiation resistance of InP under proton irradiation. Specifically, the performance of InP has been compared to that of GaAs and silicon cells after irradiation by 10 MeV protons. Also, using the present results and previously published data on 1 MeV electron irradiation, together with estimates of projected efficiencies, we compare the expected performance of these cells under both electron and proton irradiations. These results are then used to speculate on the potential advantage of using InP in the space radiation environment.

EXPERIMENTAL

The InP cells were n/p homojunctions obtained from the Ibaraki Electrical Communication Laboratories (ref. 1). Details of cell fabrication are found in reference 5. The GaAs cells were of two types, n/p and p/n. The n/p GaAs cells were homojunctions while the p/n cells were heteroface $Al_xGa_{1-x}As/GaAs$. The silicon cells were conventional 10 Ω-cm n/p with back surface fields and back surface reflectors. Additional details of the GaAs and Si cells are found in reference 6. All cells were irradiated by 10 MeV protons in the NASA Lewis cyclotron. The GaAs and Si cells were irradiated to a proton fluence of $1.25 \times 10^{12}/cm^2$ while the InP cells were irradiated to a fluence of $1.5 \times 10^{12}/cm^2$. Cell parameters at air mass zero were determined using a xenon arc solar simulator. Preirradiation cell parameters are listed in table I while figure 1 shows cell normalized maximum power as a function of proton fluence.

DISCUSSION

Present state-of-the-art InP cells have efficiencies lower than GaAs. However, when the present data are normalized to preirradiation values, it is seen from figure 1, that the InP cells exhibit superior radiation resistance under 10 MeV proton irradiation. A comparison based on present state-of-the-art numerical values would result in superior performance for GaAs and Si over the present InP cells. However, in assessing the potential of InP cells for future space use, it is preferable to compare projected efficiencies. Calculations based on reasonable material parameters show that efficiencies of at least 18 percent are feasible for InP solar cells (ref. 7). This is reasonable for InP considering the fact that AMO efficiencies of 17 percent have been reported (ref. 8). On the other hand, present day GaAs cells, after more than 15 yrs of development, exhibit efficiencies approaching 19 percent (ref. 9), while Si cells with efficiencies approaching 15 percent are available. The results of cell output calculations based on these efficiencies, and using the data of figure 1, are shown in figure 2 for a proton fluence of $10^{12}/cm^2$. The figure clearly shows that the projected output of the InP cells is greater than that calculated for the remaining cells. A similar comparison is made for 1 MeV electron irradiation at a fluence of $10^{15}/cm^2$ (fig. 3). The latter fluence is an equivalent 1 MeV electron fluence for GaAs p/n cells corresponding to the 10 MeV proton fluence used in figure 2 (ref. 10). In computing the projected output powers of figure 3 data for InP were obtained from reference 1, while for GaAs and Si, electron irradiation data were obtained from references 11 and 12. Table II summarizes the projected efficiencies for both types of irradiation. It is seen from these data that in terms of projected efficiencies, the InP cells outperform the remaining cells. In view of the low temperature annealing capabilities of InP, it is recognized that greater projected performance superiority could be attainable in space.

CONCLUSION

Considering the effort expended in bringing GaAs and Si cells to their present state, it is assumed that a comparable effort would result in achieving the potential efficiency of InP cells. When this goal is achieved, it is speculated that InP cells will have considerable advantages when used in space environments where significant radiation induced degradation occurs. Specific examples are geosynchronous orbit, where electrons and solar flare protons are significant degradation factors, and orbits around 6000 kM where protons dominate. Additional examples are long term LEO to GEO transfer orbits or highly elliptical orbits. Considering the absence of damage equivalents for InP, it is highly speculative to compute expected degradations for such orbits. However, since damage equivalents are available, for Si (ref. 12), it is instructive to estimate the degradation for this semiconductor using a 30° circular orbit whose altitude is 6482 kM. Using an admittedly thick 30 mil cover glass for this proton dominated orbit, the equivalent 1 MeV electron fluence per year is $2.5 \times 10^{15}/cm^2$ (ref. 12). For Si, this corresponds to a 33 percent degradation in almost half a year. Since the InP and GaAs cells degrade less than Si, we assume that the 1 MeV equivalent fluence for the latter is an upper limit for the III-V cells. Thus, under these assumptions, the InP cell would degrade by 6 percent, while GaAs would degrade by 22 percent. These crude calculations emphasize the fact that, in orbits where radiation is a factor, fully developed InP cells would result in greatly increased output in space. In view of this, an expanded R&D effort aimed at increasing the efficiency and lowering the cost of InP cells would appear to be warranted.

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TABLE I. - PREIRRADIATION PARAMETERS FOR ALL CELLS

Cell	Jsc ma/cm^2	Voc, V	Efficiency, %	FF, %
InP (n/p)	25.5	0.802	10.5	76.4
GaAs (n/p)	29	0.96	16.6	81.8
GaAs (p/n)	28.5	1.022	16.4	77.3
Si (n/p)	42.4	0.616	14.6	76.6

TABLE II. - COMPARISON OF PROJECTED CELL EFFICIENCIES BEFORE AND AFTER PROTON AND ELECTRON IRRADIATIONS

Cell	Efficiencies, %		
	$\phi = 0$	10 MeV protons, $\phi = 10^{12}/cm^2$	1 MeV electrons, $\phi = 10^{15}/cm^2$
n/p InP	18	16.6	16.9
n/p GaAs	19	15.3	14.8
p/n GaAs	19	14.2	14.3
n/p Si	15	8.[illegible]	10.1

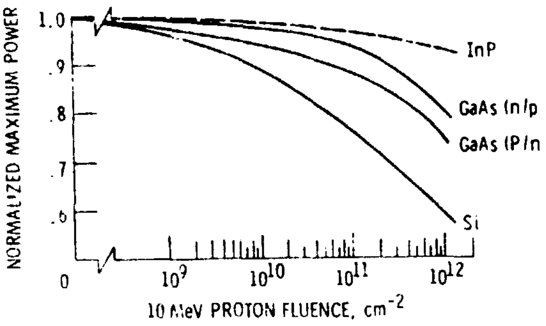

Figure 1. - Normalized maximum power as a function of 10 MeV proton fluence.

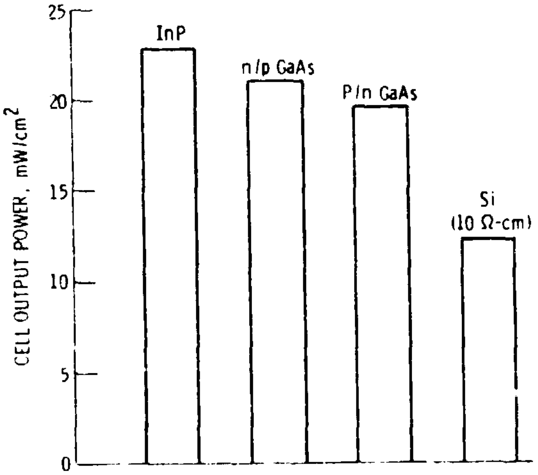

Figure 2. - Cell output power after 10 MeV proton irradiation. Fluence = 10^{12}/cm^2. BOL efficiencies from table II.

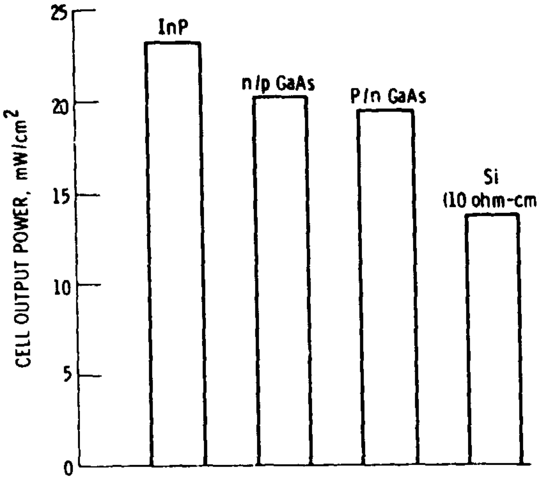

Figure 3. - Cell output power after 1 MeV electron irradiation. Fluence = 10^{15}/cm^2. BOL efficiencies from table II.

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