PROTON AND ELECTRON RADIATION ANALYSIS OF GaInP$_2$/GaAs SOLAR CELLS

P. R. Sharps, C. H. Thang, P. A. Martin, and H. Q. Hou
EMCORE Photovoltaics
10420 Research Road SE
Albuquerque, NM 87112

ABSTRACT

Electron and proton radiation damage analysis of solar cells is extremely important for predicting the response of solar cells to radiation environments in space. Two different, compatible methods of analyzing ground based radiation data have been developed [1,2]. The "displacement damage dose" method [2] is of particular interest because less experimental testing is required to make accurate performance predictions for new photovoltaic devices. In this paper we present electron and proton radiation data for the dual junction GaInP$_2$/GaAs cell as well as an analysis of the data using the displacement damage dose method.

INTRODUCTION

Accurate prediction of a solar cell's end-of-life (EOL) performance in space is essential in planning for and executing satellite missions. Prediction of a cell's performance in space is made from ground based exposure of cells to mono-energetic electrons and protons over a number of energies and fluences. A method was developed at the JPL for calculating the relative damage coefficients for both electrons (reference to 1 MeV electrons) and protons (reference to 10 MeV protons). The proton damage is converted to an equivalent 1 MeV electron damage. An equivalent 1 MeV electron fluence is calculated for a particular space radiation environment, and the degradation of the maximum power output of a cell determined for that environment. The methodology was originally developed for Si cells [2], but also applies to GaAs and other III-V based cells [3].

More recently, the displacement damage dose methodology has been developed at NRL. The motivation for the work was the accurate prediction of a cell's space radiation response based on a limited set of ground based data. The non-ionizing energy loss (NIEL) is calculated as a function of either proton or electron energy for a cell. A displacement dose is calculated for a particular space radiation environment, and the degradation in the electrical properties of a cell is determined for that orbit. In practice, the NIEL is used to convert an electron or proton fluence to the displacement damage dose. As mentioned before, the advantage of the displacement damage dose method is that a smaller amount of ground based testing is required. The two methods of predicting cell degradation have been shown to be equivalent [4]. As a solar cell manufacturer, our main interest is generation of relative damage coefficients (JPL methodology) and/or cell degradation as a function of displacement damage dose (NRL methodology) curves. Customers in turn would be able to use these curves to determine EOL performance for particular missions. The purpose of the present paper is to use the two methods to analyze radiation data on EMCORE's GaInP$_2$/GaAs dual junction solar cell.

EXPERIMENT

Figure 1 shows a schematic of the GaInP$_2$/GaAs dual junction cell that was used in this study. The cell was EMCORE's initial commercial product, and considerable development has gone in to improving the radiation hardness of both the dual junction and the triple junction [5]. The cell has the n-on-p polarity, and is designed for current matching at end of life (EOL), defined as exposure to 1 MeV electrons to a fluence of 1 x 10^{15} e/cm^2. At beginning of life (BOL), the cell is current limited by the GaInP$_2$ junction, while at EOL, the two junctions are current matched. The cells tested were 4 cm^2 in area, and did not have coverglasses.

Metal Grid	
n^{++}-GaAs Cap	AR Coatings
n^{+}-AlInP$_2$	Window
n^{+}-GaInP$_2$	Emitter
p-GaInP$_2$	Base
p^{+}-AlGaInP$_2$	BSF
p^{++}-n^{++} High Bandgap Tunnel Diode	
n^{+}-GaInP$_2$	Window
n^{+}-GaAs	Emitter
p-GaAs	Base
p-GaInP$_2$	BSF
p^{++}-n^{++} Tunnel Diode	
n-Ge Buffer	
n-Ge Substrate	
Back Contact	

Figure 1. Schematic of the GaInP$_2$/GaAs tandem cell examined in this study.

0-7803-5772-8/00/$10.00 © 2000 IEEE

The cells were measured at EMCORE before and after irradiation with a calibrated, dual source solar simulator. The radiation exposure was done by JPL, for proton energies of 0.1, 0.4, 1, 2.5, and 10 Mev, and for electron energies of 0.6 and 1.0 MeV. After irrradiation and prior to measurement in the solar simulator, the cells were annealed for 20 hours at 60 °C. At least 5 cells were irradiated at each of the electron and proton energies and fluences. All of the irradiation was done by unidirectional protons and electrons.

RESULTS AND DISCUSSION

The degradation in the V_{oc}, I_{sc}, and P_{max} caused by the proton irradiation are shown in Figures 2, 3, and 4, respectively. The relative damage coefficients (RDCs) relative to 10 MeV protons are contained in Figure 5.

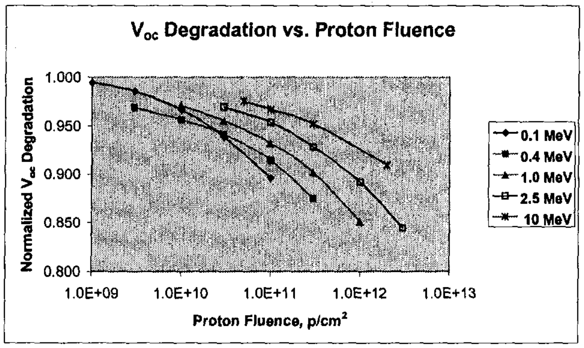

Figure 2. Degradation of the V_{oc} as a function of proton fluence for various protons energies.

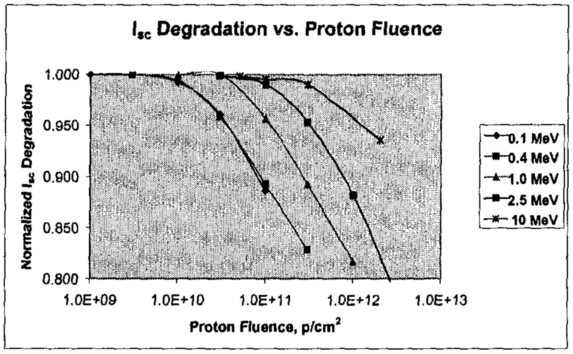

Figure 3. Degradation of the Isc as a function of proton fluence for various protons energies.

The RDC curves in Figure 5 are similar to previously published data [3] for a similar cell for the energies of 0.4 MeV and above. At 0.1 MeV, the current RDC is higher by about a factor of 2, as compared to the previously published data. However, the previously published RDC curves showed two maximums for energies below 0.4 MeV. The current study does not include enough lower energy proton data to show all of the detail as previously seen in [3].

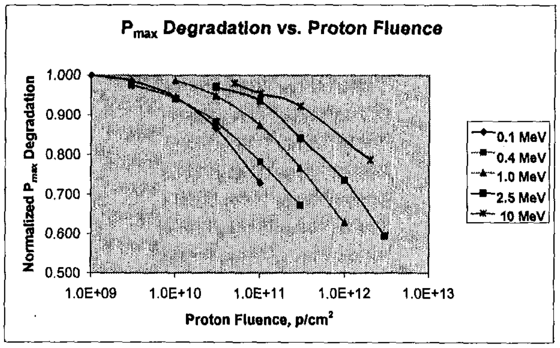

Figure 4. Degradation of P_{max} as a function of proton fluence for various protons energies.

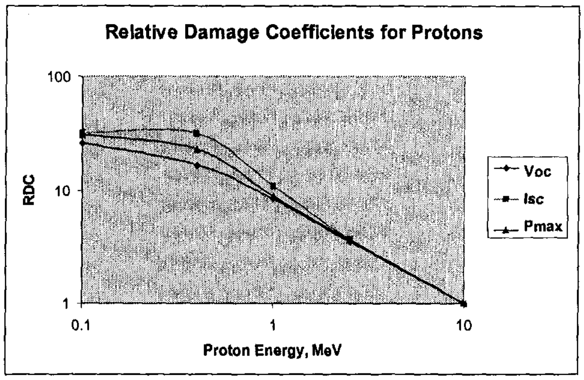

Figure 5. Relative damage coefficients for proton degradation of the dual junction cell.

The data from Figure 4 was converted to the displacement damage dose using the NIEL values and the formula presented in [2]. In order to make the calculation for the dual junction cell several assumptions had to be made. First, the dual junction cell was treated as a single entity, i.e., no special allowance was made for the two separate junctions. Some justification for this assumption comes from the cell being current limited by the $GaInP_2$ junction at beginning-of-life (BOL). Secondly, the NIEL value for GaAs was used, as there are no values for $GaInP_2$. The NIEL values for GaAs and InP are fairly close, hence the NIEL value for $GaInP_2$ should also be close to that for GaAs.

Figure 6 shows the reduction in P_{max} as a function of absorbed dose, for the proton radiation. All of the data for proton energies above 0.1 MeV merges to a single curve, although for lower fluences there tends to be more scatter. The data on this curve can be fit to the expression [2]:

$$P_{max}/P_o = 1- (0.112)*\ln[1 + D/(2.64 \times 10^9)]$$

In turn, the above equation can be rewritten to describe the response of the cell to protons with any energy above 0.1 MeV.

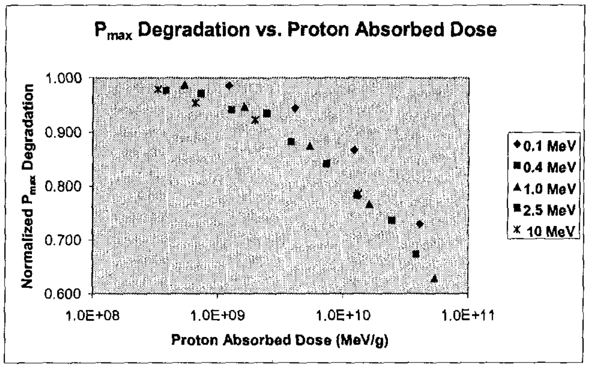

Figure 6. Power loss of GaInP$_2$/GaAs dual junction cell as a function of absorbed dose, for various protons energies.

The discrepancy of the lower energy protons has been noted and discussed [2,6]. Less than 20% of the damage was thought to be due to the protons with energy less than 0.1 MeV. The displacement damage dose method would tend to overestimate the damage of the lower energy protons by about 5%, based on the 0.1 MeV proton discrepancy. Hence, using the displacement damage dose method, and ignoring the lower proton energy discrepancy, P_{max} degradation would be overestimated at most by about 1%. However, the disparity between the displacement damage dose degradation and the actual degradation increases as the proton energy decreases [2], so the P_{max} degradation would likely be overestimated by a larger amount.

Unfortunately, we do not have more data for lower energy protons. Because of the assumption of treating the dual junction cell as single cell in using the NIEL approach, the detail that shows up in the RDC analysis of multijunction cells does not appear. The data would be useful to see how much difference there is between the "collapsed" single curve and the actual degradation for the lower energy protons.

Addition of a coverglass does not resolve the issue, for while incoming 0.1 MeV protons may no longer reach the cell, higher energy protons are slowed down such that they have energy of 0.1 MeV when they actually reach the cell. The issue with the lower energy protons may be the non-uniform damage generated by the low energy protons. As the protons slow down, the damage generation increases. For high energy protons this effect is minimal, since the amount of slowly down is relatively small. For the lower energy protons, however, the effect is more significant. If this is the cause of the discrepancy, perhaps some modification to the calculation of the NIEL for the lower energy protons can be made that will take this in to account.

Figure 7, 8, and 9 contain the degradation of the V_{oc}, I_{sc}, and P_{max} as a function of electron fluence for two different energies. Unfortunately, we did not have the time to irradiate cells at a larger number of electron energies, and so were not able to calculate the RDCs as a function of energy. However, we were able to calculate the 1 MeV electron/10 MeV proton damage equivalent fluence factors for V_{oc}, I_{sc}, and P_{max}. The results, for 10% degradation of V_{oc} and I_{sc}, and for 20% degradation in P_{max}, are in Table 1, and are similar to the values published previously [3].

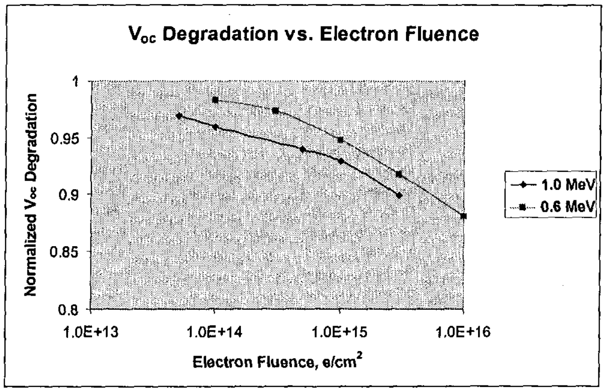

Figure 7. Degradation of the V_{oc} as a function of electron fluence for two electron energies.

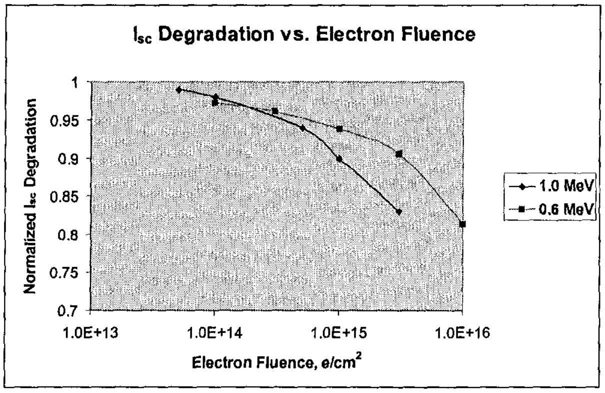

Figure 8. Degradation of the I_{sc} as a function of electron fluence for two electron energies.

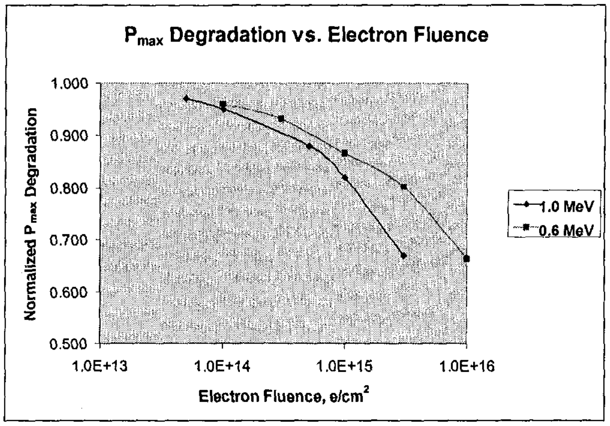

Figure 9. Degradation of P_{max} as a function of electron fluence for two electron energies.

Voc	Isc	Pmax
1,200	357	648

Table 1. Equivalent fluence factors for 1 MeV electrons and 10 MeV protons. The results are for 10% degradation of V_{oc} and I_{sc}, and for 20% degradation of P_{max}.

Using the displacement damage dose method for electron damage is more complicated than that for protons. This is because of the need to convert to an effective 1 MeV displacement damage dose [2]. A factor is needed to get the electron data to collapse to a single curve. However, the lack of electron data does show the value of the displacement damage dose method. Only two different energies are required to determine the fitting parameter that allow the data to merge to a single curve. We used the data from Figure 9, and through curve fitting we determined that the value for n is 0.35 (see [2]). The P_{max} degradation as a function of effective electron absorbed dose is shown in Figure 10, using the effective 1 MeV electron absorbed dose.

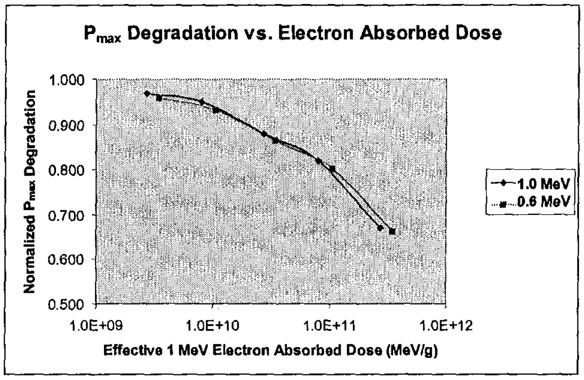

Figure 10. Degradation of P_{max} as a function of effective 1 MeV electron absorbed dose.

Irradiation of cells with a larger range of electron energies would increase our confidence in the displacement damage dose method for electrons. Unfortunately, we do not have the data at this time, but plans are underway to do a more thorough radiation study on one of our recent, more radiation hard cells.

The same assumptions used with NIEL for the protons were used with NIEL for the electrons. Again, a larger data set would also help to see if there is any detail associated with electron damage coefficients similar to that for protons that needs to be accounted for.

Finally, it should be pointed out that any predictions of a cell's response to radiation in space based on earth-bound radiation experiments need to be compared to actual space flight data. EMCORE would gladly participate in any such study through supplying cells both for earth-bound testing and also for an actual high radiation flight, perhaps with an STRV.

CONCLUSIONS

The value of the displacement damage dose method is clear. A much smaller set of radiation experiments is required to predict the performance of a cell in a space radiation environment. The issue of the low evergy protons,needs to be further clarified. More electron data at a larger number of energies would also help to increase confidence in the displacement damage dose method. A more thorough radiation study needs to be done on a multi-junction cell. In addition, the predicted radiation response from a thorough study needs to be compared to cell results from an actual space radiation environment, to test the predicted response.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Bruce Anspaugh and Bob Weiss of JPL, Dr. Rob Walters of NRL, and Dr. Dean Marvin of the Aerospace Corporation for their comments and help in preparing this paper.

REFERENCES

[1]. B. E. Anspaugh, "Solar Cell Radiation Handbook-Addendum 1: 1982-1988", *JPL Publication 82-69, Addendum 1*, 1989.

[2]. G. P. Summers et al., Proceedings of the 1st World Conference of Photovoltaic Energy Conversion, 1994, pp. 2068-2075.

[3]. D. C. Marvin, "Assessment of Multijunction Solar Cell Performance in Radiation Environments", *Aerospace Report No. TOR-2000(1210)-1*, 2000.

[4]. G. P. Summers et al., 16th SPRAT Conference, August 1999.

[5]. Mark Stan et al., Late news paper presented at this conference.

[6]. G. P. Summers et al., Appl. Phys. Lett. **71**, 832, (1997).