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A COMPARISON OF THE RADIATION TOLERANCE CHARACTERISTICS OF MULTIJUNCTION SOLAR CELLS WITH SERIES AND VOLTAGE-MATCHED CONFIGURATIONS*

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SUMMARY

The effect of series and voltage-matched configurations on the performance of multijunction solar cells in a radiation environment was investigated. It was found that the configuration of the multijunction solar cell can have a significant impact on its radiation tolerance characteristics.

INTRODUCTION

Multijunction (MJ) solar cells have the potential for extremely high efficiencies (>30%). Such cells consist of several photovoltaically active junctions (subcells) with different bandgaps stacked in optical series. This arrangement essentially splits the broad solar spectrum into portions to which the individual subcells are better matched. MJ cells are under consideration for space applications where high efficiency is important. In order to be useful for space applications, the radiation tolerance of MJ cells needs to be addressed.

The radiation tolerance of an MJ solar cell is determined by several factors. The first factor is the radiation characteristics of the individual subcells. The degradation characteristics of an individual subcell are expected to be similar (after accounting for the shielding of any overlying material) to a single-junction cell fabricated from the same material and with the same cell structure. The radiation tolerance of single-junction solar cells has been extensively studied and documented (ref. 1).

A second factor that influences the radiation tolerance characteristics of an MJ cell is its module configuration. Module configuration refers to the electrical circuit in which the subcells of the MJ cell are wired. The degradation characteristics of one subcell may affect the power available from the other subcells through limitations imposed by the electrical circuit. In this paper, we report results of a study concerning the effect of the module configuration on the radiation tolerance of an MJ cell.

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MJ CELL CONFIGURATIONS

The simplest module configuration for an MJ cell has the subcells connected in series. This cell requires only two terminals. The current from a series string of cells is limited by the cell with the lowest current. The bandgaps of the subcells for a series-configured MJ cell should therefore be chosen for matched photocurrents. In a radiation environment, the bandgaps should be chosen for matched currents at end-of-life (EOL). Since many cells degrade more rapidly in current rather than voltage, series operation could impose severe limitations to the radiation tolerance of MJ cells with a series configuration.

MJ cells whose subcells can be wired in various series/parallel circuits have been recently described (ref. 2). The voltage of cells in parallel is limited by the cell with the lowest voltage. Hence, these MJ cells require matched voltages between subcell circuits for efficient operation and are referred to as having a voltage-matched (VM) configuration. An example of a two-junction, four-terminal tandem cell wired in a voltage-matched configuration is given in figure 1. VM circuits have also been described for both two- and three-junction tandem cells with three terminals, so that the VM configuration may be used with monolithic MJ cells (ref. 2). Figures 2 and 3 show the effect of the module configuration on the efficiency versus bandgap relationship for series and VM configurations. (These efficiencies were calculated using the model of reference 2.) An advantage of the VM configuration compared to the series configuration is that it allows a wider selection of bandgaps for a given efficiency.

EXPERIMENT AND CALCULATIONS

In general, the voltage and current of a solar cell degrade at different rates with irradiation. Hence, the radiation tolerance is expected to be influenced by the module configuration. For this study, we used the measured radiation characteristics of AlGaAs (1.72 eV), GaAs, and InGaAs (1.15 eV) concentrator cells presented in reference 3. The AlGaAs and InGaAs cells have appropriate bandgaps for use with both the series and VM configurations. The initial device characteristics are presented in table 1 and the degradation characteristics under 1-MeV electron irradiation are presented in figures 4, 5, and 6. Note that the maximum power (P_{max}) of the InGaAs cell degrades very rapidly due to the rapid degradation of the current.

	AlGaAs	GaAs	InGaAs
J_{sc} (A/cm^2)	1.961	3.174	3.579
V_{oc} (volts)	1.367	1.139	0.859
Fill Factor	0.835	0.799	0.794
Efficiency (%)	16.5	21.3	18.1

Table 1. Initial IV data at 100 suns, AM0 and 25°C.

The expected performance of an AlGaAs/InGaAs tandem cell was calculated using the following procedure. Each illuminated current-voltage (IV) curve was fitted to a lumped parameter model consisting of a current source, two diodes (n=1 and n>1), and a shunt and series resistance. No physical interpretation was attached to these fitted parameters; the purpose of the exercise was to allow addition of IV curves for tandem cell modeling. Next, the tandem cell performance for independent, series, and VM configurations was calculated using the lumped parameter model for the AlGaAs and InGaAs subcells. ("Independent" configuration refers to operation of each subcell independently.) For this calculation, the photocurrent of the InGaAs subcell was set equal to the photocurrent of the AlGaAs subcell at beginning-of-life (BOL); i.e. we have assumed that the photocurrents are matched at BOL for an optimized cell. The photocurrents from the AlGaAs and InGaAs cells were assumed to degrade at the measured rates given in figures 4 and 6. The data of figure 6 was taken with full spectrum illumination while the InGaAs cell in an AlGaAs/InGaAs tandem cell will only be illuminated by a filtered spectrum. Our spectral response data indicates that the InGaAs cell degrades more rapidly in the blue, so that our calculations may overestimate slightly the current degradation expected from an InGaAs cell in the stacked configuration.

Results of the calculations are presented in figure 7. The rapid degradation in I_{sc} for the InGaAs cell is seen to have a substantial effect on the series-configured MJ cell. The P_{max} of the series-configured tandem cell, in fact, becomes less than that of a single-junction GaAs cell at high fluences despite the much higher BOL efficiency. The P_{max} degradation of the VM configuration is much less than that of the series configuration for the AlGaAs/InGaAs tandem concentrator cell since voltage degrades much less rapidly than current for these particular subcells. Initially, the VM configuration produces about 3% less power at BOL than the series or independent configurations because the voltages of the subcells are slightly mismatched. However, the subcell voltages become better matched as they degrade with irradiation. In fact, P_{max} of the VM configuration is nearly the same as the independent configuration and 39% greater than the series configuration at EOL.

CONCLUSIONS

We have calculated the expected performance of an AlGaAs/InGaAs tandem cell as a function of 1-MeV electron fluence with series and voltage-matched configurations. It was shown that the module configuration can have a significant impact on the radiation tolerance of an MJ cell due to the different rates of degradation for voltage and current of the individual subcells.

REFERENCES

1. H. Y. Tada, et al., Solar Cell Radiation Handbook, 3rd Ed., JPL Publication No. 82-69 (November 1982).

2. James M. Gee, "Voltage-matched configurations for multijunction solar cells," Proc. 19th IEEE Photo. Spec. Conf., pg. 536 (1987).

3. H.B. Curtis, C.K. Swartz, and R.E. Hart, Jr., "Radiation performance of AlGaAs and InGaAs concentrator cells and expected performance of cascade structures," Proc. 19th IEEE Photo. Spec. Conf., pg. 727 (1987).

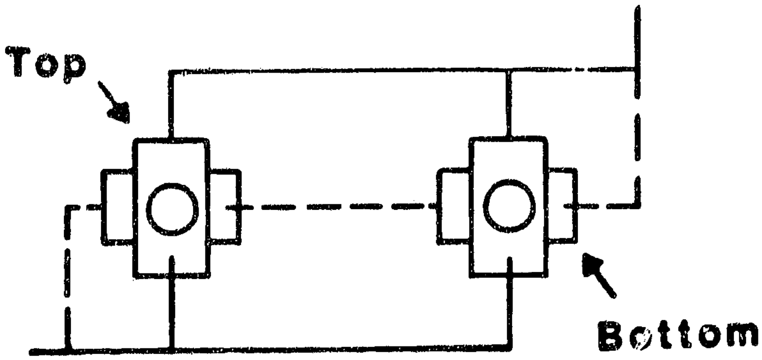

Figure 1. A voltage-matched circuit for a four-terminal, two-junction tandem cell. In the above circuit, the top subcells are wired in parallel with two series-connected bottom subcells.

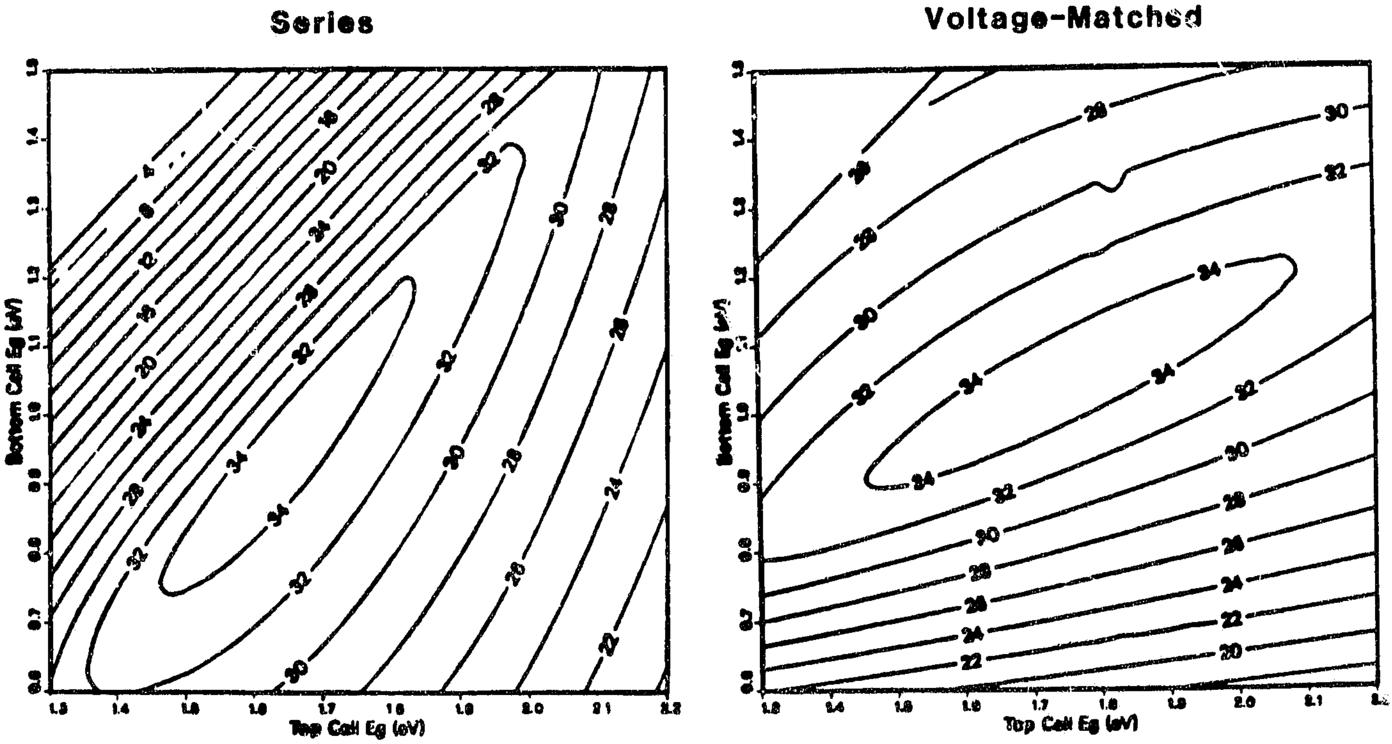

Figure 2. Iso-efficiency curves for a two-junction tandem cell as a function of top and bottom subcell bandgaps (1X, AM0).

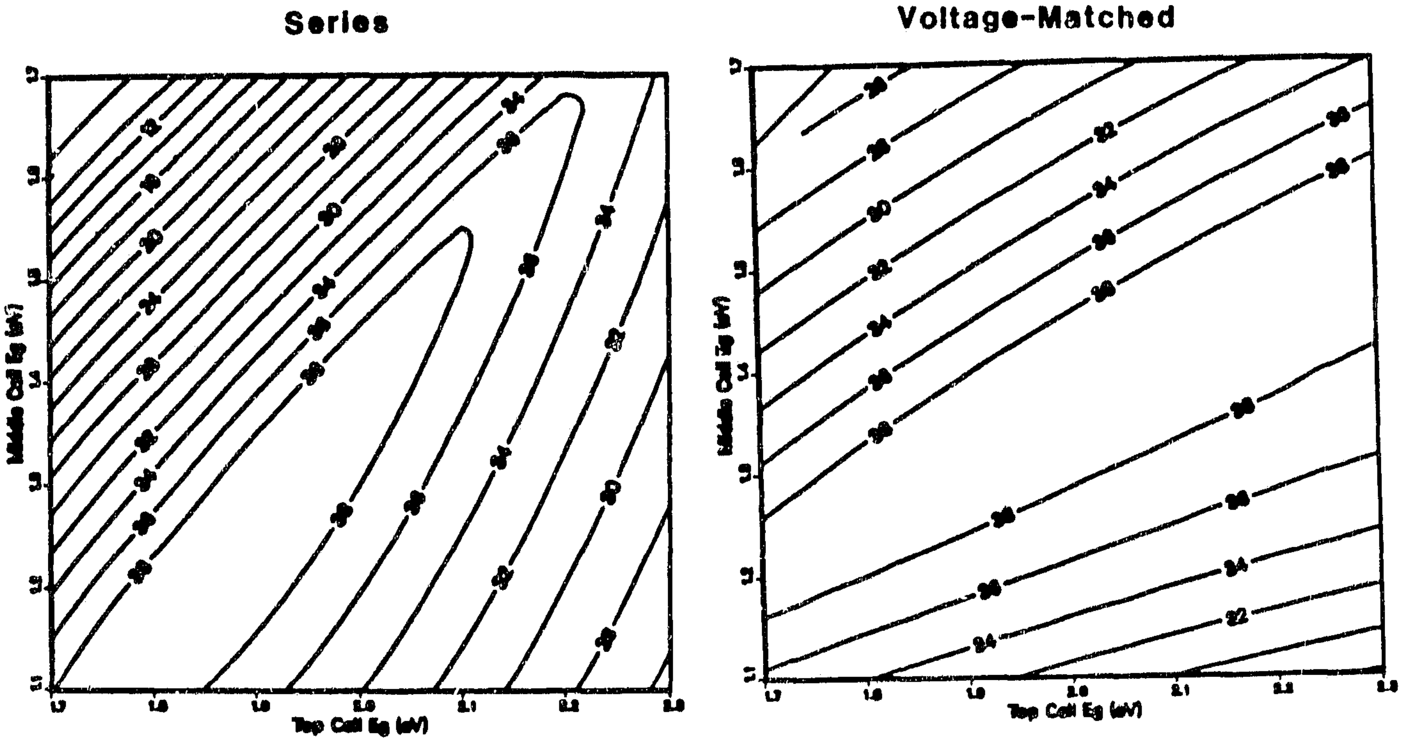

Figure 3. Iso-efficiency curves for a three-junction tandem cell as a function of top and middle subcell bandgaps (1X, AM0). The bandgap of the bottom subcell is optimized each pair of top and middle subcell bandgaps.

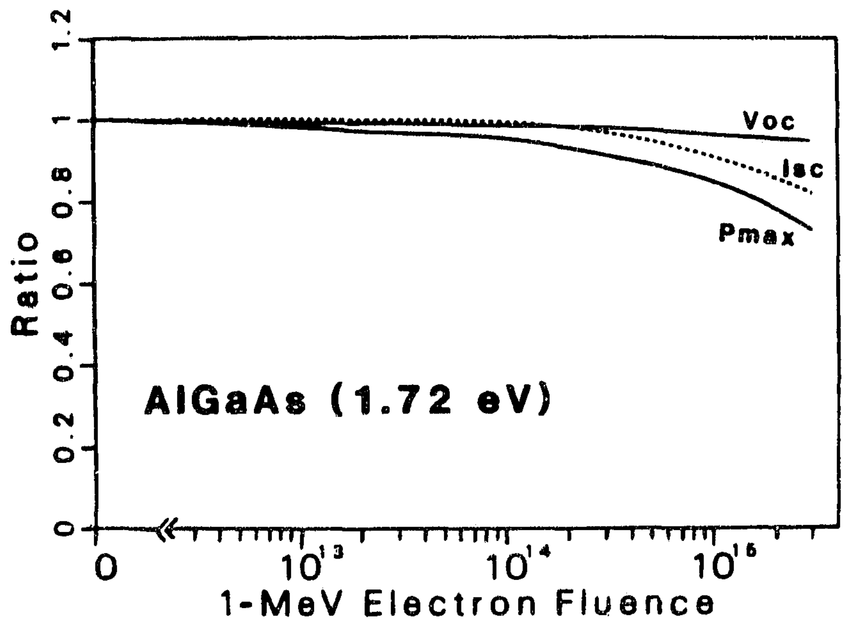

Figure 4. Ratio of degraded/initial values for V_{oc}, I_{sc}, and P_{max} of an AlGaAs (1.72 eV) concentrator cell as a function of 1-MeV electron fluence (100X, AM0, 25°C). (The units of fluence are cm^{-2}.)

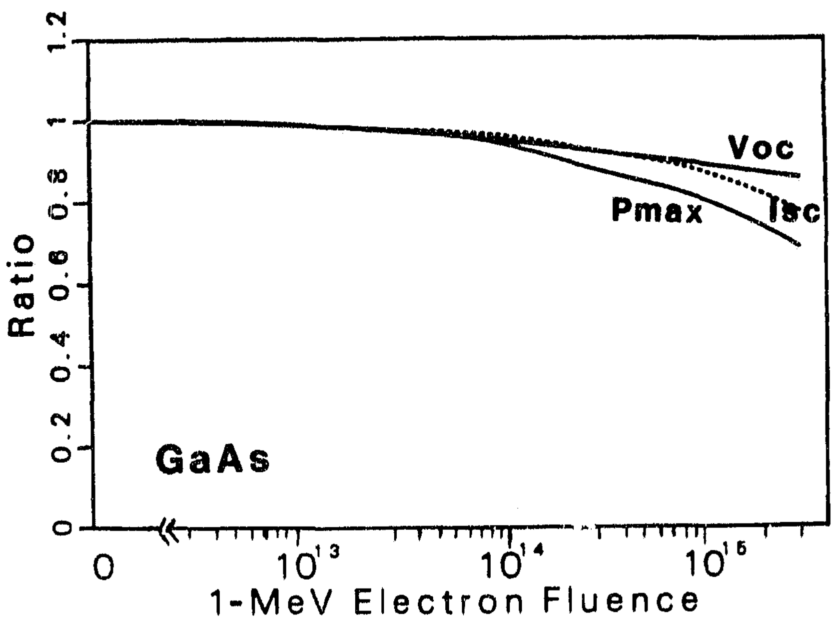

Figure 5. Ratio of degraded/initial values for V_{oc}, I_{sc}, and P_{max} of a GaAs (1.42 eV) concentrator cell as a function of 1-MeV electron fluence (100X, AM0, 25°C). (The units of fluence are cm^{-2}.)

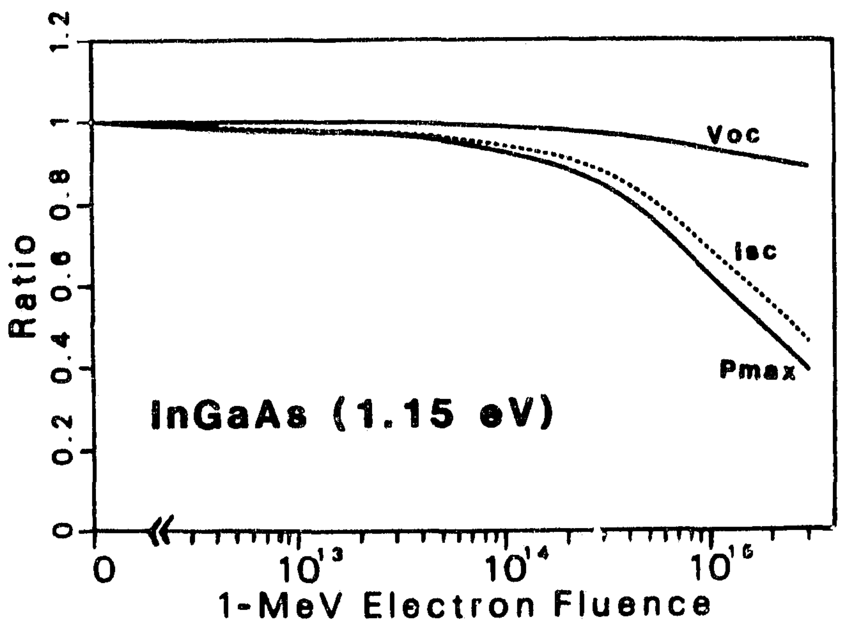

Figure 6. Ratio of degraded/initial values for V_{oc}, I_{sc}, and P_{max} of an InGaAs (1.15 eV) concentrator cell as a function of 1-MeV electron fluence (100X, AM0, 25°C). (The units of fluence are cm^{-2}.)

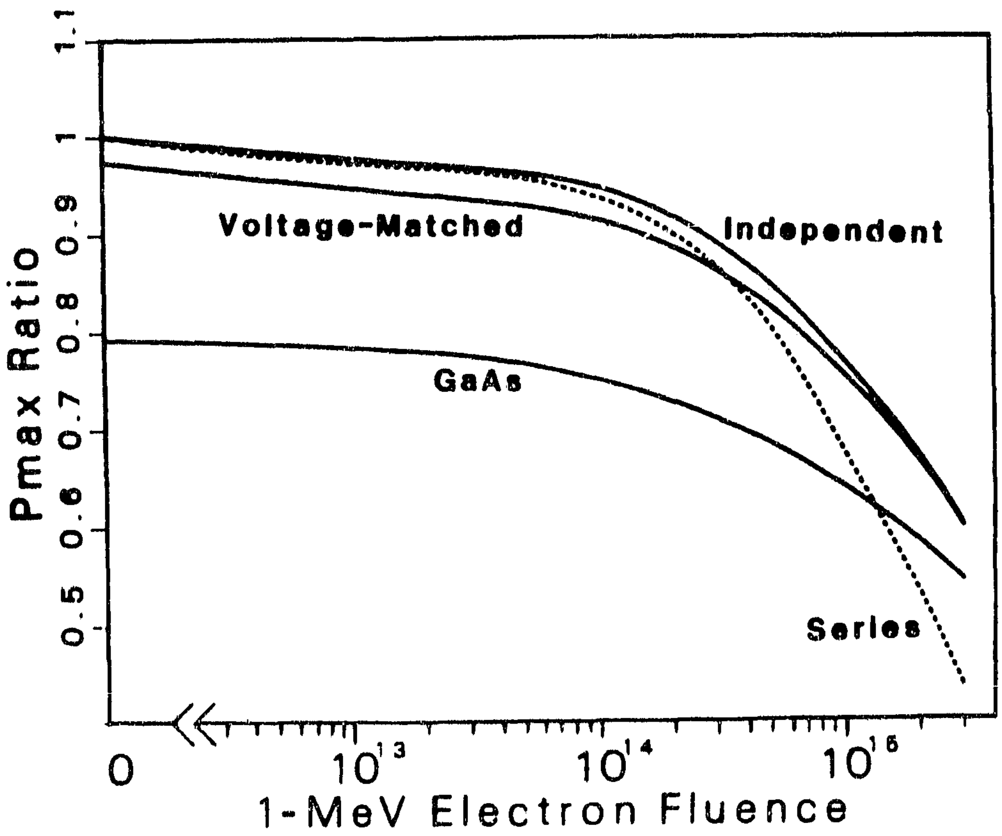

Figure 7. P_{max} at as a function of 1-MeV electron fluence for a GaAs concentrator cell and an AlGaAs/InGaAs tandem concentrator cell with a series, an independent, and a VM configuration (100X, AM0, 25°C). P_{max} is normalized with respect to the initial P_{max} of the AlGaAs/InGaAs tandem cell with an independent configuration. (The units of fluence are cm^{-2}.)