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COMPARATIVE RADIATION TESTING OF SOLAR CELLS FOR THE SHUTTLE POWER EXTENSION PACKAGE

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Introduction - The Power Extension Package (PEP) is a reusable array under development (1,2,3) by NASA Johnson Space Center. The PEP is designed to operate from the Space Shuttle Orbiter cargo bay (figure 1) and to supplement the Orbiter's fuel cell/cryogenic power source. The PEP offers a major increase in Orbiter power level and mission duration. The PEP array will operate in low earth orbit for a cumulative time of about 3 years and will be subjected to performance degradation by space radiation equivalent to 1 or 2×10^{14} 1 MeV electrons/cm^2. Laboratory tests to determine the amount of cell degradation due to radiation are thus necessary for proper cell selection and system design. The purpose of this paper is to report the results of radiation damage tests of candidate low-cost PEP cells conducted at the NASA-Lewis Research Center.

Six different cell types with the best potential for meeting the system requirements were supplied by the two PEP cell prime contractors for evaluation. The cells had combinations of resistivity, back surface reflector (BSR), back surface field (BSF), and antireflection (AR) coating. The code used to describe the cells is shown in figure 2a.

The PEP system designer must select the solar cell technologies that will yield the best combination of beginning and/or end of life performances, lowest cost and acceptable reliability and risk. This multiplicity of technologies mandates side-by-side comparative testing.

Procedure - The test conditions are shown in figure 2b. Two groups of cells were irradiated. In each group 3 cells of each type were randomly arranged in the test fixture. All the measured performance data were taken at 28° C. The orbital operating temperature can then be calculated if the thermal absorptivity (which varies depending on cell type) is known.

The cells to be used for the PEP array will be 5.9x5.9 cm in size to reduce cost. However, the cells used for this radiation damage test were 2x2 cm in size so that greater numbers of cells could be tested, thus increasing the statistical reliability of the data. As long as the small area cells have the same characteristics (material, processes, spectral response, etc.) as the large area cells and the cells are irradiated uniformly over their area, cell size is not expected to affect the radiation test results. The highest fluence attained in this test was 3×10^{14} e/cm^2 which exceeds the maximum expected for the PEP mission life as described previously.

Two methods of fluence measurement were used: A Faraday cup current integrator and control cells with known radiation degradation behavior. The maximum power of these control cells agreed well with previous data confirming the accuracy of the Faraday cup and the uniformity of irradiation.

After irradiation, the cells were annealed for 17 hours at 60° C in air without illumination to ensure that the measured performance would be stable. Because of the low fluences and the use of Czochralski-grown silicon, photon degradation effects were not expected. Therefore the standard procedure of annealing with post irradiation illumination was not used.

The current-voltage measurements of all the cells were made with an X-25 xenon arc solar simulator. The light intensity of the simulator was adjusted until the measured short-circuit current of an aircraft-flown primary reference cell agreed with its aircraft projected air mass zero (AMO) value. The reference cells used at the start of the tests were either actual candidate PEP cells flown and calibrated specifically for this test or cells with spectral responses closely matched to the PEP cells to be tested. A good spectral response match is vital to the overall accuracy of the test. The aircraft calibration procedure is described elsewhere (4).

After irradiation to 3×10^{14} e/cm^2 the PEP cells had degraded such that their spectral response no longer closely matched the spectral response of the unirradiated reference cells Therefore, these irradiated PEP cells themselves were aircraft-flown and their accurate AMO short-circuit currents (I_{sc}) measured. The maximum power and I_{sc} data at all the fluences were then adjusted based on the change in calibration due to the spectral response shifts during irradiation. At the highest fluence these adjustments increased cell output over that measured with the non-irradiated standards from 1.2% to 4.4% depending on cell type. The multilayer AR coated cells required the highest adjustments. In other words, without adjustment the data could have been in error by as much as 4.4% at 3×10^{14} e/cm^2. At zero fluence, no adjustments of this type were needed. At intermediate fluences the adjustments ranged between zero (at 1×10^{13} e/cm^2) and 4.4% and were proportional to the logarithm of the fluence.

Results and Discussion - The average maximum power of each 6-cell group at each fluence for the 10 and 2 ohm-cells is shown in figures 3 and 4 respectively. For each point, the data spread was less than 3%. These data show that the A10FRM, (i.e. the ten ohm-cm cell with a BSF, a BSR and a multilayer AR coating) had the highest beginning of life (BOL) power (76.8 mW) under laboratory conditions. At 3×10^{14} e/cm^2 fluence, the A10FRM and the A2RM cells both had the highest average power (56.4 mW). The S2FRT, a unique 2 ohm-cm BSF cell, has about 10% higher BOL power (72.4 mW) than the S2RT (65.6 mW) due to the BSF. However, the S2FRT degrades more quickly than the S2RT and at 3×10^{14} the power increase due to the BSF effect is almost completely eliminated (53.2 vs 52.8 mW). Comparison of S2FRM (73.1 mW) and S2FRT (72.4 mW) shows about a 3.7% boost in power due to the multilayer AR coating.

In terms of normalized power (i.e. maximum power at zero fluence divided by maximum power after 3×10^{14} e/cm^2) the 2 ohm-cm BSR cells degraded to 0.80 of original; the 10 ohm-cm BSR/BSF cells degraded to 0.74 and the 2 ohm-cm BSR/BSF cells degraded to 0.73 of their original power.

These radiation damage results are necessary, but not sufficient, information needed by the designer to select the cell to be used on PEP. These tests show that the cell type with the highest power output at room temperature was the 10FRM at BOL. The 10FRM and 2RM groups had equal power at EOL. The lower thermal absorptivity (measured elsewhere) of non-BSF cells results in lower orbital operating temperature and high power output. Thus the 2 ohm-cm BSR cell will have the best EOL performance in orbit. Additional information needed for cell selection which are still being generated include the influence of array design on operating temperature and the cell cost and delivery schedule. The radiation test results described here are a vital starting point in the cell selection process.

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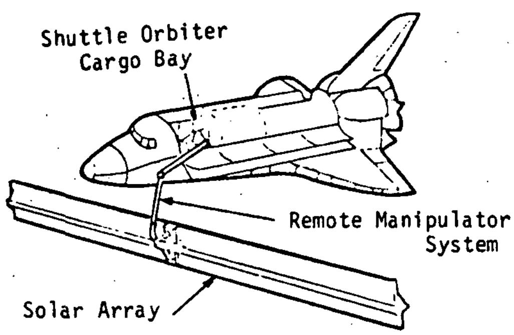

Figure 1. - PEP system with the space shuttle

2a) Cell Description Code:
- A or S-cell manufacturer.
- 10 or 2-base resistivity in ohm-cm.
- F or R-back surface field or reflector.
- T or M-Ta_2O_5 or multilayer AR coating.
- P 180-2 ohm-cm control cell, (all cells 2x2x.02 cm, no coverglass, conventional contacts).

2b) Test Conditions
- o Two irradiation groups of 22 cells each; 4-P180: 3 each: A10FRM, A2RM, S2RM, S2FRT, S2RT, S10FRT.
- o 1 MeV electron flux < 10^{12} e/cm^2/sec in air.
- o Cell temperature < 40° C during irradiation, 60° C for 17 hours in air post irradiation annealing.
- o Measurements: AMO IV at 28° C, spectral response and aircraft calibration of AMO I_{sc}.

Figure 2. - a) Code, b) Conditions

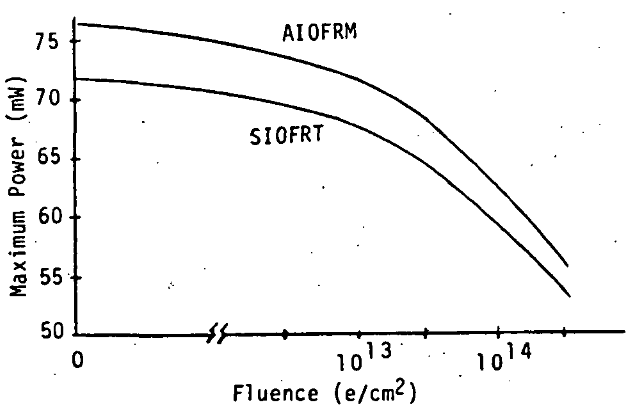

Figure 3 - P_{max} vs fluence for 10 ohm-cm

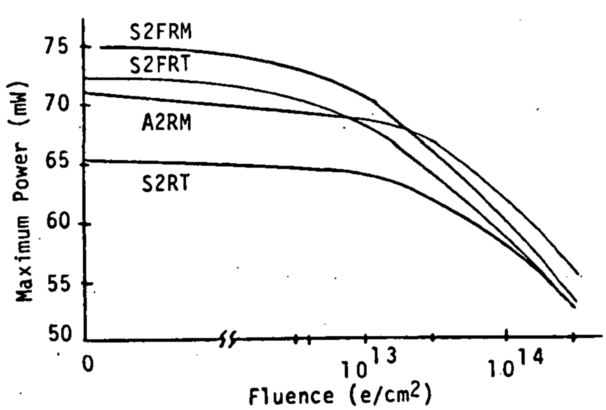

Figure 4 - P_{max} vs fluence for 2 ohm-cm

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16. Abstract

The Power Extension Package (PEP) is the prime focus of a development program to produce low cost solar cells. The PEP is a 32 kilowatt flexible substrate, retrievable, solar array system for use on the Space Shuttle. Solar cell costs will be reduced by increasing cell area and simplifying cell and coverglass fabrication processes and specifications. The cost goal is to produce cells below $30 per watt. Two and ten ohm-cm silicon cells were investigated. This paper describes a unique radiation damage test and side-by-side comparison of candidate cell types with pre- and post-irradiation airplane calibration of outer space short-circuit current.

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