SIMULATED SPACE FLIGHT TESTING OF COMMERCIAL TERRESTRIAL SILICON CELLS*

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SUMMARY

Low cost silicon solar cells, manufactured for the terrestrial market, are examined for possible space flight use. The results of preliminary space environmental testing are reported and discussed. In addition, a number of possible obstacles to the use of these cells are examined. It is concluded that the terrestrial industry could provide an extremely low cost and reliable cell for space use.

INTRODUCTION

The need for new high volume, low cost solar cell and array technology necessary to support the next generation of space missions has been recognized by many (Ref. 1). The use of the shuttle will enable much more ambitious and massive payloads to be launched into Low Earth Orbit (LEO) which will create a significant increase in mission power requirements. In addressing this need NASA has sponsored the development of low cost space cells (Ref. 2). As a result of this work space cell manufacturers have developed candidate cell designs for future mission use under the Power Extension Package (PEP) program. It has been shown that a key to significant lowering of costs is through the means of large quantity production. In the case of the space cells, although a significant increase in annual volume will be required to support future needs, this demand may not be large enough to bring about dramatic cost savings. In addition, the continuing need for specialized low volume cell types will impede the space cell manufacturers from achieving the benefits of a large volume single product line.

However, the terrestrial solar cell industry would have no difficulty in producing the quantity of cells required for future space needs. Whereas the annual space cell production volume is presently measured in the tens of kilowatts, the terrestrial production volume is many megawatts. Although there are distinctly different technology drivers for the two appplications many such as low cost and humidity resistance are similar. Furthermore the LEO mission application will reduce the need for a highly radiation resistant, low mass cell, requirements which would otherwise most likely exceed terrestrial cell capabilities.

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This paper will address the question of whether or not the utilization of cells developed for the terrestrial market can satisfy future low cost space solar power needs. In particular, the results of space environmental testing of these terrestrial cells will be presented, and a discussion of capabilities and limitations of these cells will identify their possible potential.

TEST DESCRIPTION

For this evaluation, cells were purchased from six terrestrial manufacturers. All cells were made from single crystal P type Czochralski grown silicon. Modules are commercially available from five of these suppliers; the sixth was included due to the use of unique fabrication technology which may become commonplace within the next decade. One supplier also provided two types of cells representing different approaches commercially being offered by them. These samples represent a number of different technology approaches which are summarized in Table 1.

After receipt of the samples, mechanical and electrical characterization were performed. In this manner sizes and masses were obtained along with the necessary AMO performance, and spectral response. Samples were then selected from these groups for subsequent space type environmental testing including humidity-temperature storage, thermal vacuum soak, and 1 MeV electron irradiation. These will be described below. It should be noted that none of these cells were designed to survive space type requirements and that performance in the space type tests does not reflect upon their abilities to withstand the terrestrial requirements. In fact it is an accepted terrestrial practice to environmentally test assembled modules, and not single cells. In view of this no attempt will be made to identify a particular sample with the manufacturer.

MECHANICAL AND ELECTRICAL CHARACTERIZATION

Cell shapes vary from rectangular to round, with areas ranging from 38 cm^2 to nearly 98 cm^2, all larger than the PEP cells (36 cm^2) or present space cells (4 cm^2 $\rightarrow$ 12 cm^2). The two largest cells utilize metal conductor straps on the N^+ surface in order to provide low resistive losses without large shadowing losses. Minimizing the cell series resistance is important in view of the large output currents which range from 1.4 to 3.3 Amps. The current densities of the samples averaged 34mA/cm^2 with the highest at 38mA/cm^2 and lowest at 30mA/cm^2. Cell efficiencies ranged from 8.1 percent to 12.6 percent. The performances are shown in Table 2 for each sample group. Of interest, the cell efficiencies are roughly inversely related to the cell active areas, with the exception of the large strapped samples, where resultant efficiencies fall in the mid value range of 10 percent, demonstrating the advantage of the strap concept. Fill factors (FF) generally fall below values observed on space cells, reflecting the impact of large areas and possibly less exacting contacting technologies. For these samples average fill factors varied from a low of 0.65 to a high of 0.76.

Although these efficiencies compare with a conventional 13 percent space cell, the lack of a strong terrestrial driver for low mass leads to a considerable difference in specific power. The influence of large wafer thickness and extensive solder coverage in some samples is appreciable. For samples with straps the mass of the strap external to the cell edge was excluded since this would normally be the interconnector.

The cell spectral response reflects material properties and processing variations and indicate a cell's potential performance under particulate radiation. For the samples examined here significant variations existed in the different groups' spectral characteristics, particularly in the short wavelength region (0.4 microns). For example, the highest sample's response was more than twice that of the lowest. These curves could be used to guide any necessary process or material modifications to enhance radiation resistance.

ENVIRONMENTAL TESTS

Humidity-Temperature Storage. - Selected samples were subjected to 20 days exposure at conditions of 45°C and 95 percent relative humidity. Electrical measurements were made at the end of 8 and 20 days exposure in order to evaluate changes from the initial values. With the exception of one group, no significant changes were observed during the 20 days. The sample group employing silk screened contacts showed a loss of 13 percent in power at 8 days, increasing slightly to 15 percent power loss at 20 days, the result of a significant fill factor degradation. The sample utilizing a liquid deposited AR coating showed no changes in coating appearance or output current.

High Temperature Soak. - Samples were subjected to seven days exposure at 120°C, at a pressure of less than 1×10^{-4} torr, primarily to evaluate whether any detrimental outgassing might occur from non-vacuum metallization and coating processes. No visible changes were observed and although a maximum output loss of approximately 2.5% was observed for one group this was not considered to be statistically significant.

1 MeV Electron Exposure. - Cells were irradiated in the JPL Dynamitron to a fluence of 3×10^{14} e/cm^2. Sample temperature was maintained at 28° ± 2°C during the test. Inasmuch as a number of different processes normally impacting cell radiation resistance were represented among the cells, the measured losses fell in a wide range. In general, however, the losses were comparable to what is observed on a standard space cell under similar fluence. The lowest degradation was measured at a 13.4 percent power loss, whereas the greatest was 26.2 percent. These are compared to typical space cell results in Figure 1.

DISCUSSION

The results of these initial tests indicate that cells presently being produced for the terrestrial market are, with some exceptions, capable of surviving typical space acceptance tests; that the design requirements for earth use do not exclude space use. Furthermore, the terrestrial cell is expected to improve as a product in areas likely to further enhance space capabilities. For example, efficiency will be improved and mass reduced. These will be pursued independent of space needs. Efficiency is critical in reducing overall balance of systems costs such as protective coverings, shipping, etc. In the matter of mass, the less material used the lower the product cost.

The cell shape (round, rectangular) must be considered for space systems. In LEO space applications, array drag leads to a need for high packing factors to reduce the array area. In the case of a 10 cm round cell the maximum array cell area coverage will be less than 82 percent. By cutting this cell into a square, a much better array area coverage will be possible, reducing overall array size. This will introduce some additional cell cost but would be worthwhile at the overall systems level.

A primary concern in utilizing terrestrial cells is the question of contact interconnect designs capable of surviving a very large number of thermal cycles. It has been shown that solder has limited capabilities for LEO thermal cycling conditions (Ref 3). Since present terrestrial cells generally have extensive solder coverage whether they are capable of surviving the 30,000 LEO cycles of a 5 year mission is open to question. In fact, tests are presently underway to examine the terrestrial cells' contact behavior under thermal cycling, the first step in evaluating a useful interconnect approach.

CONCLUSIONS

Clearly the matter of thick, low packing efficiency cell shapes, and massive solder quantities limits the space potential of terrestrial cells. Yet these same areas are of concern to terrestrial manufacturers seeking reduced costs. Excess amounts of material mean high material costs, and low area efficiency means high system costs; so there is a trend to improvement along these lines, that should benefit space capabilities.

Commercial terrestrial solar cells appear to be capable of surviving space type environmental testing. The present cost of these cells is significantly lower than values projected for PEP cells. These cells are not however generally compatible with the requirements for efficient space solar array manufacture. It would be worthwhile to seek cell modifications that could enhance space use and to investigate what cost impacts would occur. As mentioned above, many of these modifications, such as rectangular shapes for packing factor improvement and material thickness reduction are also beneficial to the terrestrial user, and will likely be pursued by that industry. Thus, with the PEP cell work this would allow the concept of a low cost cell for space use to be approached from two directions, enhancing the possibility for solar array cost reductions. The most critical question is whether or not the low cost cell contact schemes are compatible with the need for an interconnect method that will survive tens of thousands of thermal cycles.

REFERENCES

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TABLE 1.

TERRESTRIAL CELL FABRICATION TECHNOLOGIES

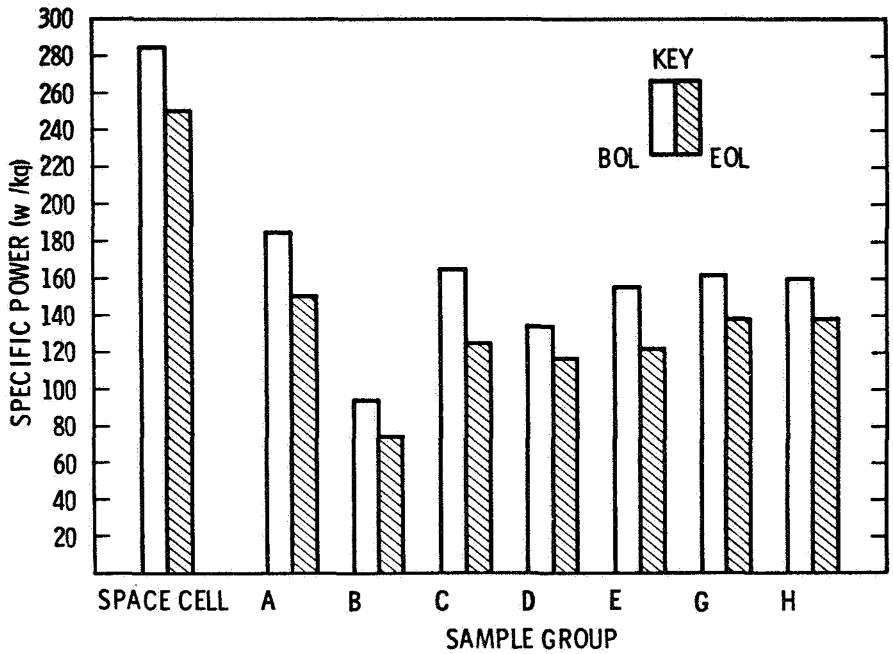
CELL PROCESS	TECHNOLOGY
Junction Formation	Diffusion * Ion Implantation
AR Coating	Texturing * CVD Vacuum Evaporation * Liquid-Bake
Cell Contacts	Ni Plate/Solder Evaporation * Silk Screen Ink Metal Straps

* Standard Space Cell Technologies

TABLE 2.

SAMPLE CHARACTERISTICS

Sample ID	Cell Area (cm^2)	Isc (A)	Pmax (mW)	FF	Eff 28°C AMO	Cell Mass mg/cm^2	Comments
A	46	1.56	701	.76	11.1	83	
B	79	2.34	886	.65	8.1	120	Full Solder Coverage
C	38	1.43	628	.75	12.6	101	
D	46	1.48	579	.67	9.5	94	Full Solder Coverage
E	82	2.57*	1030	.69	8.9*	88	*Textured, No AR, contact metal straps
G	98	3.27	1370	.73	10.3	86	N contact metal straps, Soldered P surface
H	68	2.30	826	.65	8.9	76	



- SPECIFIC POWER AT BOL AND EOL (3×10^{14} 1 mev ELECTRONS)
- REFERENCE SPACE CELL IS 2 OHM-CM, 250 MICRONS THICK

EFFECT OF 1MEV ELECTRONS

FIGURE 1