THE EFFECTS OF SPACE ENVIRONMENT ON SILICON VERTICAL JUNCTION SOLAR CELLS ON THE LIPS III SATELLITE

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ABSTRACT

This paper presents the preliminary analysis and results of a space experiment to evaluate the performance of a new generation of silicon vertical junction solar cells, and three adhesives for attaching coverglass to the solar cells. Two of the adhesives are used for the first time in coverglass applications and subjected to the space environment.

The SOLAREX vertical junction solar cells, which are of 10 ohm-cm silicon with back surface fields (BSF) and back surface reflectors (BSR) are compared to SOLAREX planar junction cells, also of 10 ohm-cm, BSF, BSR silicon. The results up to 566 days in space indicate that the two types of solar cells show about the same degradation rate in power output. There are no important differences at this point in the performance of the three different adhesives.

INTRODUCTION

The vertical junction (VJ) silicon solar cell has been shown in ground testing to have increased radiation resistance compared to planar silicon solar cells [1-3]. The reason for this improved radiation resistance, which is explained in detail in References 1 to 3, may be briefly stated as follows: the convoluted junction geometry (Fig. 1) has the effect of reducing the average drift distance through which the photon-generated electrons must travel to be collected at the junction. Therefore, when the cell is subjected to intense particle radiation which introduces minority carrier recombination centers in the cell, the electrons have an average path length of about 10 μm to diffuse before reaching the junction field. In a planar cell, the average path length, from point of generation to the junction, is of the order of 50 μm. Thus the VJ structure increases the probability that the electrons will contribute to the collected photon current.

Therefore for the above stated reason, the VJ cell is an excellent candidate for application in the radiation environment of space. Until recently, however, the advantages of the VJ cells for use on spacecraft could not be realized. Their use in space power systems has been restricted by the inability of the VJ cell to survive thermal cycling in the space environment. This was evident in results from the NTS-2 flight experiment [4-5] as well as subsequent laboratory tests, wherein the failure of the VJ module was demonstrated to be caused by mechanical degradation of the junction. The NTS-2 experiment indicated that the fragile walls of the VJ cells would probably develop cracks and fractures during the eclipse season when the temperature of the test modules varied between −80° and 103°C. Although the length of time during which the experiment was at the lower temperature was relatively brief (about 5% of the orbit), it was believed that the effects of thermal cycling were sufficiently severe so as to cause cell failure. As is shown in Fig. 2, during each subsequent eclipse, increasing amounts of the junction were degraded causing corresponding reductions of maximum power output until a catastrophic level of destruction was reached and the module failed completely during the fifth eclipse season.

The problem of using VJ solar cells in the space environment arises from the requirement that the solar cells be covered with a transparent material. Solar cells are covered with coverglass in order to provide some measure of shielding against the damage induced by the low energy proton component of the Van Allen radiation. The coverglass is attached with transparent adhesive. In the case of the planar...
Figure 2. Maximum power degradation of the vertical junction module on the NTS-2 flight experiment showing relationship of power loss to eclipse cycles (Eclipse cycles are represented by the dotted lines).

Solar cell, the principal requirements of the adhesive are that it be transparent and resistant to UV and radiation darkening. DC 93-500 is a silicone adhesive which has been developed by Dow Corning for application in the space environment and which has served well as the adhesive used on planar cells for space applications. However, the deep grooves in the surface of the VJ cell make it difficult to apply suitable coverglass using conventional encapsulating materials and techniques. The adhesive, even with careful application, tends to penetrate into the grooves. The coefficient of expansion of DC 93-500 is such that during thermal cycling which exists during the eclipse phase, the thermal mismatch between adhesive and silicon is sufficient to degrade the fragile walls of the VJ cell and thus destroy the junction. The Solarex Corporation, under Naval Research Laboratory (NRL) contract, has determined that two new adhesives which were used for applying coverglass to VJ cells can survive deep thermal cycling. The adhesives selected, based upon thermal cycling testing were DC Q3-6575 and DC 3-6527. These adhesives were recommended by Dow Corning as having superior optical transmission and clarity as well as low outgassing characteristics. These adhesives, in addition to the long-used DC 93-500 which is a space-qualified coverglass adhesive, are used in this space experiment.

EXPERIMENT SOLAR PANEL

Ten 2 x 2 cm SOLAREX solar cells with 12 mil fused silica coverglass were conventionally mounted and spaced apart on 1/4" aluminum honeycomb substrate. The cells are individually measured in the LIPS III data acquisition system which provides 24-point I-V curves. Temperature was obtained from the readings of two resistance thermometers on the rear of the substrate face sheet. The four planar cells on the panel utilized the two new types of adhesive (two cells with each type). The baseline data were obtained from witness cell #2, a SOLAREX planar cell using DC 93-500 under the same type coverglass. The other six cells on the panel were VJ cells, using the three types of adhesive, with two cells for each adhesive type.

The coverglass used for each solar cell was a 12 mil-thick fused silica (Dow Corning 7940) plate with an antireflective coating and ultraviolet filter.

Current-voltage data were obtained at NRL using a Spectro-lab X-25L solar simulator. During the spacecraft experiment integration, the panel I-V measurements were checked out in several instances with a tungsten SunGun.

RESULTS AND DISCUSSION

Space data have been processed for the period of Day 14 to Day 566 after launch. The LIPS III orbit is a circular orbit at 600 nm and 63° inclination. The data shown in Figs. 3 through 7 have been temperature corrected to 25°C from the actual values which ranged from 3° to 60°C. Also the solar intensity was corrected for the day of the year. The sun
aspect to the experimental plane was always $90 \pm 1/4^\circ$ when data was copied.

The maximum power point vs days of the planar cells is plotted in Fig. 3. The predicted degradation value band is based on data from the Solar Cell Radiation Handbook, Third Edition [6], also taking into account a predicted loss in optical transmission of the adhesives of between 2 and 4 percent over 600 days. Under these conditions, the planar cells and all three adhesives show good correspondence to the prediction.

The experimental scatter which is seen in the space data is not unusual for this type of experiment, where electronic complexity of the total spacecraft system can sometimes interact with the solar cell electronic data systems. Other physical effects, such as reflections from nearby satellite surfaces, the effect of earth albedo and telemetry problems can impact on the smoothness and accuracy of the raw data. J.G. Severns has discussed these and other effects which have been observed in the data [7, 8].

The vertical junction cell maximum power is shown in Fig. 4. In this case, the observed degradation is slightly greater than predicted. However, all three adhesives show similar performance. It should be mentioned that the lowest temperature reached by the panel is about $-23^\circ$C and the period is only about 30 minutes. Therefore one should not expect to duplicate at this orbit the type of thermal cycling damage which was seen on NTS-2 [4, 5] and shown in Fig. 2.

The short-circuit currents for the two types of solar cells are shown in Figs. 5 and 6. In this case, the predicted degradation is less severe than actually observed. This disparity is most likely due to the fact that the "generic" data in Ref. 6 cannot be exactly applicable to characterizing solar cells made by another manufacturer, and at a different time. This fact emphasizes the need for additional data to supplement the basic data provided by the Handbook, which was published in 1982. The short-circuit currents for the planar junction solar cells do show one feature that is not apparent in the case of $I_{SC}$ of the VJ cells, nor is it apparent in the case of $P_M$ degradation. What is observed is that the $I_{SC}$ of the planar junction cell with DC 93-500 adhesive is consistently about 5 percent greater than the cells with the other two adhesives. Normally, when $I_{SC}$ is greater, the $P_M$ should also be greater with all other variables being the same. However, the locations of the cells on the satellite are different. All cell types are on one panel, with the exception of the planar cell with DC 93-500 adhesive. This cell is located on a different panel. Temperature corrections are made to a uniform reference of $25^\circ$C. The higher reading cell may be subject to one of the problems described in Refs. 7 and 8. At this time it is not possible to determine the reason for this observed behavior.

Finally the two cell types, planar and vertical junction, with the DC 93-500 coverglass adhesive are compared in Fig. 7. In this case the planar cell, which had an initial efficiency slightly higher than the VJ cell, has maintained this superiority up to 566 days. The estimated 1-MeV equivalent electron fluence, through 12 mil coverglass, is $3.4 \times 10^{13}$ 1-MeV e/cm$^2$-yr, for a total of $6.3 \times 10^{13}$ e/cm$^2$ over 566 days. It is expected that the power output of the VJ cell will exceed that of the planar cell by the end of three years in orbit.
Figure 4. Maximum power vs days in orbit for Solarex vertical junction silicon solar cells with three different coverglass adhesives.

Figure 5. Short-circuit current vs days in orbit for Solarex planar silicon solar cells with three different coverglass adhesives.
Figure 6. Short-circuit current vs days in orbit for Solarex vertical junction silicon solar cells with three different coverglass adhesives.

Figure 7. Maximum power point of the Solarex planar junction and vertical junction solar cells with DC 93-500 coverglass adhesives.
CONCLUSIONS

The present experiment is completely operational and will provide valuable data for several more years. The preliminary conclusions at the end of 56 days in space are:

1. The vertical junction and the planar junction silicon solar cells show the same rate of maximum power degradation.

2. There are no significant differences in the performance of the three different coverglass adhesives, as inferred from the rate of short circuit current degradation.

3. No particular problems were observed in the vertical junction solar cell stack with any of the three adhesives.

4. There is better performance in $I_{SC}$ for the planar junction solar cell with DC 93-500 adhesive. However, there may be a subtle error which has not been discovered which may produce this effect.

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REFERENCES


