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Ultraviolet Effects on Conductive Coated Coverglasses

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ABSTRACT

Experiments on the International Sun-Earth Explorer required that the outer surface of the spacecraft be conductive. For the solar panels this was accomplished by using solar cell coverglasses coated with indium-oxide and interconnected to ground. This paper presents results of ultraviolet tests performed as part of the overall qualification program for cell assemblies using these coverglasses.

The samples were exposed under vacuum at a controlled temperature to 5000 equivalent sun hours. Coverglass transmission curves and cell assembly current-voltage curves were measured before and after the test.

Observed degradations were of the order of 1 percent more for conductively coated coverglasses than for coverglasses without conductive coatings.

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ULTRAVIOLET EFFECTS ON CONDUCTIVE COATED COVERGLASSES

INTRODUCTION

The International Sun–Earth Explorer (ISEE) spacecraft, A and C, were designed with conductive outer surfaces to avoid charge buildup which would interfere with plasma measurements. To meet this requirement, the solar panels used solar cell coverglasses conductively coated with indium–oxide and electrically interconnected to ground. Since ISEE–A and C are the first United States spacecraft solar arrays with this type of coverglass for the cells, a variety of tests were performed to determine the performance characteristics of solar cells and solar cell modules with conductively coated coverglasses and to qualify them for flight use. This paper presents the results of the ultraviolet (UV) irradiation test in which a variety of cell and coverglass configurations were exposed to UV irradiation in a vacuum environment.

OBJECTIVES

The objectives of the ultraviolet test were to determine the comparative stability of the coverglass transmission characteristics for several types of coverglass and the resulting effects on the electrical output of solar cell assemblies when exposed to ultraviolet (UV) irradiation in a vacuum environment. These objectives included the extension of previously reported (1) UV test results to include effects applicable to newer high efficiency cells.

EXPERIMENT

Test Samples

Three test samples of each of six configurations were tested. The configurations were:

1. Unmounted, conductively coated (CC) coverglasses with UV filters.
2. Bare solar cells.
3. Cell assemblies with filtered coverglasses without conductive coatings.
4. Cell assemblies with conductively coated coverglasses without filters.
5. Cell assemblies with conductively coated and filtered coverglasses using Spectrolab cells.
6. Cell assemblies with conductively coated and filtered coverglasses using Optical Coating Laboratory, Inc. (OCLI) cells.

All cells were shallow diffused, N/P type, silicon solar cells with ditantalum-pentoxide coatings. Cells of configurations 2, 3, 4, and 5 were Spectrolab cells. Only configuration 6 used OCLI cells. All coverglasses were furnished by OCLI. They were 0.3mm thick Corning 7940 fused silica. Where UV filters were used, the nominal cut-off wavelength was 350mm. The coverglasses were bonded to the cells using DC 93-500 adhesive.

The 18 samples were mounted on a water-cooled copper plate as shown in Figure 1. The cell assemblies were bonded in place using RTV-566 adhesive, while the coverglasses were held in place, without bonding, using a brass holder which overlapped onto the glass approximately 1mm on each edge. For each configuration the samples were distributed on the plate so as to reduce any systematic effects such as beam non-uniformity.

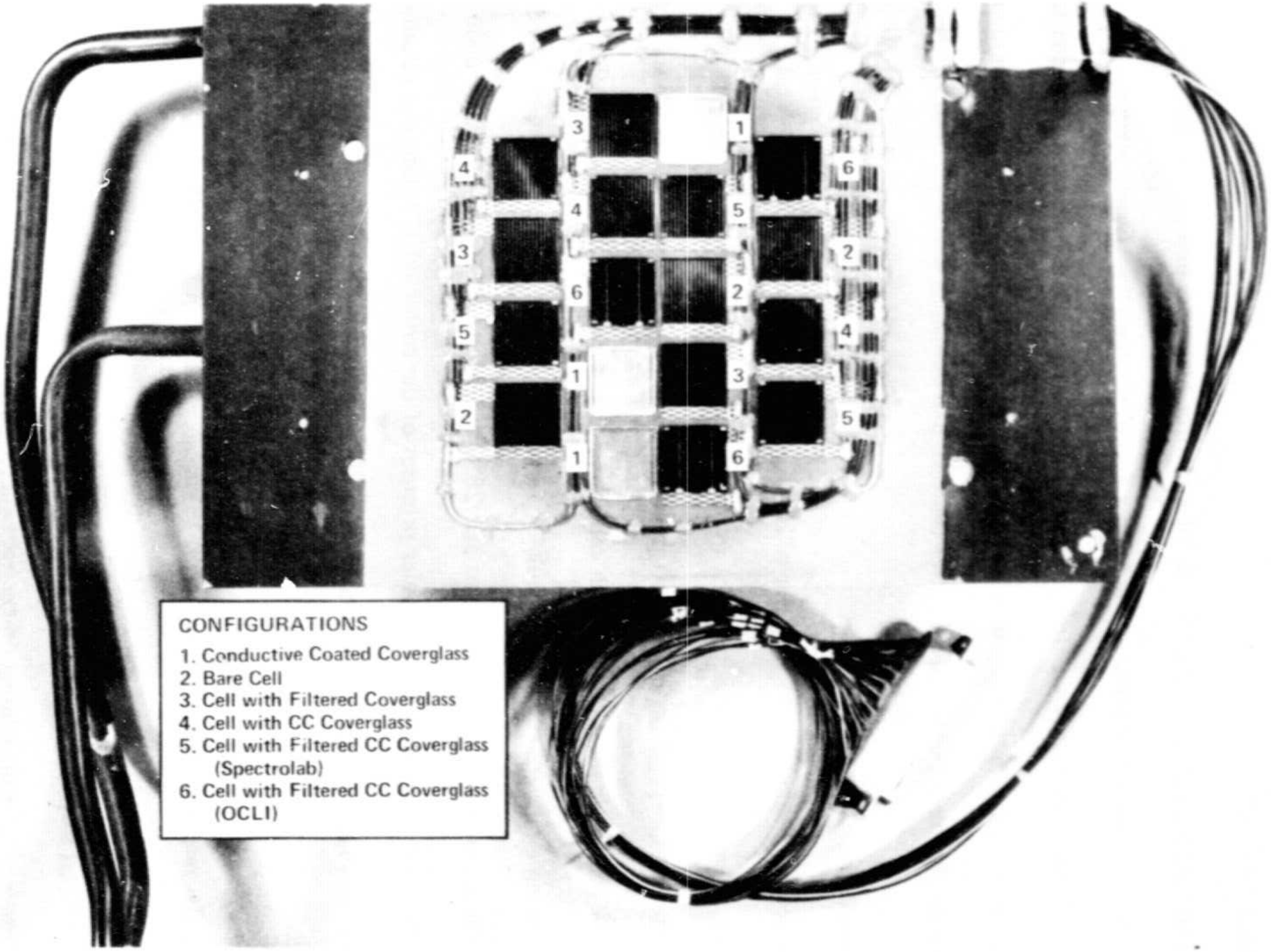

Figure 1. Testplate With Samples Mounted

Measurements

Transmission Curves

Transmission curves were obtained for a control coverglass and for the three unattached coverglass test samples in air using a spectrophotometer. Curves were measured before UV exposure and again after exposure with the coverglasses removed from the test plate holders. The control sample, which did not undergo the UV testing, was measured along with the three tested samples after the test.

Current–Voltage Curves

Electrical connection to the solar cells was made by expanded silver mesh tabs soldered to each cell. All positive tabs were interconnected in common. All negative tabs were left independent to permit current–voltage (I–V) measurements on each individual cell. I–V data were measured for each cell assembly before and after the ultraviolet exposure using a pulsed xenon solar simulator for the light source. The data were corrected to standard conditions of air mass zero and 28°C by computer referenced to a balloon flight standard solar cell. The computer printout of the corrected I–V data was obtained and I–V curves representing this data were plotted.

Irradiation

A flat response radiometer was used to measure the intensity of the X-25 solar simulator used as an ultraviolet source. Initially, the radiometer was placed at the plane of the test panel surface inside the chamber and the simulator intensity was ajdusted to give a 677 mw/cm^2 (5 sun) reading on the radiometer. The radiometer was then placed outside the chamber window to obtain the external reading corresponding to the 5 sun test plane intensity. During the test, adjustments in intensity were made to maintain the external reading corresponding to the 5 sun test plane conditions.

Temperature

During the ultraviolet exposure the temperature was monitored using thermocouples attached to the front and back of the copper plate on which the samples were mounted.

Ultraviolet Exposure

For the ultraviolet exposure, the test plate was mounted in a vacuum chamber equipped with a liquid nitrogen cooled shroud. The test plate was mounted facing a quartz window through which the concentrated output of an X-25 solar simulator shone. During the test the chamber was stabilized at a pressure of 1×10^{-8} torr. The test plate temperature was controlled by the water cooling system and ranged from 16°C to 20°C. The simulator intensity was continuously monitored and adjusted to maintain 5 suns ($677 mw/cm^2$) at the test plate. After a total exposure of 5000 equivalent sun hours (ESH) had been accumulated, the test was shut down and the test plate was removed for post-test measurements.

DATA AND ANALYSIS

Transmission Data

The pre-test transmission curves for the control sample and the three test samples are shown in Figure 2. It can be seen that there is a high degree of similarity for the curves. Because the post-test curves were almost identical, limitations, such as drift, non-linearity, etc., of the spectrophotometer made the data difficult to interpret. However, by reading the difference between the control coverglass and the tested sample both before and after the UV exposure and calculating the changes, it was possible to identify

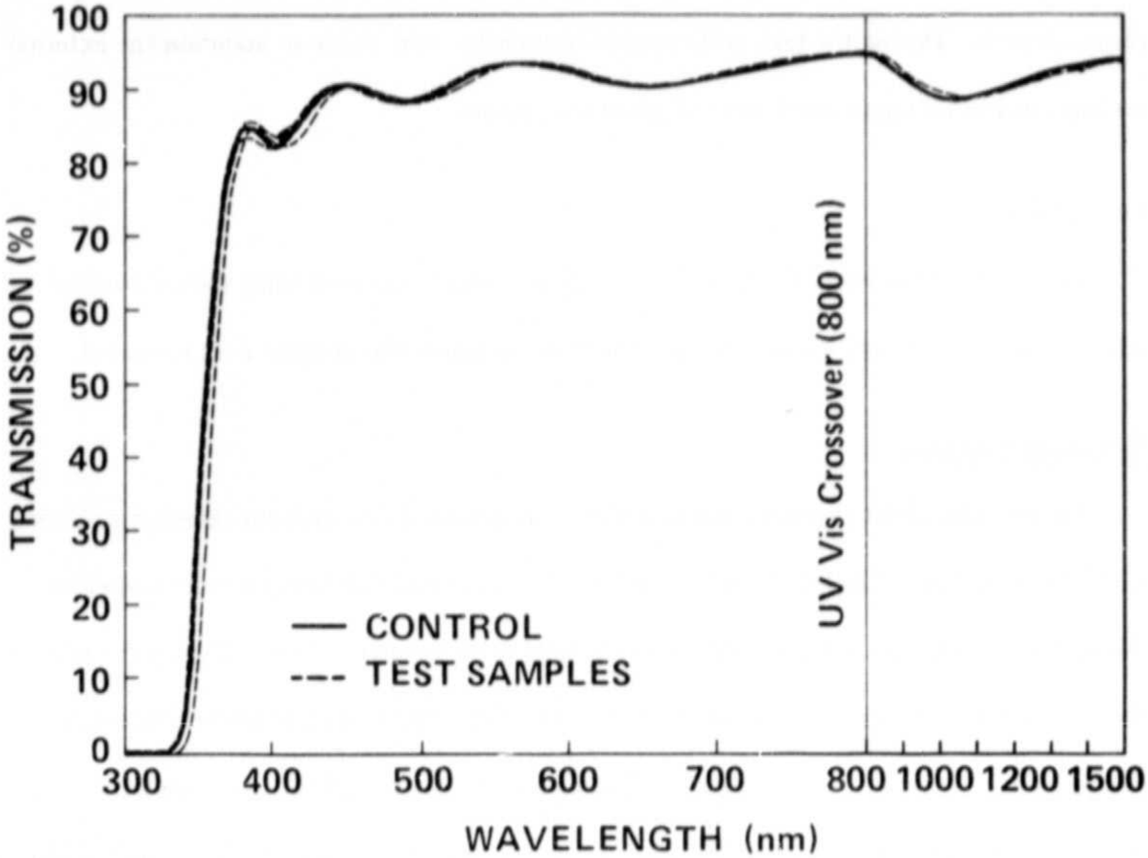

Figure 2. Pre-test Transmission of Conductive Coated Coverglasses

a definite, though small, loss in transmission. Results are shown in Figure 3. For wavelengths below 450 nm, the transmission changes rapidly and this analysis technique tends to break down. That is, small wavelength shifts result in large transmission changes. These, in turn can result in large difference errors. For wavelengths above 450 nm, Figure 3 shows nominal degradation of the order of 0.5 to 1 percent.

Electrical Output Data

Short Circuit Current

The short circuit current was read from the computer printout. This data is shown in Table 1. It shows negligible losses for bare cells and for the cell assemblies with filtered

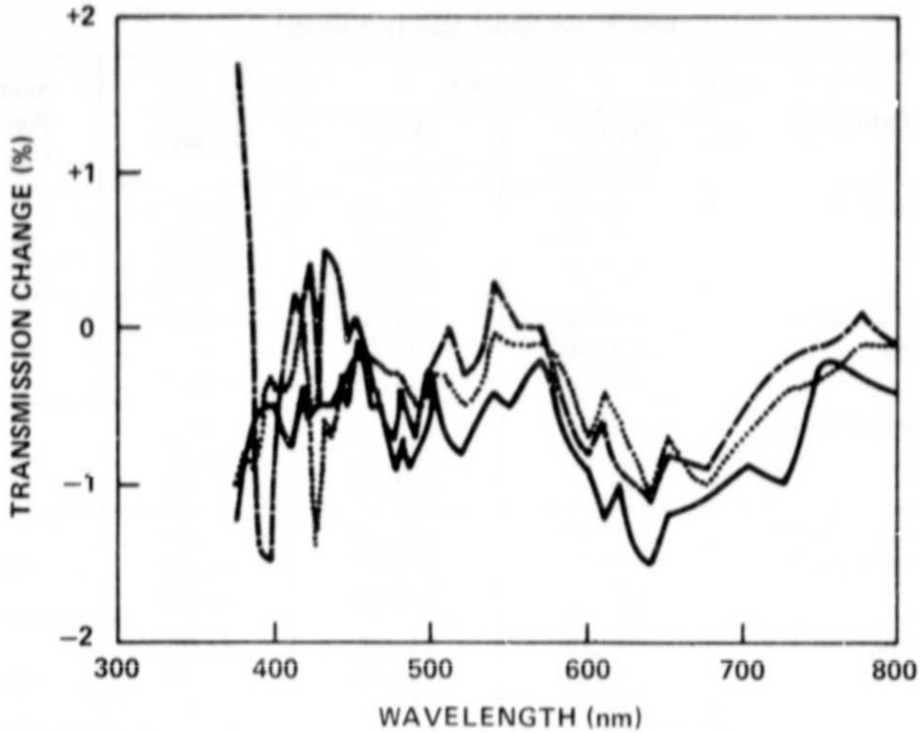

Figure 3. Net Change in Transmission for Three Samples. (Configuration 1.)

coverglasses without conductive coatings. However, the losses were of the order of 1 percent for the coverglasses with conductive coatings.

Open Circuit Voltage

The open circuit voltage was also read from the computer printout. This data is shown in Table 2. In general the change in open circuit voltage was of the order of 1 percent. This applies for all five cell assembly configurations, so the effect of coverglass degradation is negligible, as expected. Although effects of ultraviolet on the cells themselves cannot be absolutely ruled out, it is almost certain that the changes resulted from some fixed bias in the data. For example, an uncorrected temperature error of 2 to 4 degrees C could cause the same effects.

Table 1

Effects on Short Circuit Current

Configuration	I_{SC} (ma)		Percent Change	Average Percent Change
	Before Exposure	After Exposure		
2. Bare Cell	149.50 148.30 149.62	149.76 148.36 150.60	+0.17 +0.04 +0.65	+0.29
3. UV Coating Only	151.48 150.16 153.28	152.10 149.76 153.38	+0.41 -0.27 -0.07	-0.02
4. Cond. Coating Only	146.04 145.22 146.02	145.28 143.12 144.20	-0.52 -1.45 -1.25	-1.07
5. Cond. and UV (Spectrolab)	143.82 144.90 142.74	143.00 143.32 141.26	-0.57 -1.09 -1.04	-0.90
6. Cond. and UV (OCLI)	146.78 146.46 147.02	145.26 146.00 145.36	-1.04 -0.31 -1.13	-0.83

Table 2

Effects on Open Circuit Voltage

Configuration	V_{OC} (mv)		Percent Change	Average Percent Change
	Before Exposure	After Exposure		
2. Bare Cell	576.8 574.9 572.9	569.9 568.9 566.9	-1.20 -1.04 -1.05	-1.10
3. UV Coating Only	583.8 583.8 577.8	574.9 579.8 570.9	-1.52 -0.69 -1.19	-1.13
4. Cond. Coating Only	578.8 577.8 582.8	570.9 572.9 577.8	-1.36 -0.85 -0.86	-1.02
5. Cond. and UV (Spectrolab)	579.9 573.9 579.8	572.9 566.9 575.9	-1.21 -1.22 -0.67	-1.03
6. Cond. and UV (OCLI)	596.7 591.8 593.7	590.8 586.8 588.8	-0.99 -0.84 -0.83	-0.89

Power Point Voltage

Typical current–voltage curves are shown in Figures 4 and 5. For power point comparisons, peak power points were found on each of the plotted I–V curves. Before the test the peak power voltages ranged from 428 to 473 mv, with an average value of 444 mv. After the test the peak power voltages ranged from 423 to 472 mv, with an average value of 439 mv. Hence, a nominal value of 440 mv was selected for power point comparisons. These comparisons are given in Table 3. These results include both effects on current and effects on voltage. They are given to illustrate that, even assuming the effects on

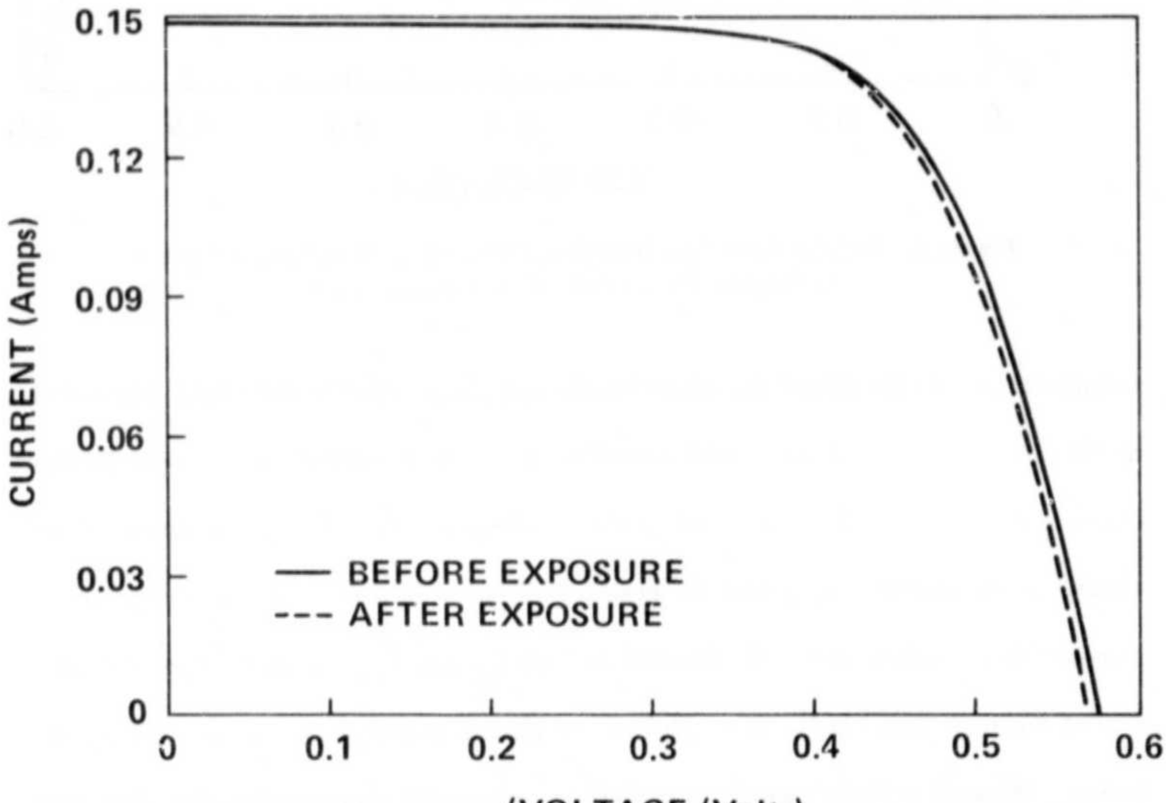

Figure 4. Typical Electrical Output for Bare Spectrolab Cell. (Configuration 2.)

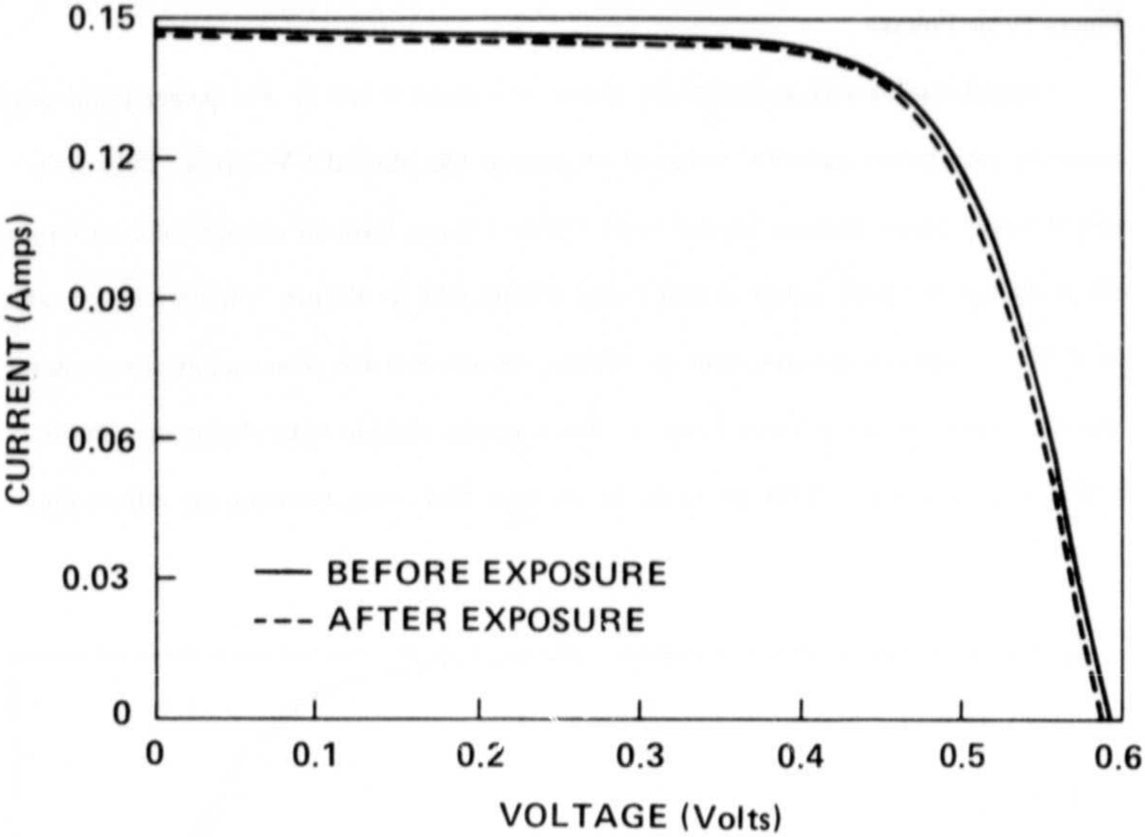

Figure 5. Typical Electrical Output for OCLI Cell, Conductive Coated Coverglass With Filter. (Configuration 6.)

voltage are due to the ultraviolet exposure, the combined effect is still small. The scatter of the data is generally determined by whether the common 440 mv, point is on the short circuit current side of the peak power point, in which case the change corresponds more closely to the change in I_{SC}; near the peak power point, in which case the change corresponds to a combination of the changes in both I_{SC} and V_{OC}; or on the open circuit side of the peak power point in which case the change results primarily from the change in V_{OC}. Because of these complicating factors, considerable caution should be exercised in drawing conclusions from the data in Table 3.

Table 3

Effects on Current at 440 mv

Configuration	Current (ma)		Percent Change	Average Percent Change
	Before Exposure	After Exposure		
2. Bare Cell	137.2 134.8 131.0	135.2 132.6 129.9	-1.46 -1.63 -0.84	-1.31
3. UV Coating Only	139.5 137.2 135.3	138.8 135.7 132.8	-0.50 -1.09 -1.85	-1.15
4. Cond. Coating Only	133.5 133.0 129.8	130.7 129.6 125.7	-2.10 -2.56 -3.16	-2.61
5. Cond. and UV (Spectrolab)	131.0 127.8 127.9	129.8 124.9 124.8	-0.92 -2.27 -2.42	-1.87
6. Cond. and UV (OCLI)	140.2 139.8 140.5	138.0 139.0 138.1	-1.57 -0.57 -1.71	-1.28

CONCLUSIONS

The following conclusions are drawn from the experiment results:

1. State of the art conductive coated coverglasses are suitably stable for flight application insofar as ultraviolet effects are concerned.

2. Ultraviolet effects on the transmission of conductive coated coverglasses exposed to 5000 ESH resulted in a transmission loss of 0.5 to 1 percent.

3. The short circuit current loss for solar cell assemblies with conductive coated coverglasses is approximately 1 percent greater than for those with conventional coverglasses after exposure to 5000 ESH.

4. An open circuit voltage reduction of approximately 1 percent was observed. This was observed for all configurations, so it is concluded that it is associated with the cells rather than the conductive coated glass.

5. The combined effects on current and voltage resulted in a total degradation of between 1 and 3 percent in the vicinity of the peak power point.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Figure 1. Testplate With Samples Mounted

Figure 2. Pre-test Transmission of Conductive Coated Coverglasses

Figure 3. Net Change in Transmission for Three Samples. (Configuration 1.)

Figure 4. Typical Electrical Output for Bare Spectrolab Cell. (Configuration 2.)

Figure 5. Typical Electrical Output for OCLI Cell, Conductive Coated Coverglass With Filter. (Configuration 6.)