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PERFORMANCE OF SOLDERED AND CEMENTED COVER GLASS SILICON SOLAR CELLS

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16. Abstract

A method has been developed for mounting protective glass covers on solar cells. This method eliminates the need for an adhesive and an ultraviolet protective filter. It consists of soldering the glass to the cell. Matching grid patterns are deposited on the cell and cover glass, after which both are solder dipped. They are then mated and heated to achieve the bond. This combination is equal in performance to the standard cemented cover glass cell in humidity stability and temperature cycling. It is more resistant to radiation damage primarily because of its higher blue response short-circuit current.

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PERFORMANCE OF SOLDERED AND CEMENTED COVER GLASS SILICON SOLAR CELLS

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SUMMARY

Silicon solar cells in Earth orbit are subject to high-energy radiation damage. One method of protection relies on a glass cover cemented to the cell. An ultraviolet filter is evaporated on the glass to protect the cement from ultraviolet damage, but this reduces the blue spectral response output of the cell. The blue response is, however, not as sensitive to radiation damage, and cell performance would be higher if the blue response output could be retained. Further improvement can be obtained when high blue (shallow junction) cells are used. More of the blue response output can be preserved by soldering the glass to the solar cell using the same contacting mask and materials as is used on the cells. In this way, the ultraviolet filter and its detrimental effect on the blue response output is eliminated. Shallow junction cells made with soldered glass covers show approximately 4 milliamperes higher short-circuit current (for a 1- by 2-cm cell) than commercial cells with cemented glass covers. This improvement is retained through a bombardment dose of 1.5×10^{16} 1 MeV electrons per square centimeter and represents 12 to 13 percent of the total current after such a bombardment. The cells with soldered cover glasses are equal to the commercial cells with cemented covers in their resistance to structural and electrical changes under 90 percent relative humidity at room temperature and also to temperature cycling simulating an Earth orbit mission. The cells with soldered glass covers also tend to remain approximately 4° C cooler than cells with cemented glass covers when exposed to simulated space temperature cycling.

INTRODUCTION

Silicon solar cells on Earth-orbit missions are subject to damage by high-energy radiation. Several methods can be applied to minimize the damage due to electron and proton bombardment. One approach is to shield the solar cell with a transparent cover, such as a quartz-glass window. Another method is to increase the blue response of the cell, since the response to the 400- to 500-nanometer range of the spectrum is relatively independent of radiation damage (ref. 1). A high blue response cell with the proper protective cover glass would yield a configuration offering better performance than now available.

The present method of mounting the cover glass on the cell relies on the use of an adhesive which degrades on exposure to ultraviolet radiation (fig. 1). An ultraviolet filter is, therefore, deposited on the cover glass to protect the adhesive. However, the

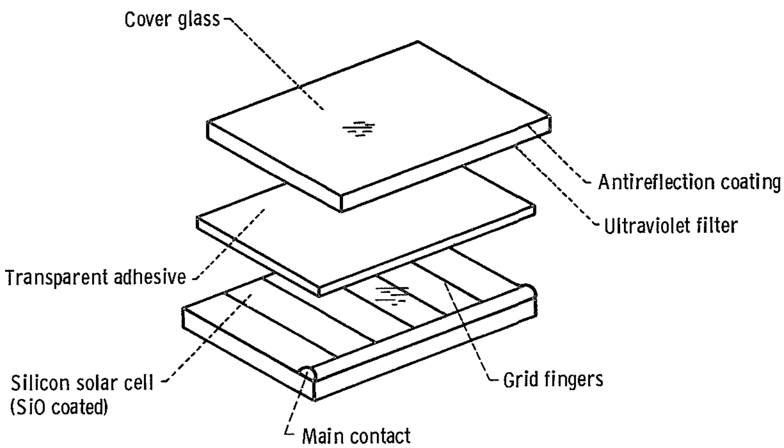

Figure 1. - Cemented-cover-glass cell assembly.

filter reduces the amount of blue light reaching the cell (ref. 2). In order to use the blue light, another method of attachment would be desirable.

A method described in reference 3 involves soldering the cover glasses to high blue response cells at the grid contacts, thereby eliminating the adhesive and the ultraviolet filter entirely (fig. 2). Earlier studies and calculations (ref. 3) had predicted a definite improvement in solar cell performance using this structure.

In this report, a comparison is made between current state-of-the-art commercial silicon cells using ultraviolet filtered quartz glass cemented covers (hereafter designated as CC assemblies) and high blue response cells with quartz covers soldered to the cell (LS assemblies) made at the Lewis Research Center.

The following comparisons are made on LS and CC assemblies: unbombarded spectral response as measured by the Lewis filter-wheel simulator (ref. 4); their response after electron bombardment; and their physical stability after storage at room-temperature high-humidity conditions and during temperature cycling under simulated outer space conditions.

In addition, spectral response comparisons are made between commercial cells with

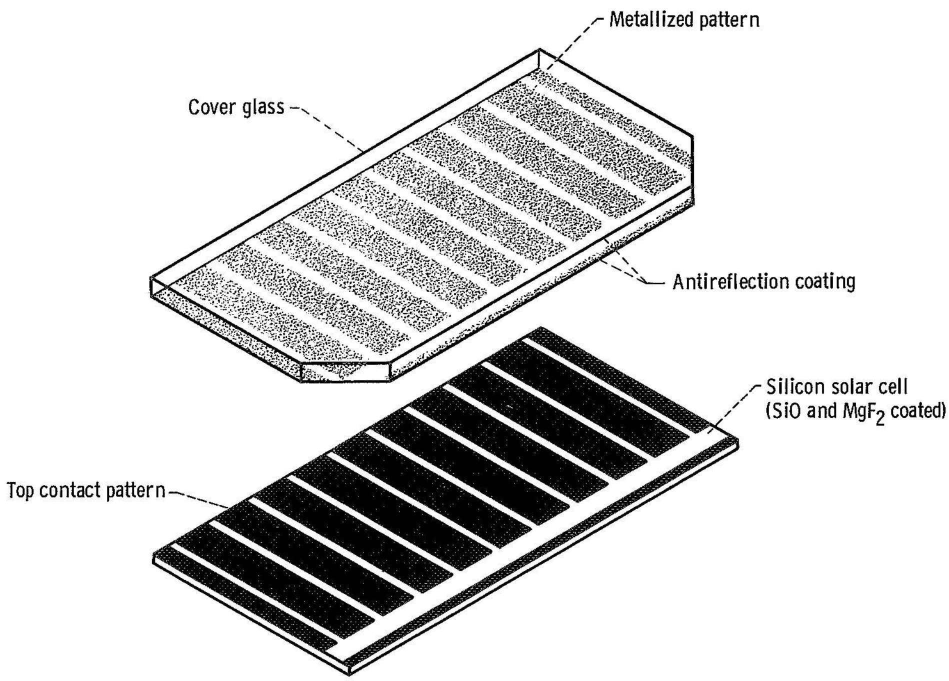

Figure 2. - Soldered-cover-glass cell assembly.

soldered cover glasses (CS assemblies) and Lewis type cells with cemented cover glasses (LC assemblies).

APPLICATION OF SOLDERABLE CONTACTS TO COVER GLASSES

The solderable contacts on the quartz cover glasses are made in essentially the same manner as the contacts on silicon cells. The glasses used are 6-mil (152.4-μm) thick Corning 7940 fused silica with an antireflection magnesium fluoride (MgF_2) coating on both sides. After treatment in boiling isopropyl alcohol, the glasses are mounted in a holder, and a mask, identical to that used in the evaporation of contacts on the silicon cells, is placed on the glasses. The holder is then placed in a vacuum system at a height of 12 inches (30.48 cm) above two evaporation boats. One boat contains approximately 0.3 gram cerium metal and the other, 2.5 grams of silver. The vacuum system is pumped down to the 10^{-7} torr range before the evaporations begin. Cerium, which is evaporated first, is brought to a temperature of about 1650° C in 2 minutes and held there for an additional 1/2 minute. The shutter is opened and the cerium evaporated to completion, in about 1 minute. After a similar preevaporation heating to 1050° C, the shutter over the silver boat is opened, and the silver is also evaporated to completion. The system is allowed to cool down to room temperature and the glasses are removed.

They are solder-dipped using Divco 335 soldering flux and a solder pot at 200° C charged with National Lead 111 solder saturated with silver. Following a thorough cleaning in boiling isopropyl alcohol, the glasses are ready to be mounted on the previously dipped cells. The cells are placed face up in accurately dimensioned recesses in an aluminum holder. Each recess is deep enough to contain a cell, cover glass, and a lead block weight. The glasses are placed on top of the cells so that the soldered surfaces face one another, and the lead blocks are placed on the cell-glass pairs. The entire unit is then placed in an oven and kept at 220° C for about 1/2 hour. After this interval, additional pressure is applied to ensure complete solder flow between cell and glass. The assembly is then removed and allowed to cool to room temperature.

DESCRIPTION OF CELL ASSEMBLIES

Type LS. The type LS assembly is a high blue response cell with a soldered glass cover. These cells were made at Lewis and have been described in reference 1. They are 1- by 2-centimeter, 14-mil (355.6-μm) thick, shallow junction, n-p cells of 10 ohm-centimeter base resistivity. The cells have cerium-silver evaporated (and sintered) contacts, 10 grid fingers, and have silicon monoxide (SiO) and MgF_2 antireflection coatings. However, it must be pointed out that these cells are experimental and that the conditions for making stable cells reproducibly have not been optimized. The cerium-silver contact is a new development and sufficient experience has not been gained so that humidity stable contacts can be obtained with every run. This new contact, and the preevaporation treatment for the SiO and MgF_2 antireflection coating, result in a degree of uncertainty in the electrical behavior of the contact due to processing and storage.

Type CC. The type CC assembly is a commercially available cell with a cemented cover glass. These cells are 1- by 2-centimeter, 14-mils (355.6-μm) thick, cells of 10 ohm-centimeter base resistivity, and have titanium-silver sintered contacts and an SiO antireflection coating. The cell is covered by a 6-mil (152.4-μm) 7940 quartz cover glass with an MgF_2 antireflection coating on the top surface and an ultraviolet filter having a 415 nanometer cutoff, facing the cell. The glass is mounted by means of Sylgard 182 cement.

Type LC. This type of assembly differs from the CC assembly only in that a Lewis cell is used and the ultraviolet filter has a 395 nanometer cutoff. This ultraviolet filter falls within the specifications (410±15 nm) for filters used with solar cells.

Type CS. The CS assembly is a commercially available cell, with a cover glass (similar to that used in an LS assembly) soldered to the cell.

TEST PROCEDURES

Spectral Response

The spectral response of the solar cells in the LS, CS, and LC assemblies were measured in the Lewis filter wheel solar simulator (ref. 4) before and after the glasses were applied. The spectral response was also measured with a nonsolder-dipped glass (with antireflection coatings on both sides) held over the cell. This condition was expected to give the least amount of transmission loss, since the glass had not undergone any treatment.

Spectral response measurements were also made on type CC assemblies.

Humidity Storage

Samples of LS and CC assemblies were placed in a humidity chamber at 90 percent relative humidity and 25° C for 1 month. Current-voltage characteristics were measured before and upon completion of this test.

Electron Bombardment

Type LS and CC assemblies were subjected to electron bombardment in air, using the NASA Lewis 3.0 MeV (maximum) Cockcroft-Walton accelerator. Doses of 5×10^{14}, 1.5×10^{15}, 5×10^{15}, and 1.5×10^{16} 1 MeV electrons per square centimeter were applied cumulatively. The spectral response was measured initially and after each bombardment level.

Temperature Cycling Under Simulated Earth Orbit Conditions

Leads and thermocouples were attached to type LS and CC assemblies and placed in a 5-foot (1.52-m) diameter space simulator chamber. The chamber walls were cooled to liquid-nitrogen temperatures to simulate Earth orbit conditions. A xenon lamp light source was used as the solar simulator and was adjusted to give AMO intensity in the plane of the solar cells. The cells were exposed to 1058 cycles of 1 hour of illumination and 1/2 hour of darkness. The chamber and associated equipment are described in reference 5.

The temperature, open circuit voltage, and short-circuit current of the assemblies were measured periodically during the test. Visual observations of the integrity of the total cell structure were made upon completion of the test.

RESULTS

Spectral Response

Thirty high blue cells (1 by 2 cm) had an average total current of 71.2 milliamperes without covers and an average total current of 67.1 milliamperes with the soldered covers. The spectral responses of a typical uncovered Lewis high blue response cell, an LS assembly and a CC assembly are shown in table I. Comparison of columns 2 and 4 reveals the higher output of an LS assembly in the 400 nanometer region as compared to a CC assembly.

The minimum losses in cell response due to application of a glass cover were determined by measuring the response of a bare cell, and then with a cover glass held over it. The glass had an antireflection coating on both sides. The losses, measured in this manner, averaged 3.7 percent. Actual results on 30 LS assemblies show losses ranging from 3.9 to 10 percent with an average value of 6.5 percent. The wide variation between

TABLE I. - SPECTRAL RESPONSE OF TYPICAL SOLAR CELL AND ASSEMBLIES

Wave-length, nm	High blue response cell			Response for commercial cell[b] with cemented cover (type CC), mA
	Response for uncovered cell, mA	Response for cell[a] with soldered glass cover, mA	Loss due to cover, percent	
950	5.31	5.10	3.95	5.34
900	11.56	10.87	5.97	11.68
800	13.06	12.62	3.37	13.29
700	13.18	12.58	4.55	12.79
600	10.59	10.08	4.82	10.29
500	6.54	6.05	7.49	6.13
450	5.03	4.58	8.95	3.78
400	5.45	5.01	8.07	.34
	70.72	66.89	5.42	63.64

[a]Cell size, 1- by 2-cm; type LS.
[b]Cell size, 1- by 2-cm; type CC.

TABLE II. - COMPARISON OF BARE AND COVERED

SOLAR CELL RESPONSES

Assembly	Response of -		
	Bare cell, mA	Covered cell, mA	Loss, percent
LS (30-cell average)			
Total response	71.24	67.07	5.84
400 nm	5.40	5.01	6.48
CC			
Total response	[a]~67	[b]63.45	[a]~6
400 nm	[a]~2.9	[b].31	[a]~90
CS (three-cell average)			
Total response	67.17	63.63	5.3
400 nm	2.90	2.79	4.5
LC (eight-cell average)			
Total response	70.71	64.65	8.6
400 nm	4.92	4.30	12.6

[a]The loss values for the commercial cells are approximate. The bare cell currents were measured on 22 bare cells of equal quality, purchased from the same manufacturer at the same time as the covered cells.

[b]Average value for 21 cells.

3.9 and 10 percent could be due to variations in the final finger and bar contact widths. Any excess solder would tend to spread and cover active areas of the cell. Changes can also occur in the transmission (or reflection) of the glasses in the course of processing solderable glass covers.

Glasses were also soldered to three commercial cells which did not have a shallow junction. The total response of these CS assemblies was about the same as for CC assemblies, but the loss in 400-nanometer response was only about 4.5 percent. The average 400-nanometer response for CS assemblies was 2.79 milliamperes as compared with 0.31 milliampere for CC assemblies (table II).

Ultraviolet filtered glasses were cemented onto Lewis cells to make eight LC assemblies. These did not show as sharp a drop in the 400-nanometer response (table II) as did CC assemblies. The blue response of 4.3 milliamperes is about 14 times higher than the 0.3 milliampere observed for CC assemblies. This difference is due to the glasses having different ultraviolet filter cutoffs (see DESCRIPTION OF CELL ASSEMBLIES). At a wavelength of 400 nanometers, the effect of shifting the ultraviolet filter cutoff from 395 to 410 nanometers decreases the transmission by a factor of 10 (see fig. 3).

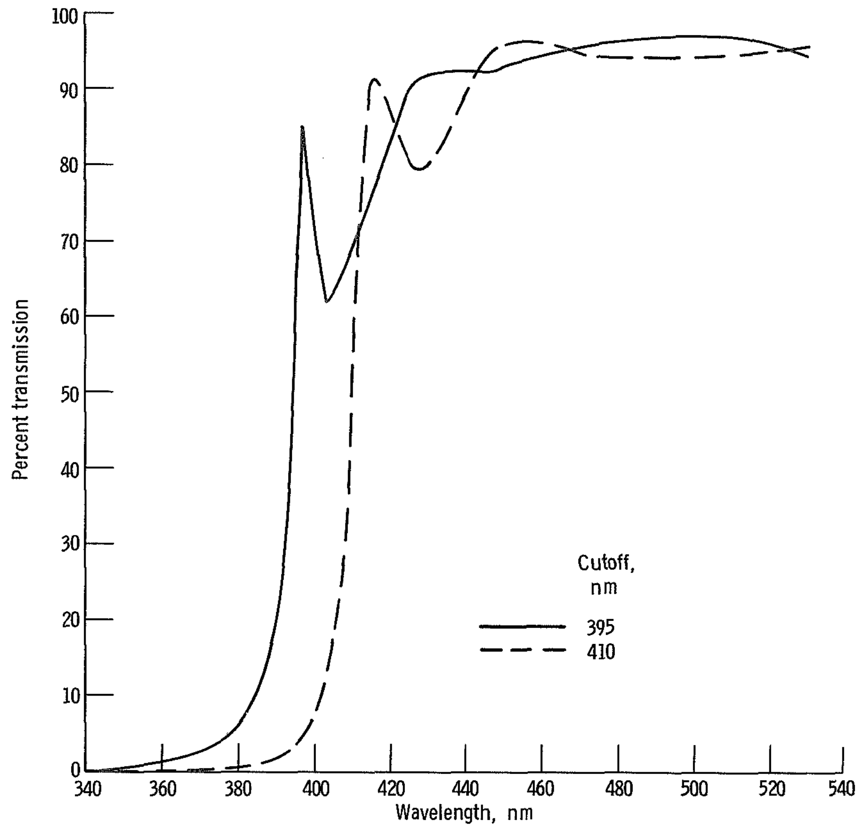

Figure 3. - Transmission of ultraviolet filtered 6 mil 7940 glass (data from Optical Coating Laboratory, Inc.).

Humidity Storage

Equal numbers (four each) of both LS and CC assemblies were stored for 1 month at room temperature and 90 percent relative humidity. Contact resistance, reverse leakage, junction characteristic (A value), and current-voltage curves were determined before and after the test. The CC assemblies showed very slight changes in their cell parameters and no change in maximum power. The LS assemblies showed deterioration in A value, about a 15-percent increase in contact resistance, and an average 4-percent decrease in maximum power. The maximum power loss may be due to contact problems as evidenced by increases in contact resistances. However, none of the glasses parted from the cells under these conditions of humidity storage.

Electron Bombardment

The LS assemblies show approximately a 4-milliampere advantage in short-circuit current over CC assemblies, primarily because of the higher blue response of the LS

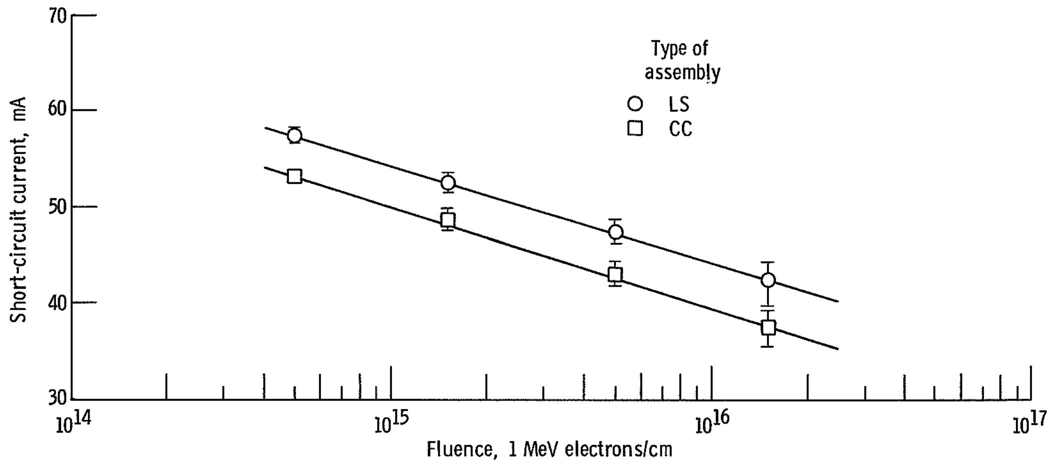

Figure 4. - Short circuit current as function of bombardment dose.

TABLE III. - RESPONSES OF LS AND CC ASSEMBLIES AFTER

BOMBARDMENT BY 1 MeV ELECTRONS

Bombardment level	Average response of six assemblies of each type			
	Type LS cell, mA	Type CC cell, mA	Diff., mA	LS cell/CC cell
Unbombarded				
Total	67.7	63.5	4.2	1.06
Blue[a]	16.3	10.1	6.2	----
5×10^{14} 1 MeV elec/m^2				
Total	57.1	53.0	4.1	1.08
Blue	15.5	9.9	5.6	----
1.5×10^{15} 1 MeV elec/cm^2				
Total	52.4	48.5	3.9	1.08
Blue	15.3	9.8	5.5	----
5×10^{15} 1 MeV elec/cm^2				
Total	47.5	43.2	4.3	1.10
Blue	15.1	9.6	5.6	----
1.5×10^{16} 1 MeV elec/cm^2				
Total	42.5	37.5	5.0	1.13
Blue	14.3	9.1	5.2	----

[a]Blue response is the sum of the responses to the 400; 450; and 500-nm filters of the filter wheel simulator.

assemblies. Figure 4 shows the effect of radiation on the total short-circuit current response of the two types of assemblies at different bombardment doses. As the bombardment dose increases, damaging the red response of both types of cells, the blue response becomes a greater proportion of the total response. At a dose of 1.5×10^{16} 1 MeV electrons per square centimeter, the difference of the average short circuit current of six of each type of assembly is approximately 5 milliampere or about 13 percent (see table III). The type LS assembly, at this dose, has the same current output as the CC assembly had at one-third of this dose. The maximum power and efficiency of the two assemblies should be in proportion to the short-circuit currents (ref. 6). This is true if the parameters, bulk and contact resistance, reverse leakage current, A value, and open-circuit voltage are the same for both types of cells. Therefore, the LS assembly would be expected to have 13 percent higher maximum power and efficiency than the CC assembly. However, the 13-percent improvement that was seen in the short-circuit current was not seen in the maximum power because of changes in the parameters. The power was measured on two samples of two types of assemblies. The actual improvement in power for these samples was only about 6 percent.

Temperature Cycling Under Simulated Earth Orbit Conditions

Test assemblies (four each of types LS and CC) were carried through 1058 cycles with the temperatures ranging from approximately -110° to about 20° C. All the glasses remained attached to the cells throughout the entire test. The temperature of LS assemblies averaged 3° to 4° C lower than those of CC assemblies. Therefore slightly higher open-circuit voltages would be expected under outer space conditions. There was no change in current for either type of assembly.

SUMMARY OF RESULTS

High blue response solar cells with soldered glass covers were compared with commercial cells with cemented and soldered glass covers. The tests included spectral response, electron bombardment, humidity storage, and simulated earth orbit temperature cycling. The results can be summarized as follows:

1. Six-mil (152.4-μm) thick protective glass covers can be successfully applied to solar cells by soldering techniques.

2. By using a shallow junction cell and eliminating the epoxy and ultraviolet filter, the total short-circuit current of a 1- by 2-centimeter covered cell can be increased by as much as 4 milliamperes.

3. A shallow junction soldered glass covered cell assembly maintains a 4-milliampere advantage (for a 1- by 2-cm cell) over a cemented cover glass assembly throughout a series of electron bombardment exposures, so that after a total fluence of 1.5×10^{16} 1 MeV electrons per square centimeter, it represents about 12 to 13 percent of the total current.

4. The soldered cover glasses did not separate from the cells during extended humidity tests. However, contact resistances and A value (junction parameter) did deteriorate slightly.

5. There was no loss in current or physical integrity after 1058 cycles of 1 hour light, 1/2 hour dark in a vacuum solar simulator. The high blue cells with soldered covers operated about 4° C cooler than commercial cells with cemented covers.

6. When glasses are soldered to commercial cells, approximately 95 percent of the 400-nanometer response is retained. This is about 2.5 milliamperes (for a 1- by 2-cm cell) higher than the cemented glass covered cell response.

Lewis Research Center,
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