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COMPARISON OF TYPES A AND C FLUORINATED ETHYLENE PROPYLENE (FEP) AS COVER MATERIALS FOR SILICON SOLAR CELLS

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16. Abstract

Fluorinated ethylene propylene film (FEP, 0.0127 cm thick) was heat and pressure laminated to silicon solar cells as a low cost substitute for quartz covers. FEP-C, treated on one side for bonding, was compared to FEP-A, an untreated FEP. With FEP-A, a silane adhesion promoter was applied to the cells. FEP-C covers delaminated during accelerated temperature-humidity testing and Earth environmental exposure testing; FEP-A covers were unchanged. No differences were observed in peel tests, but FEP-A is superior in its resistance to tearing and in retention of transmission properties after exposure to ultraviolet radiation.

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COMPARISON OF TYPES A AND C FLUORINATED ETHYLENE PROPYLENE (FEP) AS COVER MATERIALS FOR SILICON SOLAR CELLS

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SUMMARY

Fluorinated ethylene propylene (FEP) has been proposed as a low cost substitute for quartz covers for silicon solar cells. A heat and pressure lamination process was used to bond 0.0127-centimeter-thick FEP to silicon solar cells. FEP-C, an FEP with one side treated for improved bonding, was evaluated first. Bonding failure during accelerated testing led to the investigation of FEP-A (an untreated form of FEP) as a cover. Cell treatment with an adhesion promoter is required in order to attain proper bonding of the FEP-A. With this additional step, FEP-A forms an excellent bond to the cell. Samples prepared using a 5 percent silane adhesion promoter solution (A1100 in ethanol-water) were used for all tests.

Since solar cells may be subjected to a variety of temperature and humidity environments before use in space, temperature and humidity tests were conducted. FEP-C to cell bonds delaminated in 40 hours after accelerated testing at 80° C and 90 percent relative humidity, while the FEP-A to cell bond was unchanged after 32 days under the same conditions. Similar delamination of FEP-C covered cells was observed in 5 days for samples exposed to climatic conditions. No delamination was observed for FEP-A covered cells after 14 months of exposure. No differences were observed in peel tests, but FEP-A is superior to FEP-C in its resistance to tearing. Cells covered with both types of FEP were irradiated for 8000 equivalent sun hours of ultraviolet radiation. While FEP-C covered cells retained 90 percent of their initial short-circuit current, FEP-A covered cells retained 96 percent of theirs. No annealing of ultraviolet damage was observed.

INTRODUCTION

Silicon solar cell covers of fluorinated ethylene propylene offer certain advantages over quartz covers of equal thickness. These advantages are low cost and the ability to cover a large number of cells at one time. It has been reported that fluorinated ethylene propylene type C (FEP-C) can be bonded directly to silicon solar cells (refs. 1 to 3). This is an FEP with one side treated to improve bonding. Tests to evaluate the space worthiness of the FEP-C cell package were undertaken. Among the tests performed were light transmission as evidenced by short-circuit current (scc) changes, FEP-C to cell bond strength (resistance to peeling), electron and ultraviolet irradiation in vacuum, and vacuum thermal cycling. Since FEP-C covered cells may be exposed to Earth environmental conditions prior to use in space, temperature-humidity and environmental exposure tests were also performed. The results of some of these tests are also pertinent for evaluating FEP-C as a cover material for terrestial use. Shortcomings with respect to humidity storage and Earth environmental exposure soon became evident. At this point, the use of FEP-A, an untreated form of FEP, was explored. Cell treatment with an adhesion promoter is required in order to attain proper bonding of the FEP-A. For comparison purposes, similar silicon monoxide (SiO) coated silicon solar cells were covered with 0.0127-centimeter- (5-mil-) thick FEP-C and FEP-A.

Results of tests of light transmission (ref. 4), electron irradiation (ref. 5), and vacuum thermal cycling (ref. 6) have already been reported. This report will therefore discuss the following tests and results: temperature-humidity storage, Earth environmental exposure, adherence (peel), and ultraviolet exposure in vacuum.

EXPERIMENTAL AND TEST PROCEDURES

Lamination

The lamination procedure described in reference 1 was used to prepare the 0.0127-centimeter- (5-mil-) thick FEP-C covered samples used in these tests. In order to achieve bonding of 0.0127-centimeter- (5-mil-) thick FEP-A to silicon solar cells, an adhesion promoter (A-1100 silane) was used.

The cells and the FEP-A covers were first thoroughly degreased by two immersions for 2 minutes each in boiling isopropyl alcohol. After drying in air, the cells were dipped for 5 minutes in the adhesion promoter solution made by adding A-1100 silane (gamma-ammino propyltriethoxy silane) to a 90:10 ethanol-water mixture. Concentrations of the silane solutions used were 5, 1, 0.1, 0.05, and 0.0015 percent (the

"one-drop" solution). An ethanol rinse followed to prevent staining of the cells when the 5 percent silane solution was used. This concentration was used for all test samples except for the peel test samples in which case the whole range of concentrations was used. The cells were dried in air and then placed with the FEP-A covers on an Armalon covered porous base plate of a platen (see figs. in ref. 1 for lamination details). A vacuum was applied to the porous base to provide for holddown and air removal. A 0.00254-centimeter- (1-mil-) thick sheet of skived TFE Teflon was placed on top of the FEP-A covers to act as a release agent. Finally, a 0.0127-centimeter- (5-mil-) thick sheet of aluminum was placed over the entire platen as a vacuum seal. The top half of the platen was put into position and the two halves bolted together.

The platens were then inserted into a preheated press ($\sim 310^{\circ}$ C), and nitrogen gas pressure, up to 7×10^5 newtons/m^2 ($\sim$100 psig), was applied over the aluminum sheet seal. The samples were allowed to heat up to 290° C and kept at this temperature for 5 minutes. The heaters were then turned off, and cold water was allowed to flow through the press for quick cooling. After cooling, the finished samples were removed and trimmed.

Humidity Storage Test

FEP-C covered cells were stored in a humidity chamber at 90 percent relative humidity at 25°, 40°, and 80° C for 1 month or until delamination occurred, whichever came first. Four FEP-C covered samples were used at each temperature setting. Four FEP-A covered samples were stored at 80° C and 90 percent relative humidity. The samples were visually checked daily.

Earth Environmental Exposure Test

FEP-covered cells were mounted on a tilted panel facing the southern sky on a roof at the Lewis Research Center in Cleveland. Exposure to a year's entire change in climatic conditions was intended. Initially, the cells were observed for delamination daily, but as the test progressed, observations were made weekly and then monthly.

Peel Test

Qualitative: Comparisons of the peel strength of the FEP-cell bond were determined by laminating oversize covers of 0.0127-centimeter-thick FEP to 2 by 2 centi-

meter cells. The covered cell was held face up against a table and attempts to initiate peeling by pulling upward by hand were made on the samples.

Quantitative: Measurements were made using a Chatillon pull tester. Four FEP-C and four FEP-A covered cells were used. The cells were bonded to oversize pieces of FEP such that each cell had two tabs available for pulling. The tabs, 2 centimeters wide and about 2.5 centimeters long, extended from the sides of the cell and parallel to the top bar contact. The cells were placed between parallel support plates so that the tab and 0.15 centimeter of the cell were exposed. The exposed tab was then clamped between two plates, hooked to the Chatillon gage, and pulled at right angles to the cell surface. The force at which the film peeled, or tore, or the cell broke was observed and recorded.

Ultraviolet Irradiation Test

The apparatus used for the ultraviolet irradiation test has been described in detail previously (ref. 7) and consists of a vacuum chamber with a quartz plate window, above which the ultraviolet lamps were placed. A tap-water ($15^{\circ}\pm3^{\circ}$ C) cooled plate served as the base for the solar cells. The ultraviolet light intensity for wavelengths less than 0.3 micrometer was about 7.5 suns. Two uncovered SiO-coated control cells, four FEP-C covered, and four FEP-A covered SiO-coated cells were exposed. Individual samples of each group were placed alternately on the water-cooled base plate. The Lewis filter wheel solar simulator (ref. 8) was used to measure the short-circuit currents of the cells before and after a series of exposures that terminated after 8000 equivalent sun hours.

In a separate experiment, in situ measurements were made of the short-circuit current to determine whether greater ultraviolet damage to the FEP was being produced, but annealing out, when the samples were exposed to air. The control and test cells were placed in vacuum with a high intensity iodine vapor lamp externally fixed in place as the light source. The light level was set by the control cells output, and the test cells short-circuit currents were measured. After exposure to ultraviolet, and while still in vacuum, the cells short-circuit currents were again measured.

RESULTS AND DISCUSSION

Lamination

FEP-A bonding to cells was achieved with a 3000 to 1 range of silane solution concentrations. The mechanism by which the adhesion promoter acts to achieve adhesion

of the FEP-A to the cell surface may be explained as follows. At one end of the silane molecule, a silanol bond can easily be formed to a hydrophillic surface, such as silicon, SiO, aluminum, and some ceramics (fig. 1). At the other end of the molecule, the organic component reacts with the polymer to form a chemical bond. Apparently a layer no more than several molecules thick is sufficient to form a bond between the cell surface and the FEP-A.

Humidity Storage Test

In the humidity storage test at 90 percent relative humidity, the FEP-C covered cells withstood 1 month at 25° C and 1 month at 40° C. At 80° C delamination was complete within 40 hours. However, FEP-A covered cells were still in excellent condition with no visible evidence of delamination after 1 month at 80° C.

Earth Environmental Exposure Test

FEP-C covered cells first exposed to Cleveland's weather in December 1970 delaminated within 1 week. FEP-A covered cells were exposed on the roof for 14 months with no delamination. Similar tests are still in progress.

FEP-A covered solar cell arrays, using the "one-drop" silane solution, have been exposed to varied weather conditions for about a year at the RAMOS weather station on Mammoth Mountain, California, with no observable delamination (ref. 9).

Peel Test

Qualitative: Neither FEP-C nor FEP-A could be peeled by hand from the cell surface. Either the FEP tore at the edge of the cell or the cell broke.

Quantitative: Cells covered with 0.0127-centimeter-thick FEP-C or FEP-A were used. The samples were clamped and attached to the Chatillon pull tester as described previously. In the 16 tests performed no peeling occurred. However, in 13 of the tests the FEP tore, and in the remaining three, the cell cracked. The average force necessary to tear the FEP-A was found to be higher than that for the FEP-C, 31 newtons as opposed to 20 newtons. Another indication of the relatively higher strength of FEP-A was the observation that, when laminated, cell corners and edges would occasionally break through FEP-C but not through FEP-A.

Ultraviolet Irradiation Test

The results of the ultraviolet tests are shown in figure 2. After 8000 equivalent sun hours, FEP-C covered cells show a loss of almost 10 percent in the short-circuit current, while FEP-A covered cells have lost only about 4 percent. An analysis of filter wheel simulator data, table I, indicates that most of the loss in the short-circuit current of both types of FEP-covered cells occurs at the blue end of the spectrum (0.4 and 0.45 μm). The short-circuit current losses of FEP-A covered cells extend to 0.6 micrometer, while those losses for FEP-C covered cells are observed for all wavelengths up to 0.95 micrometer. The 3 to 4 percent losses in the red region of the spectrum are higher than the ±2 percent instrument error and are significant. The uncovered cells included in the test showed no change in the short-circuit current. Therefore, the loss is due to a transmission loss in the FEP.

Several FEP-A and FEP-C covered cells exposed to high intensity ultratiolet radiation in vacuum and measured in vacuum show no greater loss than that observed for cells exposed in vacuum and subsequently measured in air. There was no apparent annealing after several additional hours of storage in air.

FEP-A and FEP-C differ only in that one surface of FEP-C has been treated (by a DuPont proprietory method) to make the FEP more easily bondable. It is difficult to understand why differences in their resistance to tearing and in their sensitivity to ultraviolet radiation should exist. One possible explanation may be that the surface treatment changes the crystallinity of the polymer and thereby changes the physical properties of the material.

SUMMARY OF RESULTS

The results obtained from several tests performed on FEP-C and FEP-A covered cells indicate the superiority of FEP-A in the following:

1. No delamination of FEP-A when FEP-A covered cells were subjected to high humidity at elevated temperatures.
2. No delamination of FEP-A when it was exposed to the Earth's atmospheric conditions.
3. FEP-A had higher tear strength.

4. FEP-A had a lower loss of short-circuit current after a prolonged exposure to ultraviolet radiation.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 2, 1976,
506-23.

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TABLE I. - SHORT-CIRCUIT CIRRENT LOSSES AFTER 8000 EQUIVALENT SUN HOUR ULTRAVIOLET EXPOSURE IN VACUUM FOR FEP COVERED SiO COATED CELLS

Wavelength, μm	Percent loss in short-circuit current	
	FEP-C covered cells[a]	FEP-A covered cells[a]
0.95	3.6	1.2
.9	3.1	.6
.8	3.8	0
.7	5.2	1.6
.6	11.6	4.8
.5	17.0	4.9
.45	23.1	9.0
.4	32.5	13.8

[a]Average of four cells.

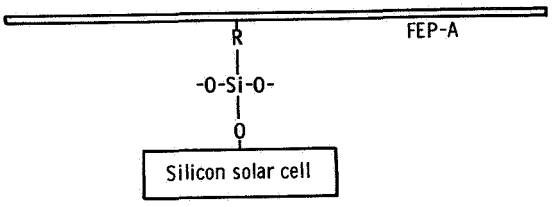

Figure 1. - Possible mechanism of bonding FEP-A using silane adhesion promoter. (Organofunctional portion of the silane, R.)

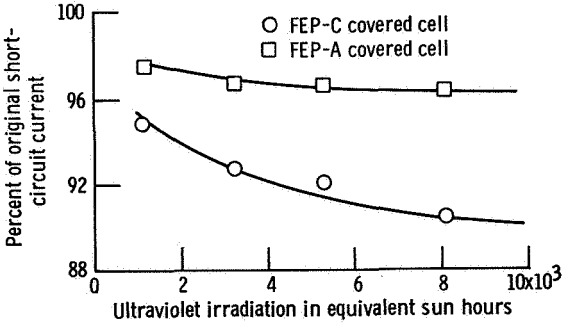

Figure 2. - Short-circuit current of FEP-covered solar cells after ultraviolet irradiation.

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