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THE USE OF FEP TEFLON IN SOLAR CELL COVER TECHNOLOGY

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SUMMARY

FEP plastic film was used as a cover and as an adhesive to bond cover glasses to silicon solar cells. Various anti-reflective coatings were applied to cells and subsequently covered with FEP. Short circuit currents were measured before and after application of the coating and of the FEP. FEP bonded to seven of the nine differently coated cells, with no change in the total short circuit current in four cases.

INTRODUCTION

FEP is being considered for use in solar cell array structures. It offers the possibility of covering many cells at once, and at the same time producing a low cost flexible array. However, it is important to determine the affect an FEP cover will have on the short circuit current (SCC) output of the solar cell. Cells with cemented covers usually have a U.V. filter on one side of the glass cover to protect the adhesive, and suffer a substantial loss of the blue-light generated current. The use of FEP eliminates the need for this filter. When silicon solar cells are exposed to a radiation environment in space, the amount of blue (0.4 µm wavelength) light generated current becomes increasingly important. This current is the least affected by radiation damage to the cell and makes up a larger proportion of the total current available as the damage to the cell increases.

FEP has been proposed (1) as a possible substitute for either the solar cell cover or the adhesive to bond a quartz cover to the cell. Two types of FEP were under consideration. One, FEP-C, has one side treated for easier bonding, while the other, FEP-A is untreated. The methods and parameters of application have been reported elsewhere (1) and are essentially similar except that an adhesion promoter must be used with FEP-A. A 125 µm (5 mil) FEP film is used for the cover, and 25 or 50 µm material is used when bonding quartz covers to cells. In all cases, results for FEP-C and FEP-A were identical.

Since better matching of coating and cover could increase the SCC output, several other materials besides the standard SiO coating have been suggested for use as possible anti-reflection coatings on silicon solar cells. Accordingly, the question of compatibility of FEP with differently coated cells arose with respect to 1) bondability, and 2) SCC output.

The Lewis Filter Wheel Solar Simulator (2) was used to determine the current contribution from selected wavelength intervals, the sum of which is the AMO SCC.

RESULTS AND DISCUSSION

FEP With SiO Coated Cells

Since SiO coated silicon solar cells are commonly used on space missions, most of the work was done using this type of cell. Cells with several other experimental coatings were also covered with FEP and evaluated. SiO AR coated cells were covered with 125 µm FEP or quartz covers using 25 and 50 µm FEP as the adhesive. In either case, no differences in SCC were observed between FEP-C or FEP-A films.

Figure 1 compares the wavelength dependent SCC for a bare cell, an uncovered SiO coated cell, and SiO coated cells with an AR-UV coated quartz cemented cover and an FEP 125 µm cover. The SiO coating increases the cell output 34%. Comparison of the two covers shows that the main difference is that the AR-UV coated quartz (0.4 ± 0.015 µm cutoff) reduces the cell output at 0.4 µm, while FEP does not.

Table 1 compares the output of the covered cells (relative to the uncovered cell) as a function of wavelength. The coated quartz cover reduces cell output at 0.4 µm by 90% and total cell output by 5.5%. Also included in the table are data on cells covered with 150 µm and 300 µm quartz (no U.V. filter) covers using 25 µm FEP as an adhesive. It can be seen that the use of FEP as an adhesive increases the current at 0.4 µm. For either 25 µm or 50 µm FEP, the results were the same.

The retention and enhancement of the 0.45 and 0.4 µm region currents is important when one considers using solar cells in a radiation environment. These currents are the least affected by radiation damage to the cell and represents added useful life of the device. It has been reported that in vacuum, the FEP covered cell can tolerate up to the equivalent of 1×10^{15} 1 MeV electrons per square centimeter with no visible signs of degradation. (1)

FEP With Other Cell AR Coatings

Several materials have been suggested for use as anti-reflection coatings on silicon solar cells. Cells coated with SiO, SiO-MgF$_2$, MgF$_2$, Si_3N_4, Al_2O_3, TiO_2 and Ta_2O_5 were prepared at Lewis. In addition, CeO_2 and graded SiO_x coated cells, as well as SiO and Ta_2O_5 coated cells were obtained from other sources.

Resistance heated tungsten boats were used for the preparation of the SiO, SiO-MgF$_2$ and MgF$_2$ coated cells. All the evaporations were carried out in vacuum upon cells mounted on a heated substrate.

Si_3N_4 coatings were deposited on cells using RF sputtering in a partial pressure of argon. Several attempts to evaporate Si_3N_4 in vacuum using a tungsten boat were not successful. The resulting coatings were very thin and the cells had low SCC. Electron beam evaporations in N_2 atmospheres were also attempted with correspondingly poor results.

Al_2O_3 and TiO_2 were evaporated using an electron beam apparatus in an oxygen atmosphere of about 2×10^{-4} torr. Once again the resultant SCC's were low. Ta_2O_5 coated cells were prepared by the electron beam evaporation of Ta_2O_5 in vacuum onto cells held on a heated substrate.

The coating factor (the ratio of coated to uncoated SCC) was determined for cells coated at NASA by measuring the SCC in air before and after the coatings were applied. The results are listed in Table 2. For coated cells obtained from other sources, the SCC was

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compared to an average value for uncoated cells. The factor for CeO_2 coated cells is only approximate because these cells have a different pattern for the top contact than the usual silicon cell. Too few samples of Al_2O_3 coatings were prepared to allow an evaluation of a coating factor. The value of Ta_2O_5 is preliminary and varied from 1.31 to 1.38. Values in excess of 1.40 have been reported (3). It appears to be a very promising coating material in obtaining higher efficiency solar cells.

All of the above coatings were evaluated with respect to their compatibility with FEP covers and the FEP bonding process. Table 3 summarizes the results of attempting to bond FEP covers to cells with various coatings. FEP did not bond to two of the nine different types of coated cells, the CeO_2 and the double-coated SiO-MgF_2 cells. Adherence, determined by attempting to lift and peel the FEP from the cell surface, was excellent for all the remaining cases. In the case of the double coating, SiO-MgF_2, the FEP peeled easily from the cell at the SiO, MgF_2 interface, leaving behind the SiO coating but removing the MgF_2. FEP did not stick at all to CeO_2 coated cells.

Table 3 also shows what happens to the total SCC after the coated cells are covered with FEP. There is essentially no change in the SCC of SiO, Ta_2O_5, Si_3N_4 and TiO_2 coated cells, while there is approximately a 5% loss in SCC for the graded SiO_x, MgF_2 and Al_2O_3 coated cells. These results depend on the optical match between the coating and the FEP. Both MgF_2 and Al_2O_3 have relatively low indices of refraction and the index of refraction of graded SiO_x probably lies somewhere between 1.9 (of SiO) and 1.46 (of SiO_2). The materials with higher indices of refraction provide a good optical match with the FEP cover to give the essentially no-loss results.

Figure 2 compares the covered cell SCC, as a function of wavelength, to the original uncovered SCC, for two 100% category coatings and two 95% coatings. In all cases there is an improvement in the blue (0.4 μm) current and a drop in the middle region (0.5 → 0.8 μm) current. The difference between the two types of FEP-coating combinations is in the degree of this drop; the higher index of refraction coatings retain more of the current in this region.

CONCLUSION

FEP as a cover material, or as an adhesive for glass covers, is compatible with SiO, Ta_2O_5, TiO_2 and Si_3N_4 coated cells, with the total short circuit current equal to that of uncovered cells. The use of FEP also leads to increased blue (0.4 μm) currents and the elimination of the need for a protective U.V. filter which increases the potential advantage of FEP covered cells when used in a space radiation environment.

REFERENCES

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Table 1

Percent Change in Short Circuit Current of FEP Covered and FEP-Quartz Covered, SiO Coated Cells as Compared to an Uncovered Cell

λ μm	150 μm AR-UV quartz (cemented) covered cell	150 μm AR quartz-25 μm FEP covered cell	300 μm AR quartz-25 μm FEP covered cell	125 μm FEP covered cell
.4	9.9%	120.4%	119.0%	127.3%
.45	95.6	106.5	107.4	107.6
.5	100.5	100.8	101.1	99.9
.6	96.6	96.6	97.1	95.7
.7	95.8	97.5	97.3	97.2
.8	98.4	98.7	98.8	99.7
.9	100.8	99.8	101.0	101.8
.95	102.2	100.7	101.3	102.3
Overall	94.5%	99.95%	100.3%	100.4%

Table 2

Anti-reflection Coating Factors for Silicon Solar Cells

Cell Coating	Coating Factor
SiO	1.34
Graded SiO_x	1.37
SiO-MgF_2	1.38
CeO_2	~1.30
MgF_2	1.30
Si_3N_4	1.26
TiO_2	1.26
Ta_2O_5	1.36
Al_2O_3	--

Table 3

Properties of Various Anti-reflection Coating-FEP Cover Combinations on Silicon Solar Cells

Cell Coating	Index of Refraction	FEP Adherence	SCC, % of Uncovered
SiO	1.9	Yes	100
Graded SiO_x	$1.9>n>1.46$	Yes	95
SiO-MgF_2	-	No	-
MgF_2	1.4	Yes	95
CeO_2	-	No	-
Si_3N_4	2.1	Yes	100
Al_2O_3	1.5→1.7	Yes	95
TiO_2	2.4→2.7	Yes	100
Ta_2O_5	2.4	Yes	100

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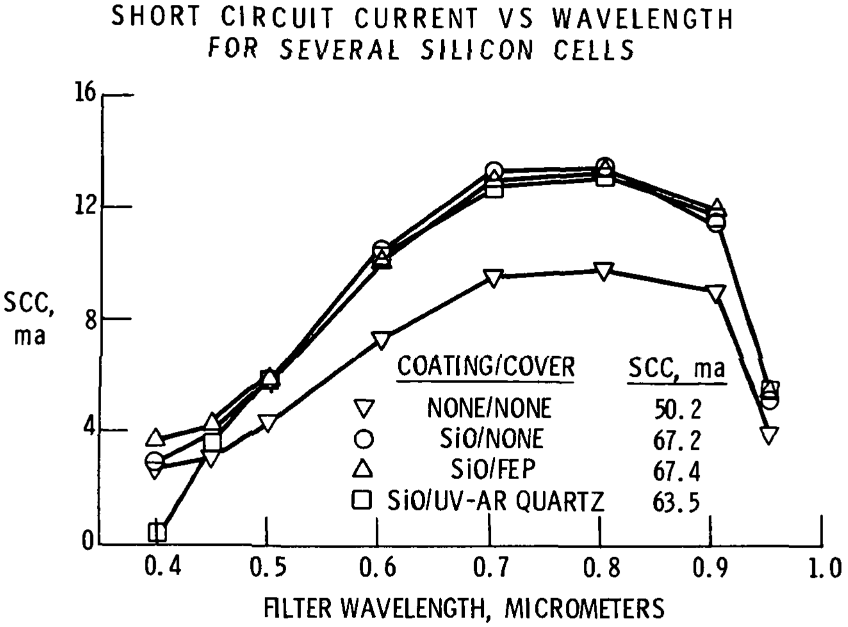

Fig. 1

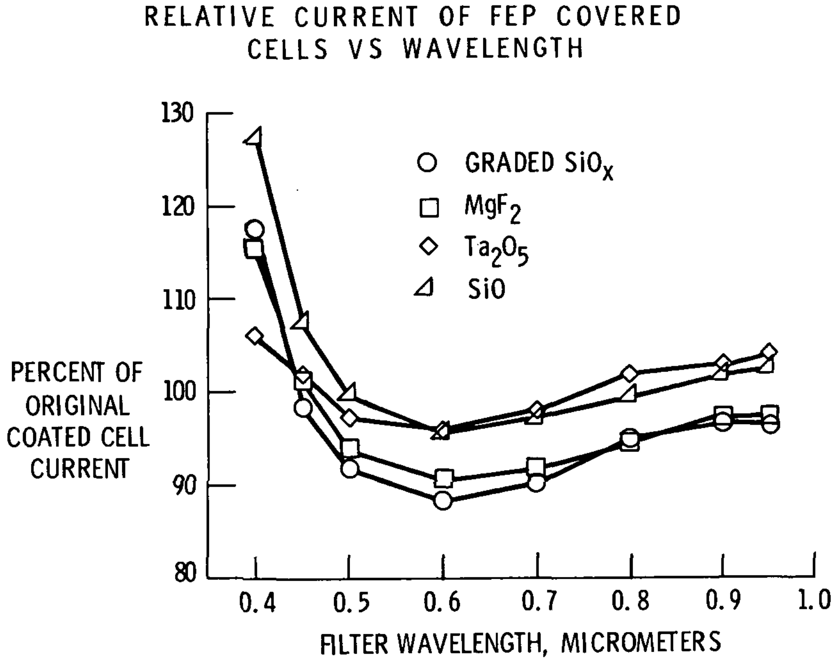

Fig. 2