A PRELIMINARY EVALUATION OF A POTENTIAL SPACE WORTHY ENCAPSULANT*

John Scott-Monck
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

INTRODUCTION

The development of 50 μm silicon solar cell technology (ref. 1), which offers a major improvement in array weight reduction, has added a new stimulus for developing an alternative to conventional fused silica coverglass. Although it is necessary to protect the cell from the catastrophic effects of low energy protons (ref. 2), for many mission applications the required shielding thickness is less than 25 μm (fused silica equivalent). However it is difficult to obtain, or work with, coverglass less than 100 μm for array assembly.

The concept of encapsulating the interconnected cell modules offers important weight and cost advantages (ref. 3). The materials and labor required to bond individual covers to cells would be significantly reduced. By optimizing the required shielding and eliminating adhesives, major weight savings would occur. This paper will describe the results of a preliminary evaluation of a new organic material which has the potential for providing the cost and weight benefits associated with encapsulation.

BACKGROUND

This polyimide polymer was developed by the Hughes Aircraft Technology Support Division for commercial utilization. Recognizing the potential of this material, a joint program was initiated with NASA-JPL to evaluate the polyimide for space applications. A test matrix was set up to provide a number of gates (go/no go) in order to minimize program cost.

JPL provided silicon solar cells which had been characterized with respect to electrical output and spectral response. Hughes TSD prepared and deposited the polyimide onto the cells, providing two groups of samples, one having $\sim$ 5 μm of polymer, the other $\sim$ 12.5 μm. JPL then retested the samples to investigate the effect of the deposition process and the optical properties of the polyimide on the cells' electrical output. The 20 cell sample group was then divided into a number of test subgroups.

JPL investigated the effect of electrons and low energy protons on the polyimide while Hughes TSD did thermal shock and humidity tests as well as thermo-

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gravometric analysis. Then a 1350 hr vacuum ultraviolet test was performed. The results of these tests are given in the following section.

TEST RESULTS

Deposition Effects

The polymer was deposited on the cells using a spray technique, then cured for 2 hours at 225°C. In some cases the film overlapped the front contact bar and had to be removed, which provided a very practical demonstration of the adherence and durability of the coating. Post deposition electrical measurements showed that the average loss in I_{sc} for the 10 samples which received a 5 μm deposition was 3.5% while for the other 10 cell group coated with 12.5 μm of polyimide, the reduction in I_{sc} was 3.1% (Figure 1). There was no evidence of curve factor degradation in any sample.

A comparison of pre and post deposition spectral response curves for a typical cell sample is shown in Figure 2. It can be seen that the response was reduced in the region below approximately 5000 nm and above approximately 7000 nm; while there was an increase in response between 5000 and 7000 nm. Obviously the polyimide refractive index is contributing to these results, but it is not possible to assess its impact on these results until the index has been determined.

Electron Effects

This is a gross test of the polyimide's optical properties under simulated space radiation conditions. Since the films are very thin, it was not anticipated that penetrating radiation would have any significant effect. Three samples from each test group were irradiated with 1 MeV electrons to $1x10^{14}$ and then $1x10^{15}$ e/cm^2 using the JPL Dynamitron facility. Spectral response comparisons were made for the pre and post irradiated samples between 3600 and 6000 nm, since this response region in the cell is relatively insensitive to the effects of electrons. There was no change in the spectral response for any of the samples irradiated.

Low Energy Proton Effects

This was a critical test since the energy selected guaranteed that the protons would be absorbed within the polyimide coating. Test samples from both groups were given two separate irradiations, each consisting of exposure to 1×10^{11} 50 keV protons/cm^2. Electrical and spectral response data was obtained after each test. In the second test, an uncovered control cell was included. Based on the severe degradation in output experienced by the control cell (Figure 3), the protons were stopped within the polyimide for both the 5 and 12.5 μm samples.

Spectral response and I-V measurements indicated no significant change between pre and post proton test data, showing that the optical properties of the films were not degraded by the protons. However, this result is slightly compromised since "bleaching" of proton induced color centers could have occured in the period of days between the irradiation and the spectral response measurements.

Thermal Shock and Humidity Effects

Samples were exposed to 25 cycles from 20°C (room temperature) to -196°C (liquid nitrogen). Following this they were subjected to a tape peel test. There was no evidence of delamination of the polyimide coating from the solar cell. However, exposure to 168 hours of 95% relative humidity while being cycled from 25 to

65°C did show some evidence of film cracking and "crazing". Subsequent tape peel tests of these samples resulted in a loss of film adherence over approximately 25 percent of the sample. This is not unexpected since the polyimide film being evaluated has a less than optimum molecular weight.

Vacuum Ultraviolet Effects

A carefully controlled vacuum ultraviolet test was performed on 5 cell samples and a quartz plate coated with the polyimide. The test chamber was designed so that it could be removed from the test area for electrical measurements while retaining the samples in vacuum. Two control cells, one covered with quartz, the other unprotected, were included in the test matrix to provide information on system's effects such as window darkening from the uv and deposition of foreign material on the surface of the test samples.

The uv source provided an intensity of 1.5 ± 0.5 suns and the samples were held between 30 to 40°C under a vacuum better than 10^{-6} torr. The short circuit current, at 28°C, of each sample was measured periodically during the test. The results are given in Figure 4. After factoring out the system's effects, the polyimide coated cell samples (5 and 12.5 μm) were calculated to have lost between 8 to 8.5 percent in I_{sc} after 1350 hrs of uv exposure. The test was terminated when the change in polyimide transparency had appeared to cease (Figure 4). There is some evidence, based on the bahavior of the control cells, to argue that the polyimide had actually degraded only 6.5 to 7.0 percent.

Pre and post test transmission measurements of the polyimide coated quartz sample show that the major loss in optical transmission occurred in the region between 3500 and 7000 nm. Unfortunately the polyimide cell samples were destroyed during an attempt to remove them from the test plate. Thus there is no post test spectral response data on the cells.

DISCUSSION

These results are highly promising since the polymer that was evaluated is an unrefined version, made from materials that were not purified to the levels that could be achieved using more sophisticated synthesizing processes. The successful demonstration that this material can be deposited by a simple spraying process and the fact that absorbed protons do not appear to cause darkening is most encouraging. The apparent stabilization and magnitude of polyimide transmission loss in uv is additional evidence to support optimism that this material has the potential to meet the requirements for space utilization. It is known that the molecular weight of the present polyimide is much less than what can be achieved. It is expected that by increasing the material's molecular weight, increased resistance to the effects of humidity can be provided.

The pre and post deposition and uv data are consistent in that no polyimide film thickness dependence was observed. It is possible that even the unrefined version of this material may be much better than results indicate. Surface contaminations or interactions between the polyimide and the cell antireflection coating might be responsible for some portion of the degradation observed in this preliminary screening.

CONCLUSIONS

A new polymer polimide possessing optical and mechanical properties potentially suitable for space applications now exists. A preliminary evaluation of the material indicates that in its present state of development, the polyimide is not ready for space qualification. Further efforts to increase molecular weight and purify the consituents used to synthesize it are warranted. Activities addressing these needs are now being pursued. If these approaches prove successful, additional testing will take place with an emphasis on synergistic effects.

REFERENCES

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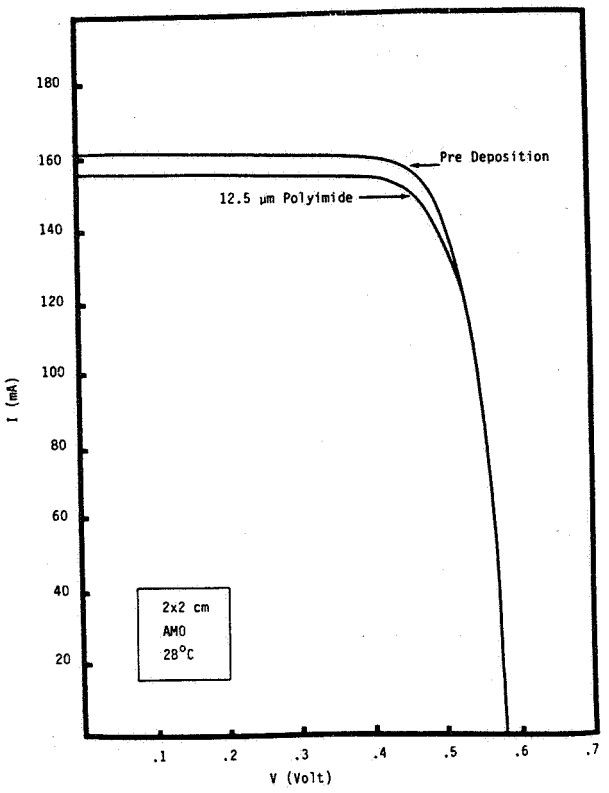

Figure 1. Effect of Polyimide on Cell Output

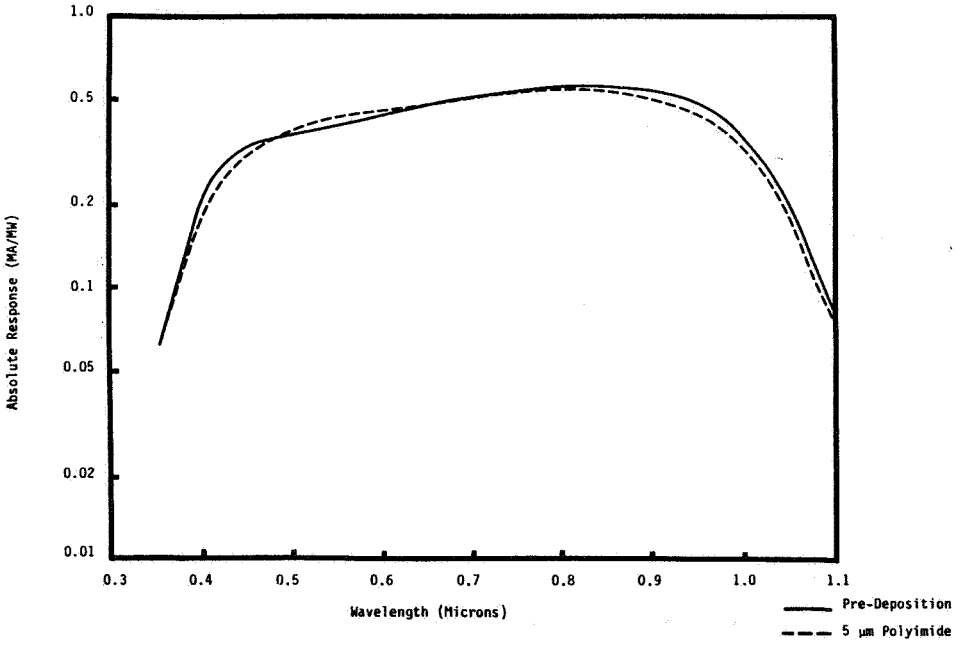

Figure 2. Effect of Polyimide on Cell Spectral Response

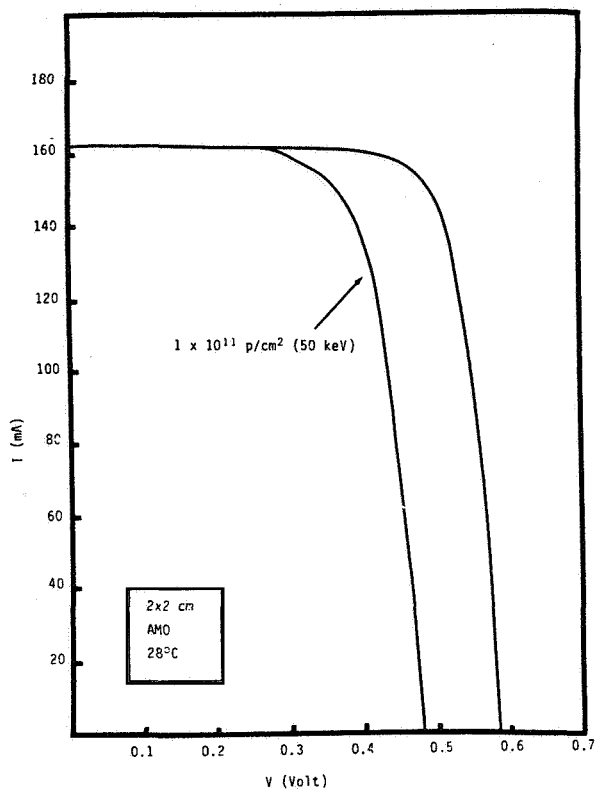

Figure 3. Effect of Protons on Unshielded Cell

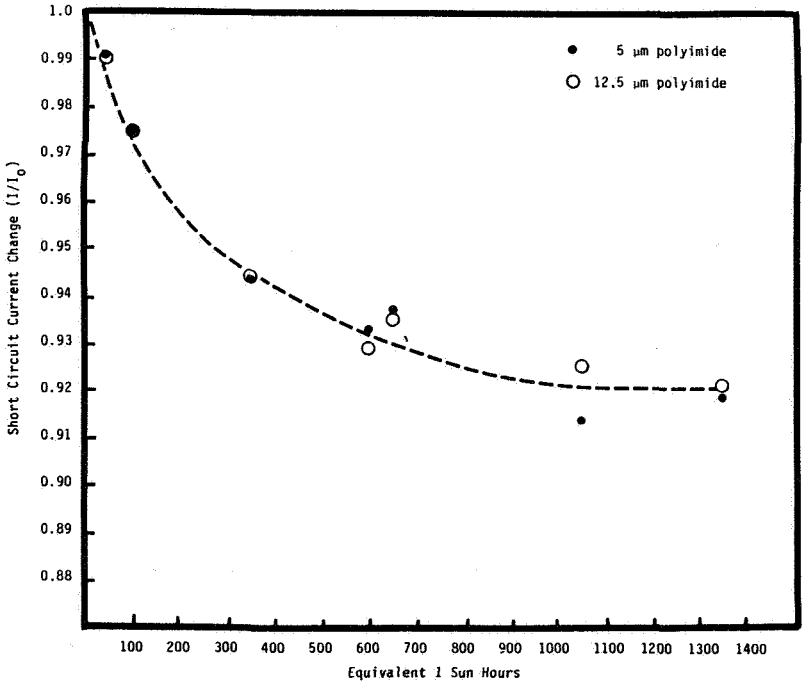

Figure 4. Effect of UV on Polyimide Coated Solar Cells