AMORPHOUS SILICON-BASED MINIMODULES WITH SILICONE ELASTOMER ENCAPSULATION

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ABSTRACT

We recently fabricated one and two cell, amorphous silicon based mini-modules encapsulated with a modern silicone elastomer. The quality of the encapsulation was found to be good. This paper reports details of this experiment.

INTRODUCTION

Ethyl vinyl acetate (EVA) is the most commonly used material for the encapsulation of terrestrial solar cells. It is well known that EVA turns yellow upon extended exposure to ultraviolet light. This yellowing upon exposure to UV light is a characteristic of most carbon-based polymers. Silicon-based polymers (silicones) may not show this effect. Although silicones were used to encapsulate solar cells in the 1970s and 1980s, they were dropped in favour of ethyl vinyl acetate due to its lower cost [1]. However, the price of silicone elastomers has come down over the years and their quality and ease of application have improved, which may make them suitable for encapsulating solar cells once again. We have recently fabricated 4"x 4" and 4"x8" minimodules encapsulated with a combination of a silicone elastomer and Dupont Tefzel.

EXPREIMENTAL DETAILS

We fabricated two a-SiGe based minimodules and encapsulated them with silicone elastomer. The a-SiGe cells were fabricated on stainless steel in a p-i-n configuration by RF plasma enhanced chemical vapour deposition (PECVD) [2]. Indium-tin oxide (ITO) was used for the top contact. After ITO deposition, the cells were shunt passivated by a light-assisted electrochemical process, details of which will be reported separately [3]. The cells had a total area of 100 cm^2 and an active area of 81 cm^2. Two modules were fabricated, one with a single cell and one with two cells in series.

The first module consisted of a single cell with a current collecting grid and bus bars on two sides of the cell. The current collecting grid used a spacing of 1 cm. 250 μm diameter tinned copper wire was used for the grid. The wires were positioned onto the surface of the cell using a jig to facilitate alignment. The wires were then attached to the front contact using a graphite-based conducting paint in order to reduce the contact resistance between the grid wires and the ITO. A diode (1N4007) was attached between the positive and negative bus bars to provide protection against reverse voltage.

The second module consisted of two 4"x4" a-SiGe based cells connected in series. The cells were made with a process identical to the one described above. The same type and thickness of wire was used to form the grid, but it was attached using a conductive silver epoxy instead of graphite. Reverse protection diodes were installed between the positive and negative terminals of each cell. Fig. 1 shows the two-cell module prior to encapsulation.

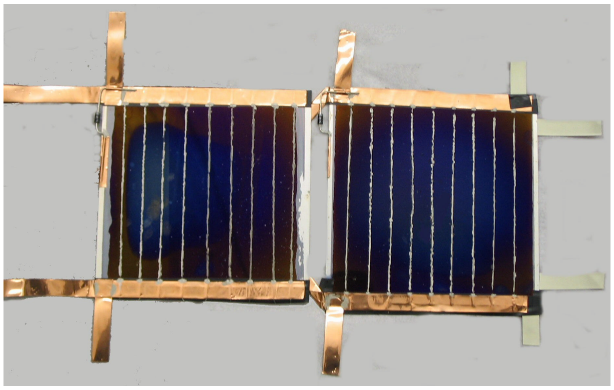

Figure 1: Two-cell module prior to encapsulation

The silicone used in our experiments was Dow Corning's Sylgard 182. Sylgard 182 is a blend of silanes $(\text{-Si-})_n$ and siloxanes $(\text{-Si-O-Si-})_n$ with alkyl groups substituting some of the hydrogen atoms, i.e. it has a silicon backbone, which makes it different from carbon based polymers such as EVA. Sylgard 182 (like many other formulations) cures slowly at room temperature; higher temperatures accelerate curing. However, temperatures in excess of 180°C may lead to decomposition of the elastomer. Table 1 shows the curing times required for Sylgard 182 at various temperatures.

Temperature	Curing Time
Room (20°C)	>8 hours
65°C	4 hours
100°C	1 hour
150°C	15 minutes

Table 1: Curing times for Dow Corning Sylgard 182

Glass slides were encapsulated on both sides with EVA/Tefzel and silicone elastomer/Tefzel in a vacuum laminator. The EVA used was the 15420P/UF formulation from Specialized Technology Resources. Fig. 2 compares the light transmission of these samples with that of a plain glass slide.

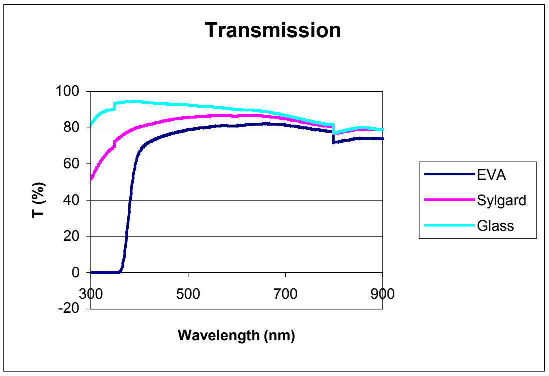

Figure 2: Transmission of glass encapsulated with EVA and Sylgard.

In the thickness applied, the Sylgard-encapsulated slide showed better light transmission throughout the visible wavelength range than the EVA encapsulated slide. Its UV cut-off was more gradual than that of EVA, which blocked all light of wavelength shorter than 360 nm.

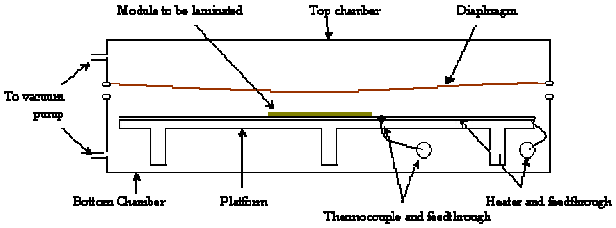

Figure 3: Sketch of the vacuum laminator

Both assembled mini-modules were then vacuum laminated with the silicone elastomer and Dupont Tefzel. The Tefzel served as a glazing. The vacuum laminator used is shown in Fig. 3. It consists of two shells separated by a silicone rubber diaphragm. The "sandwich" to be laminated is placed on a platform in the lower shell. The platform contains a heater and thermocouple. First, both shells were evacuated to a pressure of ~1 Torr. The top shell was then slowly vented to atmospheric pressure, causing pressure to be applied on the "sandwich". The temperature was then raised to 125°C and maintained for 30 minutes. Finally, the sandwich was allowed to cool to room temperature under pressure. The lower shell was then vented and the sample unloaded. Being a liquid, the silicone flowed well, and no trapped bubbles were found in the laminated minimodules. Coverage of raised features (e.g. the diodes and grid lines) was excellent. Fig. 4 shows a photo of the encapsulated 4"x4" and 4"x8" minimodules.

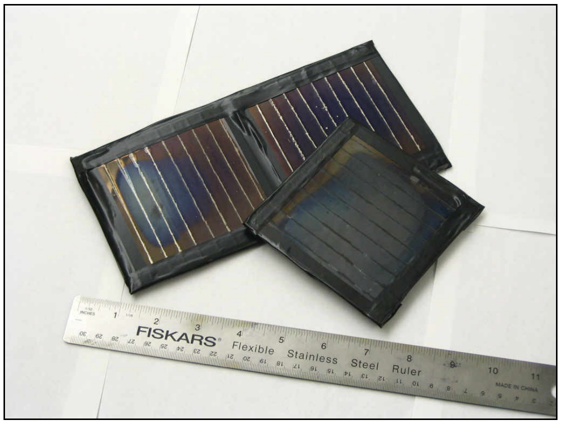

Figure 4: Silicone elastomer encapsulated, a-Si/a-SiGe based minimodules

The cells produced the expected open circuit voltages of 0.8 V and 1.6 V for the single and two-cell minimodules, respectively. The short circuit current was 183 mA for the 4"x4" minimodule, and 760 mA for the 4"x8" interconnected minimodule, corresponding to current densities of 2.2 and 9.4 mA/cm^2, respectively. The currents were limited by the series resistance of the grids and interconnects, which at approximately 1 Ω per cell for the silver paint-attached grids and 4 Ω per cell for the carbon paint-attached grids, were excessive for the expected I_{sc} of ~1.6A. With the reverse protection diodes removed and under a reverse bias, the current in the 4"x8" minimodule increased to approximately 1.0A (J_{sc}=12.4 mA/cm^2), indicating that it was indeed the series resistance that limited the performance of the cells. Analysis showed that most of the series resistance in the second minimodules was due to the ITO top contact; reducing grid pitch and/or increasing the ITO thickness will lower it.

CONCLUSION

Both minimodules encapsulated with silicone elastomer were functional. The quality of the encapsulant in terms of adhesion and bubble-free lamination was found to be good. Its light transmission for the thickness applied was found to be better than that of EVA. There are other silicone elastomers that meet degassing and stability criteria for space use, for example Dow Corning 93-500. Such elastomers may be suitable for the encapsulation of space solar cells. We conclude that silicone elastomers can be used as an alternative encapsulant for encapsulating solar cells.

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