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Study of compatibility of silicone-based electrically conductive adhesives and conductive backsheets for MWT modules

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Abstract

We investigate the compatibility of silicone-based electrically conductive adhesives and different surface finishes of the conductive backsheet (CBS) used in MWT module assembly technology. We find that the same ECA can lead to dramatically different properties of the electrical contact depending on the kind of surface finish. On lower cost surface finishes, such as those based on Organic Solderability Preservative, it is more challenging to achieve a low ohmic and stable contact using an ECA. Nevertheless, a silicone-based ECA, called *Dow Corning®* PV-5802, was developed that leads to excellent performance (low cell-to-module losses) and durability as evidenced by mini-modules passing 2000 hours of damp heat and 600 thermal cycles.

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Keywords: MWT modules; Electrically Conductive Adhesive (ECA); silicone; durability ; conductive backsheets

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1. Introduction

The combination of Metallization Wrap Through (MWT) cell technology and automated module assembly based on conductive backsheet (CBS) and electrically conductive adhesive (ECA) has the potential to reduce overall complexity of PV module manufacturing and reduce cost/Watt peak [1]. In an effort to achieve the cost reduction potential, new types of conductive backsheets with lower cost are now offered by conductive backsheet suppliers. Typically they feature low-cost surface finish, which makes it more challenging to create a low ohmic and reliable

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contact using ECA. In this contribution, we focus on the compatibility issues that can occur between ECAs and CBS and share the experience that we have acquired on that topic.

2. Experimental

Silicone-based electrically conductive adhesives were formulated by mixing silicone polymers, metal fillers and a catalyst for addition cure. The ECAs were screenprinted on test structures and cured at 150 ºC. After curing, the resistivity was determined using a four point probe resistance measurement technique. Contact resistance measurements were obtained with Transfer Length Measurement (TLM) attaching Sn-alloy coated Cu ribbons or strips of CBS with ECA on screen-printed a Ag electrode in a way to form a TLM pattern, and then measuring resistance with a four probes configuration.

Four cells mini-modules were made on various CBS. All of them featured PET as the core material with a top layer of a fluorinated polymer, as well as a thin Cu foil glued on the polymer and patterned chemically. Small dots (~ 1.5 mm in diameter) of ECA were applied by stencil printing onto the foil. A perforated sheet of Ethylene Vinyl Acetate encapsulant (EVA) was placed over the CBS, leaving the ECA dots exposed. The perforation of the EVA sheet is achieved by a hole puncher consisting of of an array of parallel pins going down and punching holes, similar to a hole puncher for paper. MWT cells with 31 contact pads were placed one by one on the foil. Then, a second sheet of EVA and a cover glass was placed on top, the whole sandwich was flipped upside down and introduced in the laminator, where vacuum was pulled and the temperature increased to 150 °C. The ECA cures at the same time as the EVA during lamination.

After lamination, the illuminated IV curves of the mini-modules were measured. Some samples were placed in climate chambers and submitted to either damp heat conditions (85°C, 85 % relative humidity) or thermal cycling (-40°C - 85°C). The samples were pulled out from the climate chambers at regular intervals and measured, in order to monitor the degradation.

3. Results on Ag-finished conductive backsheet

In a first phase of the project, the conductive backsheets (CBS) that were used had a similar design and appearance as printed circuit boards. A green solder mask covered most of the area of the CBS, and the contact pads were finished by Ag plating (see Fig. 1). The ECA's tested in combination with that type of CBS had a high (ECA A), respectively medium (ECA B) Ag content. The resistivity of those ECAs after curing was measured to be in the order of 5×10^{-4} Ohm cm and the contact resistance on a Ag surface was below 100 μOhm cm^2. The Cell-To-Module efficiency losses were low, in all cases below 1.5 %. In accelerated aging, the mini-modules were very stable, staying at around 100 % of their initial power after 1000 hours in damp heat conditions and also around 100 % after 200 thermal cycles (Fig. 2).

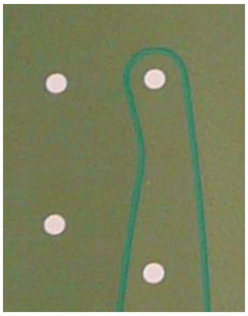

Fig. 1. Detail of an early conductive backsheet featuring Ag-finished contact pads

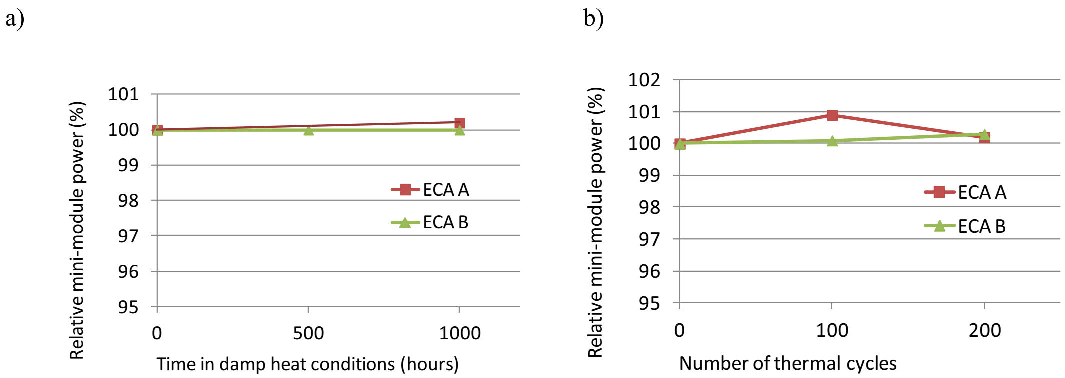

Fig. 2. a) Relative power of 4 cell modules using a Ag-finished CBS after DH(85/85) test ; b) Relative power of 4 cell modules using a Ag-finished CBS after a TC (-40/+85ºC) test

4. Results on OSP-finished conductive backsheets

As a result of a strong drive to reduce module assembly cost, the conductive backsheet manufacturers have simplified their CBS design and structure. In the next series of experiments, a new CBS was used that did not feature any solder mask, and only had a thin organic layer on the surface, a so-called 'Organic Solderability Preservative' (OSP) layer. OSPs are used in PCB technology to keep a Cu surface free of oxidation and solderable. XPS measurements on the CBS surface revealed that the OSP contained C, O and N atoms in ratios consistent with a substituted benzimidazole, a common type of OSP. Moreover, spectroscopic ellipsometry measurements indicated that the average thickness of the OSP was around 27 nm.

Mini-modules were made following the same procedure as described in section 2. It should be however pointed out that these mini-modules did not feature any solder mask (in contrast to those in section 3) or any other insulation lacquer (ILD). A picture of a mini-module made with such a CBS is shown in Fig. 3.

Fig. 3. Picture of a 4 cells mini-module using a CBS without solder mask and with OSP-finish

When mini-modules were made using this new CBS and ECA B, a large Cell-to-Module Efficiency loss was observed, between 2.5 and 5 %, which is unacceptably high. Moreover, it was observed that the power of the mini-modules degraded even when kept in the dark at room temperature (Fig. 4). Clearly the contact between ECA B and the OSP-finished Cu foil was poor and moreover degraded over time. It is remarkable that although ECA B gave excellent and durable contacts on Ag-finished backsheets, its performance was completely unsatisfactory on OSP-backsheet. This is related to the nature of the contact and highlights the need to co-develop ECA and foil surface finish, or at least to systematically check the compatibility between the two key materials in this module assembly technology.

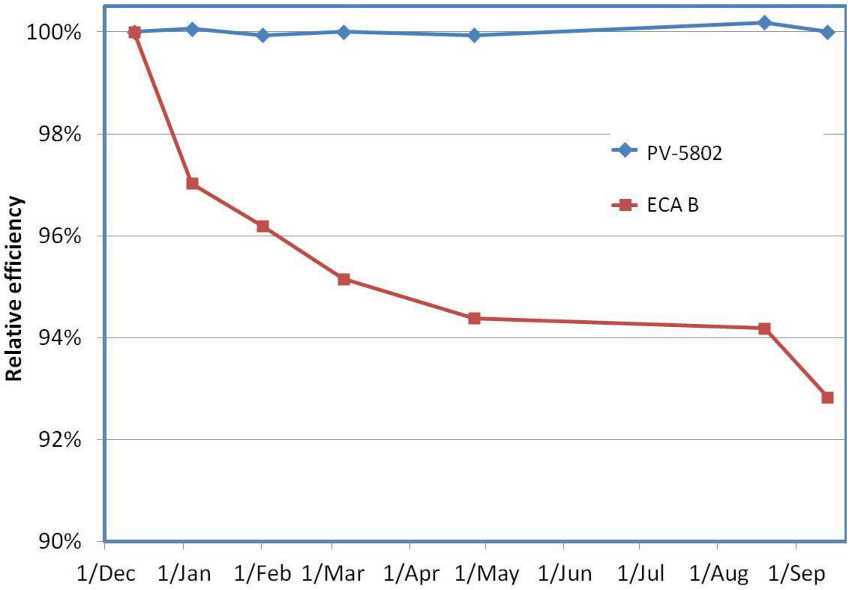

Fig. 4. Room temperature degradation monitoring of two mini-modules with OSP-finish made with two different ECAs

A new ECA was formulated that targeted both achieving a good contact on OSP-finished CBS and a lower cost by lowering further the Ag content. The new material is called *Dow Corning*® PV-5802. It is a one-part printable paste which cures into a solid with a resistivity of 2×10^{-4} Ohm cm. The cure chemistry of the material is designed such that the material cures during a typical module lamination cycle at 150 °C for several minutes. Common to other silicone ECAs [2], the material is flexible throughout the PV module operating temperature range (- 20°C to 80°C), with a shear storage modulus G' below 2×10^{7} Pa throughout the range. The specific contact resistance between the ECA and OSP-finished Cu is calculated from TLM measurements to be much lower than 500 $\mu\Omega$ cm^2 (estimation – there is uncertainty due to the asymmetry of the contact structure used). When making mini-modules with this material using OSP-finished CBS, the Cell-to-Module efficiency losses are low (between 1.4 and 1.8 %), in the same range as for the mini-modules from section 3 even though there is no Ag-finish on the CBS. These mini-modules were checked to be stable in the dark (Fig.4), and turned out to be also extremely stable in accelerated aging, reaching 2000 hours in damp heat conditions, and 600 thermal cycles (Fig.5). In case of thermal cycling, no onset of degradation was observed even after 600 cycles.

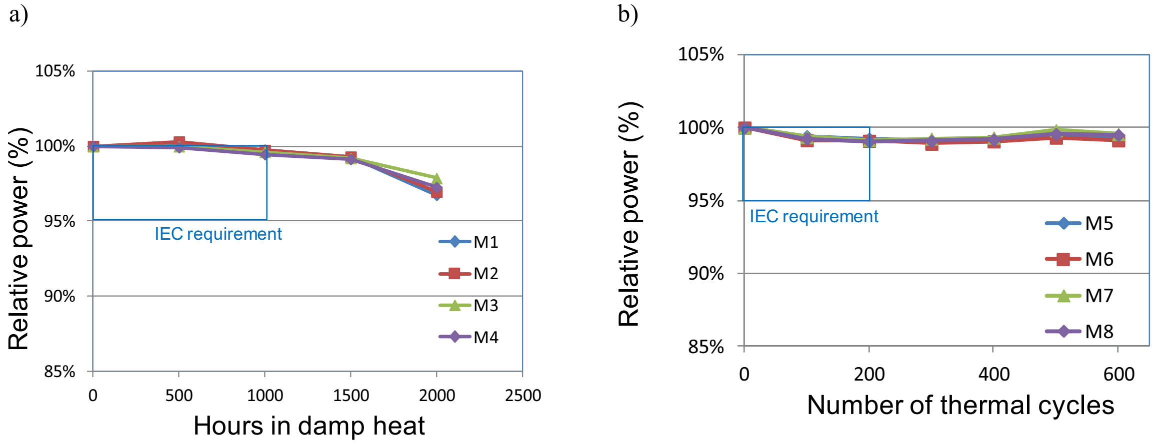

Fig. 5. a) Relative power of 4 cell modules after DH(85/85) test ; b) Relative power of 4 cell modules after a TC (-40/+85ºC) test

These accelerated aging results are outstanding and give evidence of the durability of interconnection using PV-5802 and OSP-finished CBS. Nevertheless, further analysis was carried out to understand the degradation mechanisms. A mini-module that had gone through damp heat aging and failed from 2500 hours of damp heat was kept in the climate chamber until 3000 h and then was analyzed through visual inspection, electroluminescence and Lock-In Thermography, to try to determine the cause of degradation (Fig. 6). It appeared clearly that the degradation was linked to moisture ingress through the backsheet at the periphery of the mini-module and then inwards towards the center of the cells. It was unclear what exactly had failed (Al metallization, Ag metallization or ECA interconnection joint), but clearly the failure was triggered by the impact of moisture. A similar study on a mini-module that had gone through 600 thermal cycles revealed no damage.

It should be mentioned that full size industrial back-contact modules do not feature such a wide region between the cells and the edge of the laminate. Moreover, they have a frame and frame sealant, which limit moisture ingress from the periphery. Finally, the fraction of cells located at the edge of the module is lower compared to mini-modules. Combining these factors, it is expected that degradation through moisture ingress will be even slower than for the mini-modules studied here. And indeed, recent full-size modules made using PV-5802 and OSP-finished CBS on an automated industrial line have passed 2 x IEC requirements in terms of damp heat and thermal cycling with less than 2 % degradation [3], and 3 x IEC requirements with less than 5 % degradation for damp heat and less than 2 % degradation for thermal cycling [4].

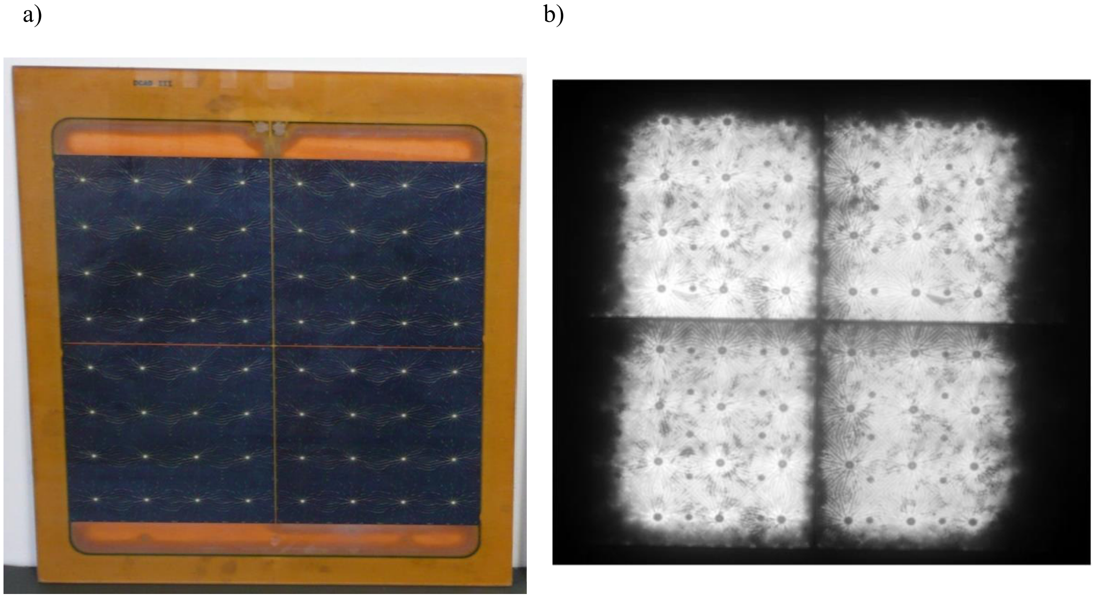

Fig. 6. a) Picture of a 4 cells mini-module as described in section 4 after 3000 hours in damp heat conditions, b) corresponding EL picture

5. Results on recent conductive backsheets

CBS manufacturers continue their efforts to lower the cost of their CBS, and therefore regularly new types of CBS become available, either with different OSPs or different surface finishes altogether. The mini-module tests that we have done applying PV-5802 with these new CBS have so far all yielded low CTM losses and excellent behavior in accelerated aging.

6. Conclusion

This study demonstrated the critical importance of checking the compatibility of ECAs with the type of conductive backsheets. We showed that an ECA that gives a very low CTM loss and good durability on Ag finished backsheet can fail dramatically on another type of CBS. A new silicone-based ECA with low Ag content was introduced, called PV-5802. In the tests on OSP-finished conductive backsheets, we found low contact resistance, low CTMs and outstanding stability in accelerated aging.

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