LOW TEMPERATURE SOLAR CELL ENCAPSULATION WITH NOVEL SILICONE ELASTOMER FOR BUILDING INTEGRATED PV

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ABSTRACT: In this paper we introduce a new silicone solar cell encapsulant technology based on a two-part condensation cure chemistry, and implement with it an encapsulation process involving a dam and fill approach and in-lamination sealing. Bubble-free laminates have been fabricated both in a laboratory laminator and in a large area plate laminator. In order to achieve a transparent edge with water vapor barrier properties, a double edge materials procedure is introduced, where a transparent PIB is used as dam material, and a clear moisture cure sealant is backfilled into the groove between the glass plates and the transparent PIB. This technology is anticipated to be highly suited to BIPV applications, where module durability, hotspot resilience and better fire resistance are critical.

Keywords: Encapsulation, silicone, BIPV

1 INTRODUCTION

Policies tackling the climate and energy crises encourage incorporating photovoltaics in buildings to bring them closer to zero emission. Many buildings have limited roof space, and therefore integration of PV in façades is increasingly practiced and anticipated to become commonplace in the future. Building-Integrated Photovoltaics (BIPV) has existed for a long time, but uptake has been slow due to various challenges relating to technical aspects, excessive cost, and compliance issues to building codes. One by one hurdles are being overcome and BIPV projects are becoming more commonplace and affordable. Most façade BIPV modules are glass-glass laminates, which require an encapsulation process quite different from that for standard modules.

Conventional encapsulation materials based on ethylene vinyl acetate or polyolefin elastomers are not perfect fits for BIPV. Ideally a BIPV component would have a lifetime of 50 years or more, to match the lifetime of other components in a building skin. Resistance to high temperatures is desired, so that hot spots created during exceptional operating conditions do not lead to permanent laminate damage. Good fire resistance properties are also required. Another specific aspect of façade BIPV is that some laminates are very thick, much thicker than conventional PV laminates. These high mass panels require a lot of energy to be heated up to lamination temperature and involve a long process time because of the slow heating up and cooling down. A low temperature or even room temperature lamination process enables faster manufacturing and is therefore advantageous for BIPV applications.

Silicone encapsulation of solar cells is almost as old as photovoltaics itself. Early solar panels used silicone as encapsulant, and it is still the material of choice for space solar panels. The properties of silicone encapsulants in operating PV modules have been observed to degrade very little over long periods of time [1], resulting in modules showing lower degradation rate during field operation[2]. Also in extended accelerated ageing studies, exceptionally low degradations have been observed[3, 4].

In this work we introduce a new type of silicone solar cell encapsulant which enables lamination at temperatures down to room temperature, we describe the lamination process and show results at blank laminate and mini-module levels, after lamination and also after accelerated ageing.

2 NOVEL SILICONE SOLAR CELL ENCAPSULANT

The silicone encapsulant used in this work is DOWSIL™ 9955 Encapsulation and Lamination Silicone, which is part of a new generation of silicone elastomers. It is a two-component material, which requires mixing right before application. Some key properties of the material are listed in Table 1.

Table 1: Properties of silicone encapsulant DOWSIL™ 9955

Material property	Value
Before cure	
Viscosity	2800 mPas
After cure	
Transmittance	> 90% (5 mm slab, 450-760 nm)
Hardness	10 shore A
Elongation at break	190%
Flammability rating	UL94 HB

Unlike all other transparent silicone encapsulants, this new type of material is based on a condensation cure technology instead of a platinum-catalyst addition cure chemistry. This results in a more robust cure chemistry (fewer incompatibilities with other materials) and the development of strong adhesion on most common substrates (glass, aluminum, etc.) without the need to prime the surface prior to application.

Because of the intrinsic fire resistance properties (silicones get charred when exposed to a flame rather than burn and melt), it was possible to obtain a flammability rating under a small flame test, in contrast to all organic polymer-based encapsulants.

Laminating solar cells with a liquid silicone is very different from the conventional film-based processes but is not necessarily more complex. In this paper we explain a convenient process to achieve good encapsulation results.

3 ENCAPSULATION PROCESS USING SINGLE EDGE MATERIAL

Because the encapsulant is liquid, a dam is required to confine the encapsulant during the process. This dam is useful for the fabrication sequence but can also provide additional functions, for instance vapor barrier properties.

3.1 General process

The schematic process sequence is given in Figure 1. A dam is first applied by applying a line of hotmelt edge material along the perimeter by extrusion. The silicone encapsulant is then dispensed on the glass, the solar cell or solar cell matrix placed, onto which some additional silicone is dispensed. The top glass is placed on top without pressing. In the vacuum chamber, air is first evacuated including the air present inside the sandwich structure. The evacuation times range between 5 and 15 min. Then the top glass is pressed down slightly while in the vacuum chamber, enough to compress the dam material a little and create a tight seal. Finally, the vacuum chamber is vented, and the atmospheric pressure compresses the whole structure to its equilibrium status. As silicone is incompressible, the final thickness of the region between the glass plates is determined by the amount of encapsulant used. A thickness of 0.8 mm as is typical for crystalline Si solar cells and conventional ribbon interconnection is typically targeted, but other thicknesses can be achieved by using less material if the solar cell string allows it, as for instance is the case for some thin-film solar cell technologies.

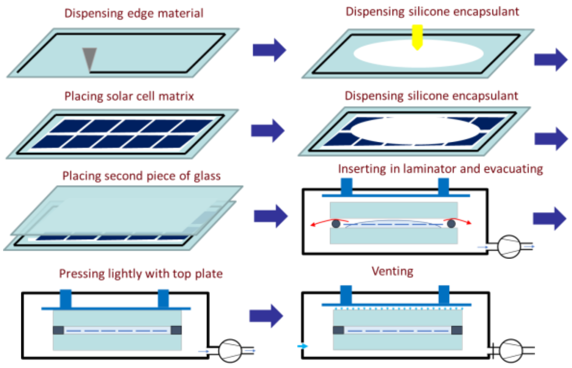


Figure 1: Suggested process with single edge material

Note that the silicone encapsulant is not yet cured after lamination and is still liquid. The encapsulant cures over the following hours but the module can already be moved. The long pot life of the encapsulant and liquid state right after encapsulation helps eliminate the remaining bubbles in the laminates, which is a common challenge in glass-glass lamination.

3.2 Small area laminate with silicone hotmelt as dam material

The application was first done on small area samples (20 x 20 cm^2) using a small vacuum chamber equipped with a top pressing plate. The glass was 4 mm float glass, the solar cell was a 156 mm multicrystalline Si solar cell, tabbed and attached with bussing ribbons. The dam material was a silicone hot melt product, DOWSIL™ 2400 Silicone Assembly Sealant. This type of material is solid as delivered, but becomes a viscous liquid when heated up. After application, if exposed to moisture in ambient air, chemical cross-linking occurs, resulting in a strong solid elastomer that will no longer melt when heated up, with excellent adhesion to glass. Silicone hotmelts come in different colors, but this one is perfectly transparent. The process with this edge material takes place completely at room temperature. Bubble-free laminates were repeatedly achieved. In figure 2 we show a picture of such mini-module.

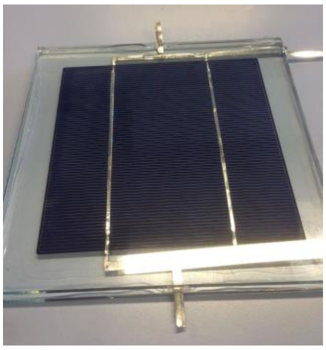


Figure 2: Photo of a mini-module obtained with silicone hotmelt as edge material

While silicone hot melt enables an easy process and can lead to visually pleasing laminates, it has the disadvantage that it does not provide a good water vapor barrier. Silicone hotmelts, like all silicones, have a comparatively high water vapor transmission rate (WVTR). Many solar cell technologies are sensitive to moisture, and therefore an effective vapor barrier at the edge of the glass-glass laminates is needed to pass the standard damp heat test at 85 °C and 85% relative humidity.

3.3 Larger area laminate with TPS as edge material

Experiments with a higher WVTR edge material were carried out in a larger area equipment. The edge material was a so-called thermoplastic spacer (TPS) material. TPS is a polyisobutylene (PIB)-based hotmelt material containing reinforcing fillers, desiccant particles and adhesion promoters. This type of material is used as an alternative to pre-shaped aluminum or silicone foam spacers in the fabrication of insulated glass, but also as edge material for thin-film PV modules. The equipment was a laminator from equipment manufacturer LISEC (model VPL-42/17 vacuum laminator). The glass was standard 3 mm extra-white solar glass and the solar cells were modern monocrystalline silicon PERC cells interconnected with a multi-busbar approach. As TPS requires a minimum temperature to soften sufficiently and develop adhesion, the process was carried out at 110°C.

Several mini-modules were made using the process described above. A picture of such a mini-module with TPS edge sealant is shown below.

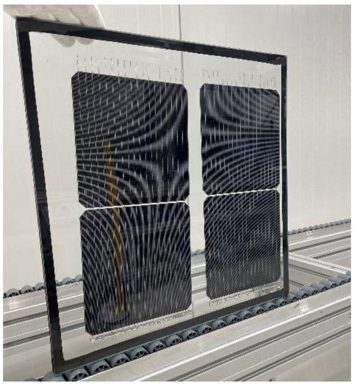


Figure 3: Photo of a four cells mini-module with TPS edge

4 ENCAPSULATION PROCESS USING DOUBLE EDGE MATERIALS

4.1 Process

While the TPS edge seal provides the moisture barrier function required to pass damp heat module testing, it creates a wide opaque (black) area along the edge of the PV laminate, which is undesirable for BIPV applications. The silicone hot melt on the other hand provides a perfectly clear edge but is an insufficient water vapor barrier. To solve this the following process was developed. Instead of the TPS material, a transparent, unfilled PIB material is used as dam material. Pure PIB is a non-reactive material that slowly flows at room temperature when unconstrained. It is applied with a hot melt gun similarly to silicone hot melt or TPS. The line of transparent PIB is dispensed at a distance from the glass edge, in such a way that, after lamination, the outer surface of the PIB joint is a few mm from glass edge. Then, after the laminate has been taken out of the laminator, a transparent or translucent sealant is backfilled into the groove formed by the two glass panes and the dam to prevent the creep of the transparent PIB and provide anchoring of the edge joint. In our experiments we either used the translucent neutral sealant DOWSIL™ 791T Weatherproofing Sealant or a silicone hotmelt, for an even more transparent edge.

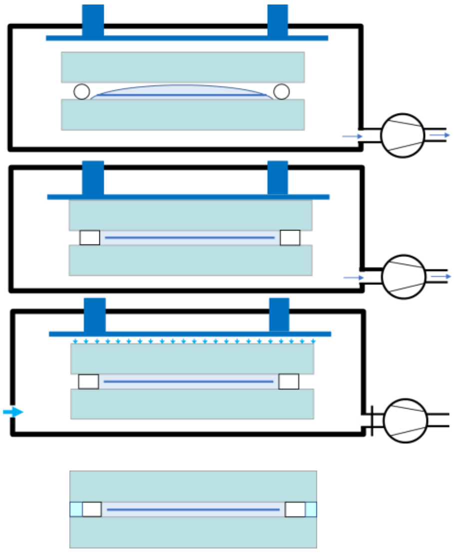


Figure 4: Schematic process with double edge materials. The last step (backfilling step) is carried out subsequently, outside the laminator

The back-filling process is commonly implemented in insulated glass unit manufacturing and can be automated. Figure 5 shows an example of manual backfilling.

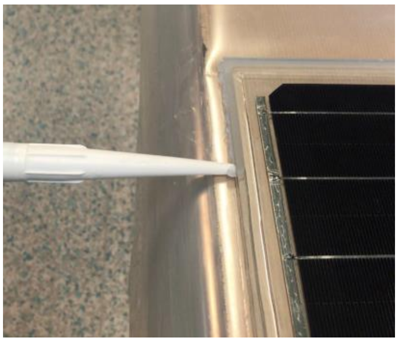


Figure 5: Backfilling process

Note that this fabrication sequence takes place completely at room temperature. Figure 6 shows a mini-module obtained through this process. For these tests, monocrystalline PERC solar cells with 4 busbars were used, in combination with 3 mm float glass pieces. The outer edge was obtained by backfilling with a translucent silicone sealant.

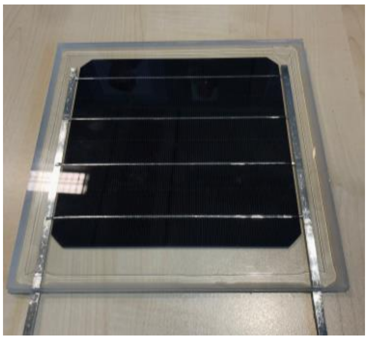


Figure 6: Picture of completed mini-module fabricated with the double edge materials process

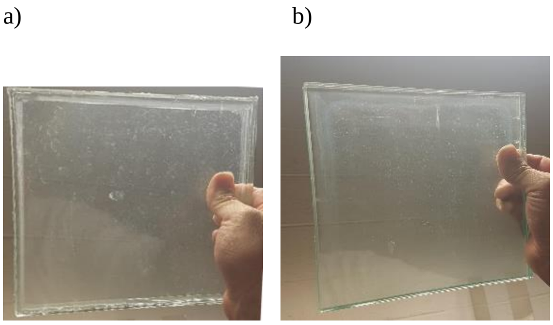
4.2 Vapor barrier effectiveness

The double edge materials process was investigated with a comparative test. Two small laminates were produced with different edge structures. One only had silicone hot melt as edge sealant, and the second had the double edge structure transparent PIB / silicone sealant. For this experiment, no solar cell was inserted during lamination, and the backfilled silicone sealant in case of the double edge materials sample was a silicone hot melt.

Figure 7: Glass-glass laminates with the two types of transparent edge structures, prior to damp heat ageing (right: laminate with only silicone hot melt edge material, left: laminate with combination transparent PIB and silicone hotmelt back-filling)

Note that the transparent PIB does not contain any desiccant, in contrast with TPS material, and is therefore expected to be a less effective moisture barrier. However, because of the low WVTR of PIB itself, the relatively large width of the PIB seal and the small cross-section of the space between the two glass panes, it is expected that the PIB seal will provide a sufficient barrier. The laminates were put in a climate chamber for 1000 hours in 85 °C/ 85 % relative humidity conditions.

The silicone encapsulant has the property to show slight haziness when in presence of moisture. This property is used here to determine whether or not moisture has reached the inside of the laminate. Photos of the laminates after ageing are shown in Figure 8. A milky halo can be seen for the sample with only silicone hotmelt as edge sealant. On the contrary, no such halo can be seen for the sample featuring the double edge sealant structure.



a) b)

Figure 8: Photos of glass-glass test laminates after 4 weeks in 85 °C/ 85 % RH, a) with double seal transparent PIB/backfilled silicone hot melt, b) with only silicone hotmelt edge seal.

This absence of degradation of laminates with double edge materials in damp heat is also observed at mini-module level. Three mini-modules similar to the one shown in Figure 6 were measured with an illuminated IV system, placed in 85/85 damp heat conditions, and then measured again. Table 2 give the results after 475 hours of damp heat.

Table 2: Illuminated IV results of mini-modules with double edge materials before and after 475 hours of damp heat treatment (average of 3 mini-modules)

	Isc (mA)	Voc (mV)	FF (%)	Power (W)
Before damp heat	8992	666	72.1	4.32
After 475h damp heat	9017	663	73.2	4.38
Average change	+0.28%	-0.4%	+1.51%	+1.37%

As can clearly be seen there is no degradation after 475 hours of damp heat. The accelerated ageing procedure will be continued until 1000h.

4.3 UV resistance

In contrast with TPS material, pure PIB does not contain any pigment or filler. UV light can therefore reach not only the interface between glass and PIB, but also the bulk of the transparent PIB joint. To ascertain whether this could degrade the double materials edge structure, a laminate with encapsulated solar cell and double materials edge was exposed to UV (50 W between 300 and 400 nm) for 1000 h. Visual observation after ageing revealed no sign of degradation and discoloring.

5 DISCUSSION

Solar cell encapsulation at room temperature is not new. In fact early PV modules were made used silicone in a casting process, a process which is still used sometimes where laminating equipment is not available[5]. The process combining the in-lamination sealing and the special silicone encapsulant introduced here is however quite different. Process speed can be much higher as lamination and curing are decoupled. Moreover, no priming is needed, as the encapsulant provides strong and durable chemical adhesion, in contrast with addition cure transparent encapsulants.

This encapsulation process is not only applicable for BIPV, but potentially also for all PV applications where superior longevity and temperature resistance is desirable, such as desert modules or floating PV. The low temperature aspect of the lamination process is also of great interest for emerging solar cell technologies that cannot withstand typical lamination temperatures, such as perovskite-based solar cells.

6 CONCLUSION

Solar cell encapsulation with a transparent silicone elastomer has advantages for several PV applications, including BIPV. In this paper we introduced a new silicone solar cell encapsulant technology based on a two-part condensation cure chemistry, and implemented with it an encapsulation process involving a dam and fill approach and in-lamination sealing. Bubble-free laminates could be easily fabricated both in a laboratory laminator and in a large area plate laminator. In order to achieve a transparent edge with water vapor barrier properties, a double edge materials procedure was introduced, where a transparent PIB is used as dam material, and a clear moisture cure sealant was backfilled into the groove between the glass plates and the transparent PIB. This structure was shown to be effective in preventing moisture to enter the laminate.

7 REFERENCES

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