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CLIMATE CHAMBER TEST RESULTS OF MWT BACK CONTACT MODULES

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ABSTRACT: Large, 6x10 cells back contact modules have been manufactured at ECN using multi-crystalline Sunweb® metallization wrap through (MWT) cells manufactured at Solland Solar, a conductive back sheet foil and conductive adhesive as interconnection material. The modules have been exposed to thermal cycling and damp heat tests according to IEC61215 ed. 2 requirements. For one set of materials, modules passed 300 thermal cycles and 2000 hours of damp heat exposure. Wet leakage tests performed after 1000 hrs and 2000 of damp heat exposure and with an applied voltage of 1000 V yield an insulation resistance of 670 $M\Omega \cdot m^2$ and 180-320 $M\Omega \cdot m^2$ respectively. This is well beyond the specification of 40 $M\Omega \cdot m^2$, proving the insulation of this type of module is more than sufficient. This shows that the MWT module concept using conductive adhesive as interconnection is robust. The reliability depends on the combination of materials used, as modules using other materials show failure after 1000 hrs of damp heat exposure. By further understanding the degradation mechanisms involved, stability of the module concept can be improved. IEC qualification testing of these MWT modules has started.
Keywords: reliability, back contact module, MWT cells, IEC61215

1 INTRODUCTION

Back contact module technology developed by ECN [1,2] offers the advantage of faster manufacturing, lower yield loss and higher power conversion efficiency compared to conventional modules based on H-pattern cells. The modules are manufactured by placing a conductive back sheet foil, printing the conductive paste, punching the back side encapsulant, cell pick and place and front side encapsulant and glass placement at a module line developed by TTA/Eurotron [3]. The last step is a combined interconnection and curing step using a laminator. The interconnection method and the back sheet foil used in back contact modules are different compared to H-pattern type modules, and hence the reliability of this kind of modules needs to be proven before they can be manufactured on a large scale.

In standard H-pattern modules, neighboring cells are interconnected by soldering tabs. This interconnection method is unsuitable for thin cells because of the high temperatures involved and requires at least 3 mm distance between the cells to minimize stress. ECN's back contact module technology comprises an interconnection method which is very different. For our technology, a conductive pattern is applied onto a back sheet foil by an etching of a metal layer. A conductive adhesive is printed onto the foil opposite to the positions where contacts are located at the back of the cell. (An alternative method makes use of solder material, but this is not covered by this paper.) Cells are then placed by a pick and place system, see Figure 1. This is a low stress interconnection method which is a lead-free, high-yield process, suitable for thin cells and also allows a distance between neigbouring cells of ~ 1.25 mm, increasing total area efficiency [4]. ECN recently obtained a world record of 17% aperture area efficiency for multi-crystalline solar modules [5].

The use of conductive adhesives in conjunction with a back sheet foil with an integrated conductive metal pattern is a fundamentally different technology and raises novel scientific issues in terms of reliability. The interconnection between the cell and the foil is novel and other types of corrosion, interconnect cracking or delamination may occur compared to the soldered tabs in an H-pattern module with a TPT back sheet foil. The foil consists of a conductive pattern with insulation, see Figure 2 for a schematic cross section of the back contact module and an indication of possible failure locations. The reliability of both the interconnection and the foil depend on the thermal mechanical properties and moisture stability of many different components (and their interactions).

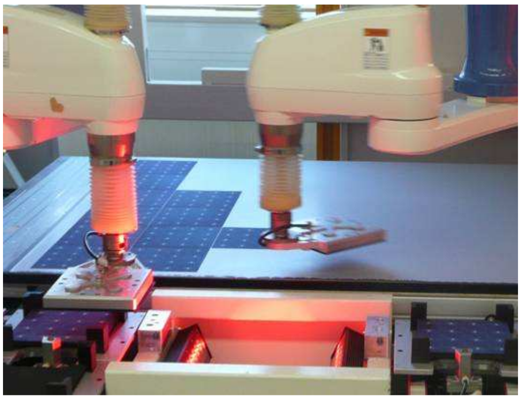


Figure 1: Cell pick and place in the back contact module manufacturing process.

Over the past year, ECN has put a lot of effort into improving the stability of the conductive backsheet foil itself. This paper focuses on stability of the interconnections, as a function of different insulation materials on the foil. This has been tested by manufacturing 6x10 cells modules using Sunweb® cells from Solland Solar, and by measuring performance and recording infrared and electroluminescence images as a function of climate chamber (thermal cycle and damp heat) exposure. Wet leakage tests have been performed after 1000 hrs and 2000 hrs of damp heat exposure.

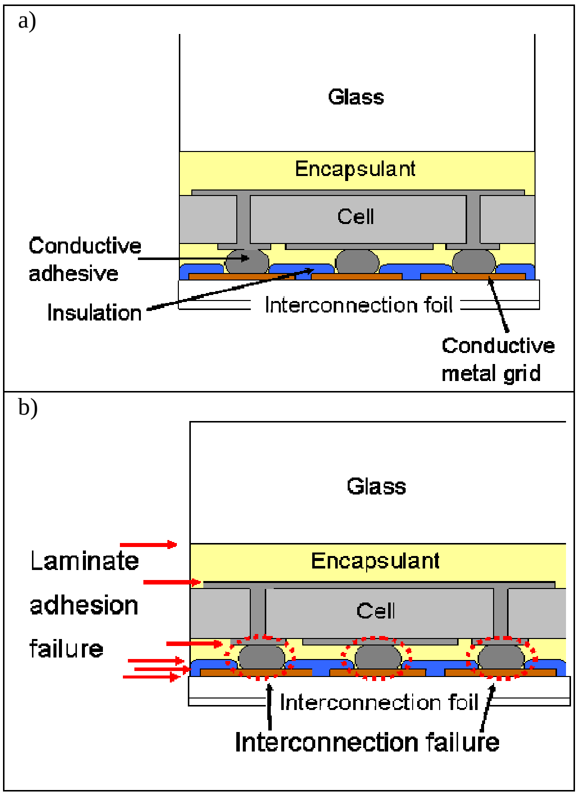


Figure 2: a) Schematic cross section of a back contact module. b) Indication of positions where failure could start to occur. Red arrows indicate points where adhesion of layers is relevant, the dotted circles indicate where interconnection failure could start.

2 EXPERIMENTAL

Eight 6x10 cells modules were manufactured with two different types of insulation material, four of each insulation material. These were distributed among thermal cycle and damp heat chambers according to Table I.

Table I: Module identification and distribution among the climate chambers.

	Thermal Cycle (TC)	Damp Heat (DH)
Insulation I	M1	M3
	M2	M4
Insulation II	M5	M7
	M6	M8

Climate chamber tests were performed according to IEC 61215 ed. 2 [6]. Thermal cycle tests were performed between -40 and +85 °C with 7.5 A forward bias (equal to the MPP current) above 25 °C. Damp heat testing was performed at 85°C and 85% relative humidity. Wet leakage test were performed by subjecting the module to a water bath and an applied system voltage for 2 minutes (system voltage has to be at least 500 V).
Analysis has been performed by infrared (IR) and electroluminescent (EL) imaging [7,8], which can identify malfunctioning interconnections. In both cases, a forward bias is applied to the module. The difference is that with IR imaging heat due to current flow is detected by detecting IR light in the 3–13 μm wavelength range, whereas EL directly measures the near infrared radiation of about 1 μm that results from radiative electron-hole recombination in the silicon cells. Malfunctioning interconnections will cause temperature variations that can be detected by IR imaging because the current flow will be higher (lower) at locations where contacts are functioning (malfunctioning). EL imaging will identify malfunctioning interconnections if they lead to series resistance variations and thereby to reduced electron-hole recombination (thus to darker regions) close to these interconnections.

3 RESULTS

3.1 Thermal Cycle

Figure 3 shows the relative power (R/R_0) of modules M1, M2, M5 and M6 up to 300 thermal cycles.

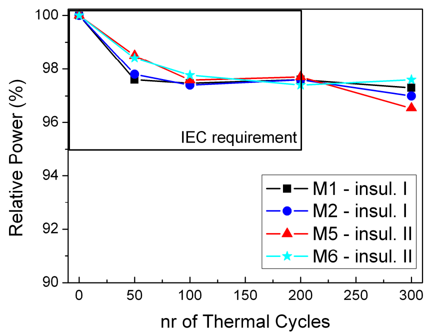


Figure 3: Relative power after exposure to 300 thermal cycles for modules M1, M2, M5 and M6.

For all of the 4 modules power reduction is observed after the first 50 cycles, after which the power output stabilizes for at least up to 300 cycles. For both sets of modules, the relative change in open circuit voltage (Voc) is approximately 0.5%. The relative changes in fill factor (FF) and short circuit current (Isc) are between 1-1.6%, see Table II.

Table II: Short circuit current, open circuit voltage and fill factor for the modules at t=0 and after 300 thermal cycles.

	Isc (A)		Voc (V)		FF (%)	
	t=0	300 TC	t=0	300 TC	t=0	300 TC
M1	8.1	8.0	37.0	36.8	75.7	74.8
M2	8.1	8.0	37.2	37.0	75.7	74.7
M5	8.0	7.9	37.0	36.7	75.7	74.5
M6	8.1	8.0	37.0	36.8	75.1	73.9

The loss in FF tends to indicate a small increase in series resistance, possibly as a result of failing interconnections.
Infrared analysis shows a uniform temperature distribution among the modules, both before and after thermal cycle testing, for all of the modules (not shown). Electroluminescence imaging is more sensitive. Figure 4 shows representative EL images for M5 before TC testing and after 300 thermal cycles. The blue ellipse indicates a cell with a crack which was already present at t=0. The crack is not growing at all upon thermal cycling, showing the limited stress that is applied on the cells in

the back contact module. The white ellipses indicate regions where the EL intensity has significantly dropped upon thermal cycling. These may indicate locations where the interconnection between foil and cell has been lost. The largest EL intensity drop was observed between 0 and 50 thermal cycles, in correspondence to the power drop that was also largest between these two data points (Figure 3).

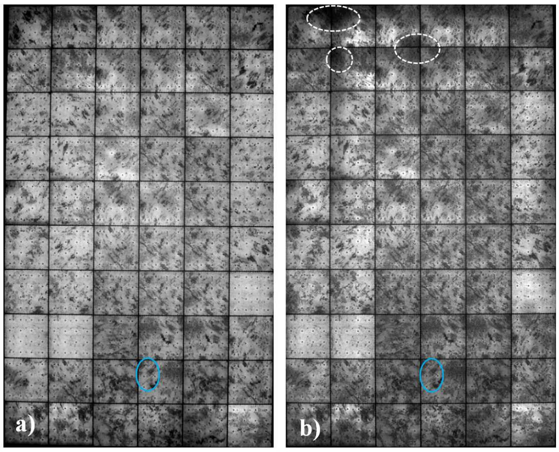


Figure 4: EL images of module M5, before (a) and after (b) 300 thermal cycles. The blue ellipse indicates a cracked cell. The white ellipses indicate regions where the EL intensity has dropped upon thermal cycling. Images were taken with 8A forward bias.

Each cell has 16 emitter contacts and 15 base contacts. If one contact interconnection fails, the current through the other contacts will increase, but the cell remains operational. Due to the thermal mechanical stress during thermal cycling, less than 20 out of 1860 (60x31) interconnections in total may have failed for module M5 after 300 thermal cycles. This does not significantly reduce the output power, but can explain the observed FF loss of 1-1.5%.

3.2 Damp Heat

A significant difference was observed between the two groups of modules after damp heat testing (85°C, 85% relative humidity). The relative power of modules with insulation I is 97.7% and 97.2% after 1000 hrs and 95.1% and 96.4% after 2000 hrs of damp heat testing. The relative power of modules with insulation II is 96.9% and 94.2% after 1000 hrs and 68.5% and 67.0% after 1250 hrs of damp heat testing, see Figure 5. For these modules testing was stopped after 1250 hrs and failure analysis was carried out.

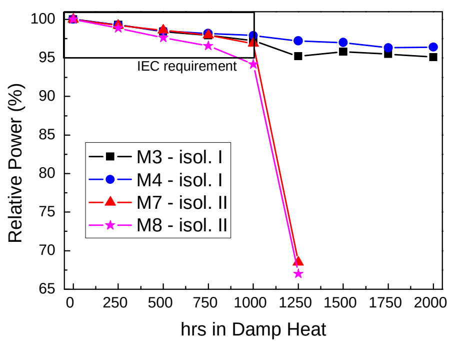


Figure 5: Relative power after 2000 hrs of damp heat exposure for modules M3, M4, and after 1250 hrs of damp heat exposure for modules M7 and M8.

The I/V characteristics of modules M7 and M8 show a stronger decrease in fill factor upon damp heat testing than modules M3 and M4. For example, Module M8 dropped over 3% in fill factor after 1000 hours, from 75.5 to 73.0%, whereas module M4 dropped less than 0.2% after 1000 and less than 2% after 2000 hours, see Table III.

Table III: Short circuit current, open circuit voltage and fill factor for the modules after up to 2000 hours of damp heat exposure.

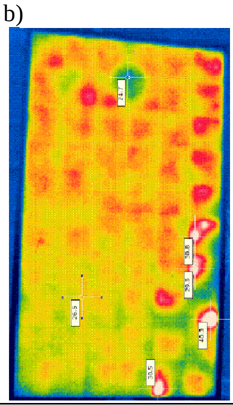
Module name	Hours of DH	Isc [A]	Voc [V]	FF [%]
M4	0	8.1	36.3	75.8
M4	1000	7.9	36.2	75.7
M4	2000	7.9	36.3	74.5
M8	0	8.0	36.3	75.5
M8	1000	7.8	36.2	73.0
M8	1250	7.8	26.9[a]	70.2

[a] One failing string after 1250 hours.

This could imply that the series resistance of M8 has increased much more than that of M4 as a result of failing interconnections. The large drop in Voc for M7 and M8 shows a whole string is failing. This was confirmed by performing I/V measurements per string.

Indeed, infrared analysis clearly shows the absence of hot spots in modules M3 and M4 after 2000 hours of damp heat exposure (Figure 6a), where temperature differences are less than 2 °C over the complete module. For modules M7 and M8 after 1000 hours of damp heat exposure, on the other hand, hot spots are observed with for the six hottest hotspots temperature differences of 5–15 °C compared to the rest of the module (Figure 6b). All hot spots are mainly located within one string.

Destructive failure analysis at the location of the hotspots showed that interconnects around the hot spots had failed, causing increased current flow through the interconnections that were still functional. Thus the presence (or absence) of hotspots indicates the failure (or limited failure) of interconnections. After 1250 hours, all interconnections were lost in some of the cells, explaining the failure of the string.

a)	b)
	

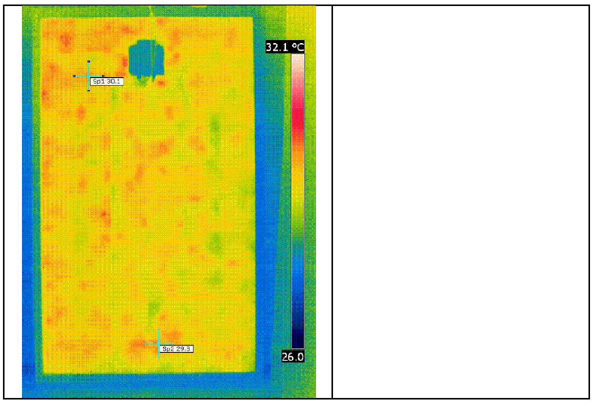


Figure 6: IR images of a) M3 after 2000 hrs damp heat exposure. Temperature differences are less than 2°C, and b) M7 after 1000 hrs damp heat exposure (just before string failure started to occur). Temperatures measured range from 24.7°C (green) to 40.3°C (bright red).

2.3 Wet leakage current tests

In the wet leakage test performed according to the IEC61215 (and IEC61730) ed. 2 requirements, the module is subjected to a water bath and the system voltage is applied to the module for 2 minutes. The measured resistance*area may not be less than 40 MΩ·m^2. Table IV shows the measured insulation resistances*area for the modules after 1000 hrs and 2000 hrs of damp heat exposure, using an applied systems voltage of 1000 V. After 1000 hrs of damp heat, the insulation resistance is more than 10 times the test requirement and after 2000 hrs still more than 4 times the test requirement. MWT back contact modules can thus be manufactured in a such a way that they comply with the IEC wet leakage current requirements, even with a system voltage of 1000 V.

Table IV: Insulation resistance*area for modules M3, M4 and M7 after 1000 and 2000 hrs of damp heat exposure, V_{sys} = 1000 V

	1000 hrs DH	2000 hrs DH
M3	670 MΩ·m^2	180 MΩ·m^2
M4	640 MΩ·m^2	320 MΩ·m^2
M7	640 MΩ·m^2	n.a.

3 DISCUSSION

In these modules, the cells and interconnection materials are identical. The results described above show that the reliability of the interconnections between the cells and the conductive back sheet foil not only depends on the contact area on the cell, the conductive adhesive and the contact surface of the conductive back sheet foil, but also on the interactions between them and their environment. Encapsulant and insulation around the contacts can also play a role. The exact effect of individual components on the stability of the interconnection as a whole is currently the subject of further investigation. The fact that modules have passed both 300 thermal cycles and 2000 hrs of damp heat exposure proves that MWT back contact module technology using conductive adhesives is a robust concept. IEC testing of this concept is on-going. The understanding of the influence of individual components on contact degradation will enable further stability improvement.

4 CONCLUSIONS

The MWT back contact modules have passed climate chamber testing of 300 thermal cycles and 2000 hrs of damp heat exposure. This proves it is a robust concept. Wet leakage test performed with an applied system voltage of 1000 V after 1000 hrs damp heat exposure, show an insulation value more than 10 times the test requirement. IEC testing of back contact modules is on-going. The reliability can be further improved, this requires a deeper understanding of the behavior of all components during climate chamber testing and of the interaction between components.

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