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# Durable MWT PV modules made using silicone electrically conductive adhesive and an automated assembly line


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## ABSTRACT

Metal wrap-through (MWT) module technology is an attractive approach for increasing module efficiency. This paper shares the results of MWT module fabrication using a silicone electrically conductive adhesive (ECA), a conductive backsheet (CBS) with a thin organic layer surface finish, and an automated module assembly line. Very low cell-to-module (CTM) power losses are observed, leading to a multicrystalline Si module power of 266W and a full-area efficiency of 16.8%. The modules are very stable in damp-heat conditions and thermal cycling, demonstrating minimal degradation after 1.5 × IEC requirements in terms of damp heat and thermal cycling, and well below 2% degradation after 2 × IEC requirements. These MWT modules have received IEC 61215 and IEC 61730 certification.


## Introduction

Recent developments in the PV market have increased the need for high-efficiency crystalline Si PV module technologies. Many emerging high-efficiency technologies, however, tend to increase the complexity and cost of cell and module fabrication. The combination of metal wrap-through (MWT) cell technology and automated module assembly, based on a conductive backsheet (CBS) and electrically conductive adhesive (ECA), has the potential to reduce both overall complexity and cost/Wp. This paper describes the fabrication of such MWT modules using an automated module assembly line, and highlights the durability that can be achieved with this module concept when suitable materials are used.

## Module concept

MWT cells [1] have front-side finger contacts which connect to the rear surface through vias in the Si wafers. As a result, the main contacts for both polarities are located at the rear of the solar cell. This structure leads to higher efficiency (lower shading losses) and lower Ag consumption than for traditional H-pattern solar cells.

Although it is possible to apply the traditional interconnection technology based on Cu ribbon soldering to MWT cells, the location of all contacts at the rear enables a more automated and simplified module build-up in which the components are added on top of each other [2] (Fig. 1). The assembly starts with a CBS: this backsheet has a metal foil laminated onto it, which has been patterned to create an interdigitated interconnection circuit. Small dots of ECA are printed onto the CBS using stencil printing; these dots are of the order of 1mm in diameter and there are more than 1000 of them on the foil. A perforated sheet of EVA is placed on the CBS so that the ECA dots are aligned with the holes in the EVA sheet, while keeping some spacing between the ECA and the EVA material. The cells are then put onto the CBS by a pick-and-place machine in such a way that the main electrodes at the rear are placed exactly on the ECA dots. A second sheet of EVA is then laid on the cells, followed by a glass sheet which will become the module's front cover.

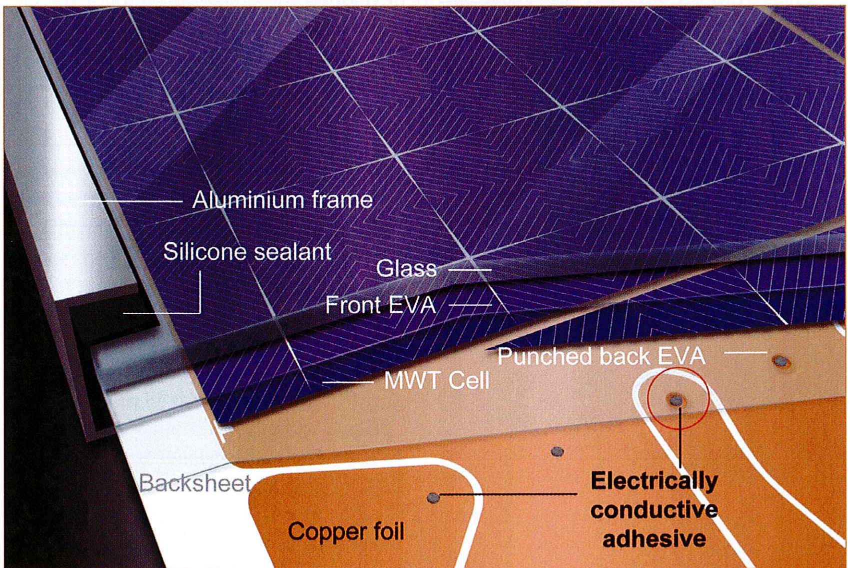



**Figure 1. MWT module build-up.**

"The location of all contacts at the rear enables a more automated and simplified module build-up."

The whole sandwich is then flipped to ensure that the glass is at the bottom, and introduced into a laminator for a conventional lamination cycle. During lamination, the EVA melts and fills all the empty spaces in the construct, including the space that had been left between the ECA and the edges of the holes in the EVA. The EVA and the ECA both cure during the lamination cycle. After lamination, the module is finished in the same way as a traditional module.

This module structure and build-up sequence has several advantages compared with traditional module assembly. Cell interconnection occurs in one go for all the cells through ECA curing during lamination, which enhances throughput. Moreover there is less manipulation of the cells and no local heating to very high temperatures as with soldering: as a result, the cells are subjected to less mechanical stress. This type of module assembly is therefore more suited to very thin cells, opening the way to lower Si wafer cost [3]. The large cross-section and the tapered shape of the Cu connectors ensure low cell-to-module (CTM) fill factor losses and further enhance module efficiency.

## Experiments

Full-size (60-cell) modules were fabricated using an automated module assembly line from Eurotron (Fig. 2), located at Tianwei New Energy Factory in Chengdu, Sichuan Province, China. The line applies the different steps described above in an automated way. Multicrystalline MWT cells from Tianwei's cell manufacturing line were used; these were current matched, and all the cells in a module came from the same power class. The CBS featured a Cu foil, a white interlayer dielectric (ILD), and contact areas where the Cu foil was finished by a thin organic solderability preservative (OSP) layer. For the interconnection between the foil and the cells, a silicone-based ECA was used (see next section).

"Cell interconnection occurs in one go for all the cells through ECA curing during lamination, which enhances throughput."

After lamination, the modules were completed with the integration of junction boxes, bypass diodes and frames. The modules were measured the next day in a flash IV tester and by electroluminescence.

Modules from an initial manufacturing run were then placed in climate chambers to undergo accelerated ageing in damp heat conditions (85°C, 85% relative humidity) and thermal cycling (–40 to 85°C). The modules were removed from the climate chambers at regular intervals to monitor their performance and to compare measurements with those taken immediately before accelerated ageing. After the initial modules passed the standard requirements in terms of damp heat and thermal cycling, a new series of modules was prepared on the same line and in the same way, and sent to a testing company for IEC certification. In another MWT module production run, solar cells with a higher average efficiency were used, capitalizing on the progress in solar cell technology at Tianwei.

## Silicone-based electrically conductive adhesives

ECAs are an emerging class of materials for PV modules [4]. The ECA is a critical component in the module structure described in previous sections: it must provide reliable contacts and adhesion during the entire lifetime of the module. Moreover, it has to be well suited to the selected application technique, cure completely during the encapsulant lamination cycle, and provide low resistivity and low contact resistance on a low-cost CBS.

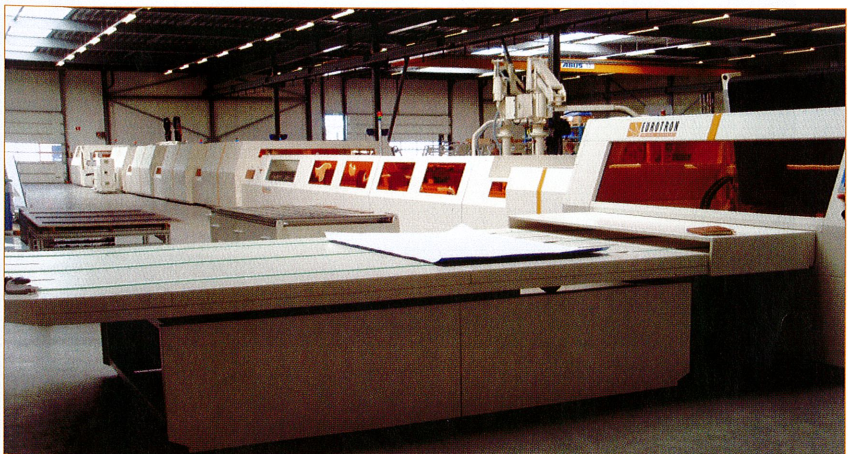


Figure 2. Assembly line for the MWT modules used in the experiments.

There are various types of ECA, but most are based on an epoxy polymer matrix. Silicone polymers are another option, which are well suited to the application. Because of the very low glass transition temperature of silicone, it is possible to achieve soft but elastic properties of the ECA throughout the temperature range in which the PV module will operate [5]. These properties are expected to be favourable in the application, because excessive stress to the cells and joints caused by differences in expansion and contraction of the foil and the cells during thermal cycles is avoided. The rubbery state of the material provides stress relief, which is beneficial for durability. Silicone materials are also intrinsically durable owing to the strong Si–O chemical bonds in the polymer backbone.

"The ECA must provide reliable contacts and adhesion during the entire lifetime of the module."

The silicone-based ECA *Dow Corning*® PV-5802 was used for the experiments in this work. This ECA is a one-part metal-filled (but lead-free) paste that cures into a 'rubbery' yet highly conductive solid (resistivity < $4\times10^{-4}\Omega cm$) after a few minutes at 150°C. It has been designed to be compatible with OSP-covered Cu foils, providing good adhesion and low contact resistance on OSP-finished CBSs. As anticipated, the material showed a low elasticity modulus, even at freezing temperatures, in contrast to some organic ECAs (Fig. 3). Early tests with four-cell mini-modules had previously indicated that the behaviour of mini-modules using PV-5802 in thermal cycling was indeed outstanding, demonstrating a degradation of less than 1% after 600 thermal cycles [6].

## Results and discussion

The modules produced as described above turned out to have a uniform high quality. The CTM power loss was very low (no higher than 0.3%); for many modules it was actually negative (which means that, going from cells to module, there was in fact a power *gain*). Although it varies depending on the specific module materials and module designs, the CTM power loss of traditional modules is typically of the order of several percentage points. Back-contact modules with CBSs often have a CTM power loss of around 1%. The fact that the present modules show an even lower CTM power loss of around 0% is attributed to the low contact resistance provided by the particular ECA that was used.

Illuminated *I-V* data for the modules in the second series are shown in Table 1; the data are for full-size (including frame) light-soaked modules, and measurements were taken at an independent testing institute. An average module power of 257.4W was obtained, and there was a narrow power distribution. Because of the low surface area of the modules compared with traditional modules (low spacing between cells and no bussing area), the efficiency is very high for industrial multicrystalline Si modules. The electroluminescence images were uniform and did not reveal any issues (Fig. 4).

In order to further enhance its PV module offering, Tianwei is continuously improving its solar cell technology. MWT technology enables cell efficiency gain to be directly translated into module power gain. Table 2 shows the results of more-recent modules that were made using cells with 17.8% average efficiency. For the best module, a maximum power of 266W was obtained, with again very low standard deviation; the corresponding efficiency of 16.8% is outstanding for an industrial-type multicrystalline module.

A good initial module performance is of course not sufficient to guarantee a high-quality PV product: the behaviour under accelerated ageing is at least as important. The results of damp-heat and thermal-cycling testing are shown in Figs. 5 and 6. It is immediately apparent that the modules comfortably pass the requirement of less than 5% degradation after 1000h of damp heat and 200 thermal cycles, as prescribed by IEC 61215. In fact, the observed

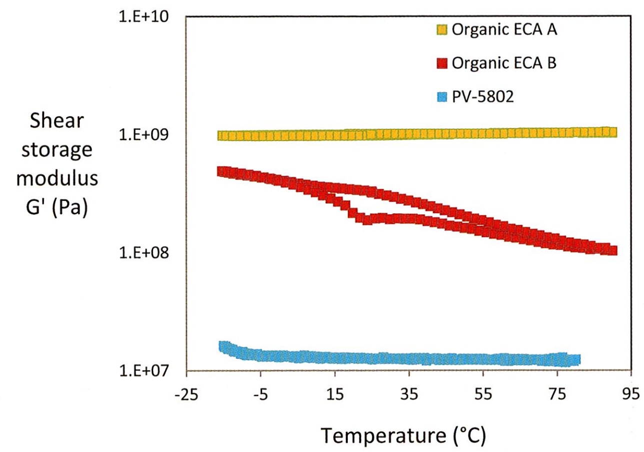



Figure 3. Dynamic mechanical analysis of three cured ECAs. Organic ECA A is very stiff throughout the operating temperature range. Organic ECA B has a strongly varying modulus depending on the temperature. Dow Corning PV-5802 demonstrates a low modulus throughout the entire relevant temperature range.

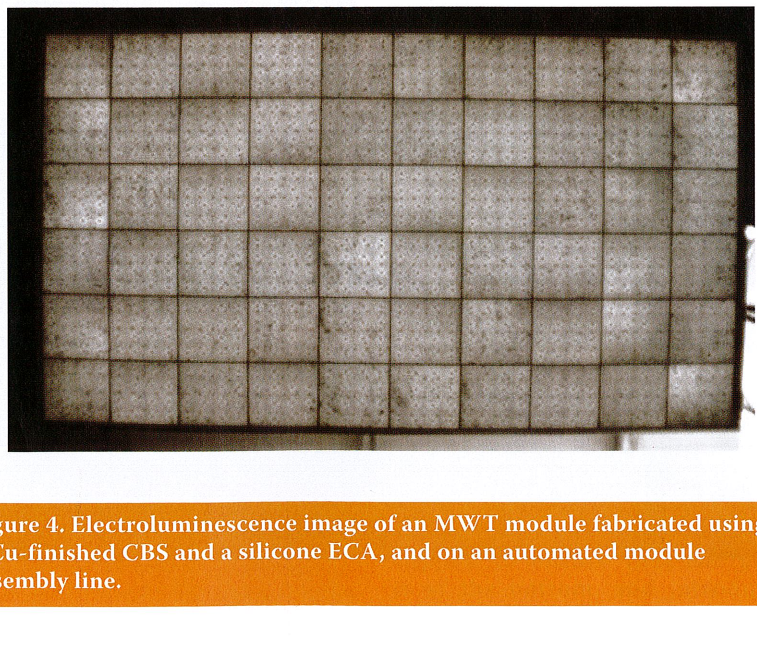


Figure 4. Electroluminescence image of an MWT module fabricated using a Cu-finished CBS and a silicone ECA, and on an automated module assembly line.

| | $V_{OC}$ [V] | $I_{SC}$ [A] | $FF$ [%] | Eff. [%] | $P_{max}$ [W] |
|---|---|---|---|---|---|
| Average | 37.62 | 9.12 | 75.0 | 16.2 | 257.4 |
| Best module | 37.61 | 9.11 | 75.3 | **16.3** | 258.1 |

**Table 1. Illuminated *I-V* data for MWT modules (independently measured after light soaking; full-area efficiency; module area = 1.588m$^2$).**

| | $V_{OC}$ [V] | $I_{SC}$ [A] | $FF$ [%] | Eff. [%] | $P_{max}$ [W] |
|---|---|---|---|---|---|
| Average | 37.95 | 9.11 | 76.8 | 16.7 | 265.6 |
| Best module | 37.97 | 9.12 | 76.8 | **16.8** | 266.0 |

**Table 2. Illuminated *I-V* data for MWT modules made using high-efficiency MWT multi-cells (internal measurement; full-area efficiency; module area = 1.588m$^2$).**

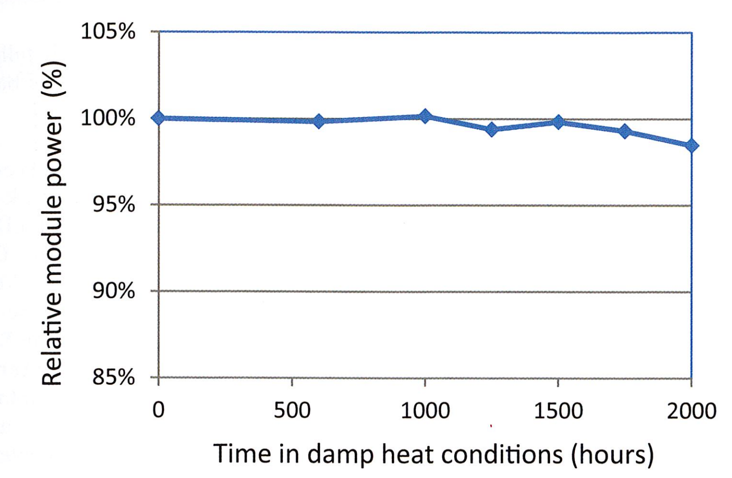



**Figure 5. Relative power of an MWT module as a function of time in damp heat testing conditions (85°C, 85% relative humidity).**

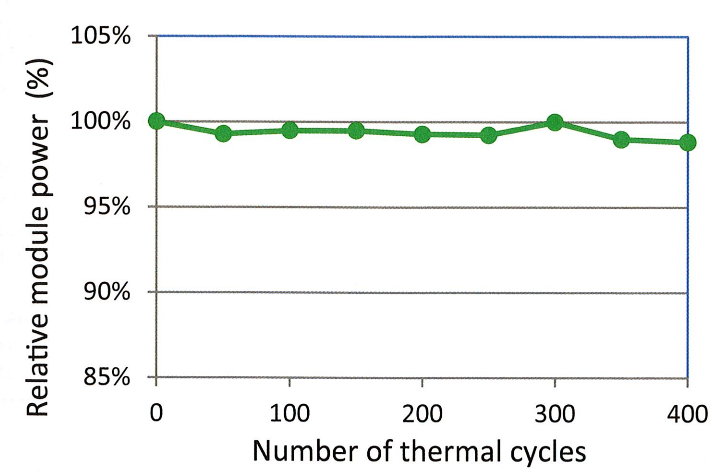



**Figure 6. Relative power of an MWT module as a function of the number of thermal cycles (–40 to +85°C).**

degradation after 1.5 × IEC requirements is still minimal, at well below 0.5%. There seems to be an onset of degradation from 1750h of damp heat, but it is still only 1.5% after 2000h.

As for thermal cycling, the degradation is 1.2% after 400 thermal cycles but a steady degradation does not yet appear to have kicked in. The overall conclusion is that the modules show excellent stability under extended accelerated ageing, which is evidence that the module assembly method and the bill of materials selected result in high-quality, highly durable modules.

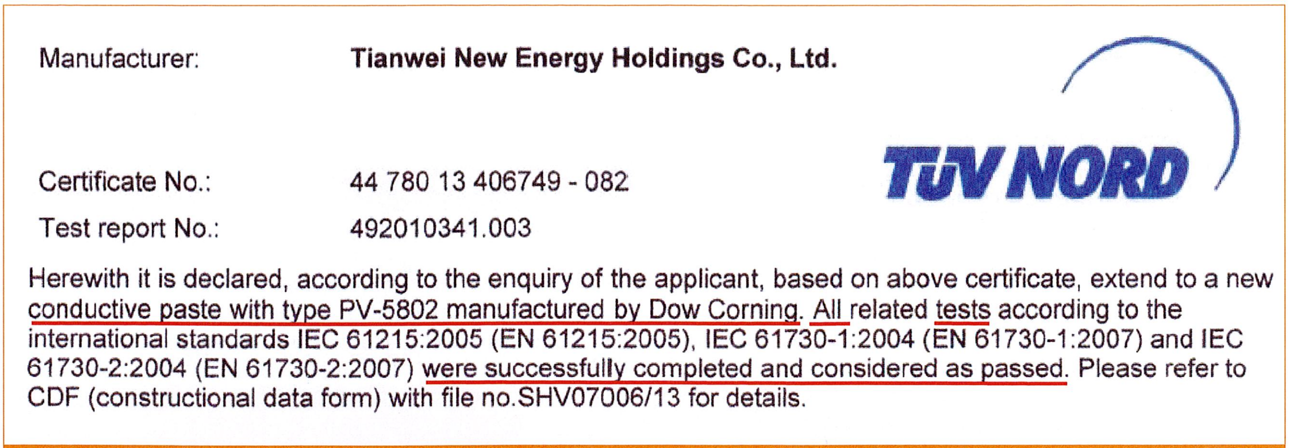
Consistently with these observations for the modules made in the initial run, the modules made afterwards, and which were sent to TUV Nord for IEC certification, behaved well in the various tests. As a result, the testing institution issued an official document certifying that this type of module with this bill of materials complies with the IEC61215 and IEC61730 requirements (Fig. 7).

The excellent durability observed for this type of module is equivalent to that of high-quality modules made using traditional cell and module technology. This is an important breakthrough for MWT module technology. On many occasions, doubts have been raised about the durability of MWT modules, and the scarce durability data available could only provide limited reassurance. The emergence of advanced materials specifically developed for the application, in combination with state-of-the art assembly equipment, is leading to a new phase in MWT technology deployment, where poor reliability is no longer a concern.

"The modules degraded very little in accelerated ageing tests, comfortably passing IEC requirements."

## Conclusion

The results of MWT module fabrication using a silicone ECA, an OSP-finished CBS and an automated MWT module assembly line have been presented. High-efficiency multicrystalline Si modules were obtained, with a power of up to 266W and an efficiency of 16.8% thanks to low CTM power losses. The modules degraded very little in



Manufacturer: Tianwei New Energy Holdings Co., Ltd.

Certificate No.: 44 780 13 406749 - 082

Test report No.: 492010341.003

Herewith it is declared, according to the enquiry of the applicant, based on above certificate, extend to a new conductive paste with type PV-5802 manufactured by Dow Corning. All related tests according to the international standards IEC 61215:2005 (EN 61215:2005), IEC 61730-1:2004 (EN 61730-1:2007) and IEC 61730-2:2004 (EN 61730-2:2007) were successfully completed and considered as passed. Please refer to CDF (constructional data form) with file no.SHV07006/13 for details.



**Figure 7. Excerpt of the certificate for the MWT modules fabricated using an automated module assembly, a CBS with OSP-finished Cu foil, and a silicone ECA.**

accelerated ageing tests, comfortably passing IEC requirements, and with degradation well below 2% after 2 × IEC requirements. Another set of modules was sent to an external testing company and passed all the tests: as a result, an IEC 61215 and IEC 61730 certificate was delivered for this type of module.

## Acknowledgements

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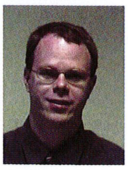

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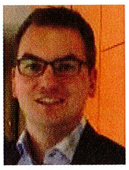

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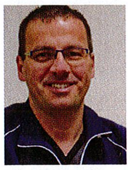

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