Adapting conventional tabbing–stringing technology for back-contact solar cells and modules

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ABSTRACT
In anticipation of the expected increase in the use of back-contact cells in future PV modules, a number of different concepts have been proposed. This paper focuses on one approach that aims to stay close to conventional solder-based technology (tabbing–stringing) while still allowing the use of back-contact cells (which have more complex back-side metallization schemes). The advantages and disadvantages of such an approach are discussed, and the development of this technology is described in terms of process flow, materials, characterization and reliability.

Introduction

The current standard technique for manufacturing crystalline Si PV modules is based on two-side-contacted cells and has been widely adopted. The method consists of first interconnecting the separate cells into strings by soldering ribbons from the front of one cell's contacts (tabbing) to the contacts on the back of the neighbouring cell (stringing). The strings are then interconnected and laminated between a transparent glass or polymer front sheet and a glass, metal or polymer back sheet using an encapsulation material, the most common being the cross-linking material ethylene-vinyl acetate (EVA).

However, with the drive towards higher efficiencies, several different concepts for silicon back-contact solar cells have been proposed, investigated and developed. Well-known back-contact cell concepts include the emitter wrap-through (EWT) and the metallization wrap-through (MWT), which rely on cross-sectional conduction using vias in the silicon to draw the current out of the front-side active area. As an alternative concept, interdigitated back-contact (IBC) cells have both polarities at the back through an interdigitated grid.

All back-contacted cell concepts aim to avoid optical shadowing effects by reducing the front-side metallization. For each type of cell, different layouts have been developed, resulting in various module interconnection and integration flows [1]. It is important to note that since all cell contacts are on the same side, there is an increased risk of shunting during interconnection when the second-level (interconnection) metallization is applied. To avoid shunting, alignment is more critical, and (whenever the interconnection metallization has to cross the metallization with opposite polarity on the back side of the cell) an additional insulating layer is essential.

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MWT interconnection methods

A method for fabricating modules with MWT cells is discussed in this paper. For these types of cell, two main groups of module interconnection flows are currently in competition: 1) technologies based on the use of integrated backsheets; and 2) interconnection schemes much more closely related to conventional module (stringing) technology as described earlier.

Both schemes allow a larger cross section of conductors between cells, resulting in lower efficiency losses at the module level. For both groups, the use of an insulating layer between the connectors and the metallized back side of the cell is needed to avoid shunting cells. In practice this suggests the use of an insulating layer with holes that must be positioned over the back side of the cell in such a way that they face

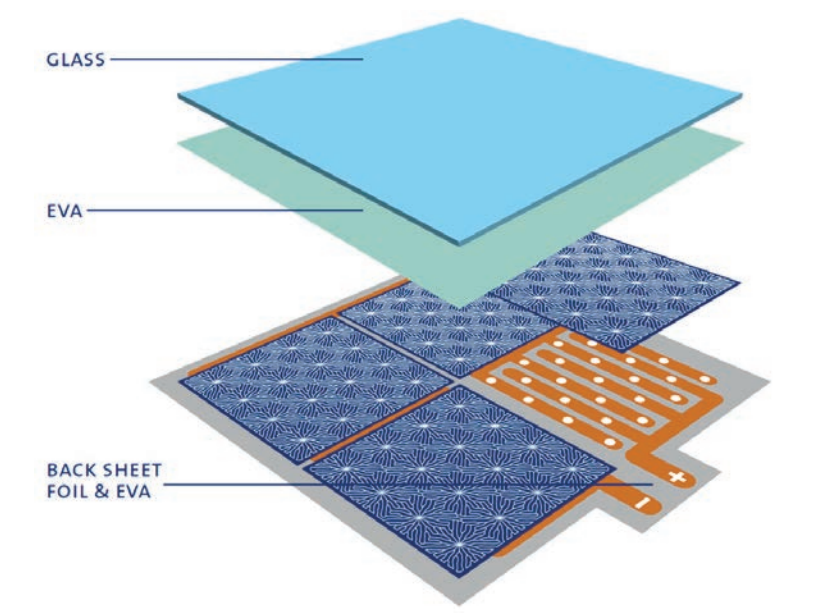

Figure 1. Schematic expanded view of the integrated backsheet approach.

the contact points of both polarities in order to allow electrical connection to the second-level (module-level) interconnection metallization. The making of the holes and the alignment of the insulating layer are two operations.

In the case of the first group, based on integrated backsheet approaches, all current flows through a patterned laminated copper foil with integrated electrical circuitry, which also incorporates the laminate films required at the back side of the module to protect the strings inside from the environment. The typical build-up of such technologies is shown in Fig. 1 [2]. Of interest in this group of technologies is the limited cell-level handling and process steps, as both lamination and interconnection of the cells could take place during the same step. Moreover, only one alignment step is necessary to align the backsheet with conductors to the cells. On the downside, dysfunctional cells or cell strings cannot be measured or replaced after interconnection, owing to the integrated approach of lamination and interconnection. The integrated backsheet also has a more complex build-up than that of a standard backsheet (in that it requires patterning and alignment of conducting and insulating layers), which leads to higher costs. Both (low-temperature) conductive adhesives and solders can be used for electrical connection of the cells with the integrated backsheet.

With the second group, consisting of interconnection schemes similar to conventional stringing approaches, separate MWT cells are first interconnected with ribbons into strings by soldering, ensuring that insulation is present between cell metallization and ribbons wherever shunting might be an issue. This insulation layer can be applied to the cells as part of the cell process by incorporating a dielectric at the cell level, or by laying up an insulating sheet [3]; in either case, a patterning and alignment operation is required. The stringing is then followed by a lay-up step, in which all strings are aligned and interconnected with end (bussing) ribbons. Since the strings are electrically connected before module lamination, defective strings can be traced and repaired or replaced, reducing yield losses after lamination. On the downside, these technologies, of course, require more cell-level handling, increasing the risk of cell breakage, especially in view of the trend towards thinner cells.

Approach, process flow and steps

In this paper a technique belonging to the second group – i.e. based on stringing technology [4] – is investigated. For this approach, a woven glass fibre sheet is used as an insulation layer, which covers the entire area where shunting between ribbon and cell metallization might be an issue. Electrical connection is established only where conductive material penetrates the fibre sheet. This can be achieved by applying solder paste locally to the contact pads of the cell; this process then replaces the patterning and alignment operations for the insulation layer. The main difference with this technique compared with standard technology for stringing two-side contacted cells is clearly the addition of a woven glass fibre insulator. Fig. 2 schematically gives an overview of the process flow. The technology developed for this approach is described in detail in the following process steps, numbered as shown in the figure.

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Step 1: The MWT cell (description)

MWT back-contact cells (156mm × 156mm) from Photovoltech were prepared from monocrystalline silicon wafers according to the process described in Van Kerschaver et al. [5], wherein the contact points to the two oppositely doped regions are placed on the back-side surface. As shown in Fig. 3, the back side of the cell consists of a non-solderable aluminium coating, and six rows of solderable silver contact points. The first, third and fifth rows

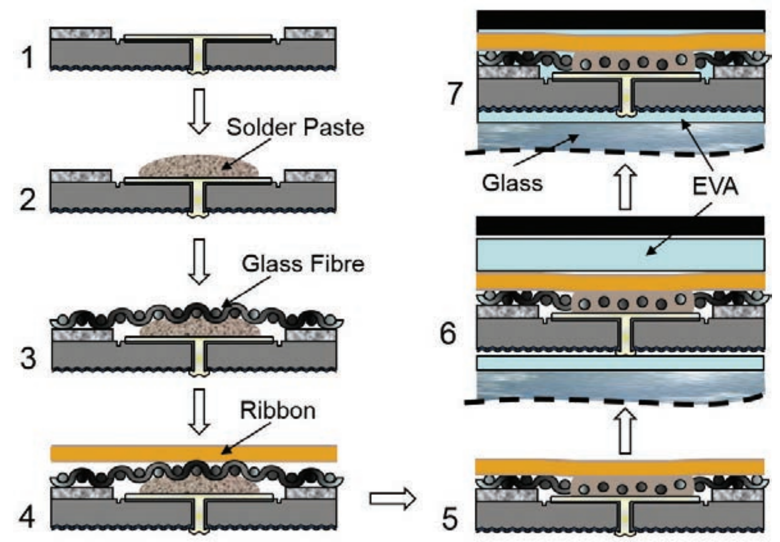

Figure 2. Schematic overview of the process flow.

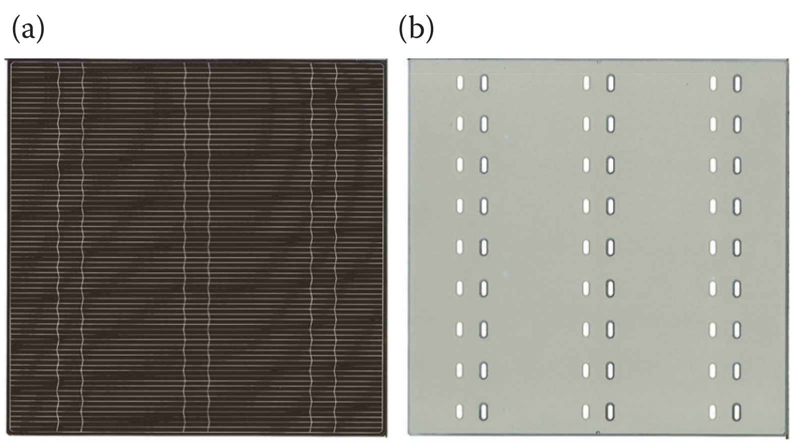

Figure 3. Front-side (a) and back-side (b) appearance of the Photovoltech MWT cells used.

(Fig. 3(b)) provide the emitter region with nine solderable contact points, connected through vias to the fingers on the front (illuminated) side and surrounded by a groove in order to be electrically isolated from the aluminium metallic layer. The second, fourth and sixth rows are solderable contact points for the back-side base region.

Step 2: Solder paste dispensing

Drops of solder paste are deposited on all cell contact points by fluid dispensing. The solder paste consists of a no-clean (NC) flux basis containing Sn/Pb/Ag alloy powder; this was selected because of its versatility in soldering to the alloy covering the connectors and its resistance to the later step of EVA lamination. The amount of solder paste is adjusted according to the thickness of the insulating layer which will be applied in the next step.

Step 3: Laying a uniform layer of insulating fabric material

A uniform layer of woven electrically insulating fibres is applied to the back side of all the cell strings, each consisting of 11 cells. The plain weave fabric with a black finish is texturized, and no special openings are made in the fabric after its manufacture. In order to cover the connectors in the space between the cells for aesthetic reasons, the fabric weaving is denser outside the cell area. The fabric covers the entire surface of the cells and is made of glass fibre material. No alignment of the fabric is necessary, since no pattern with openings is created for placing on each contact point. The material is resistant to the temperature required for soldering as well as for the later lamination (encapsulation) step. Examples of such a fabric are shown in Fig. 4.

As this insulator is the main differentiator of this technology from standard tabbing–stringing technology in terms of materials, the choice of woven glass fibre for the insulating fabric material will be examined in greater detail. First, it is already used for various purposes in solar panels and exhibits excellent physical properties that will contribute to the dimensional stability and reinforcement of the modules. Furthermore, woven glass fibre has excellent electrical insulation chemical properties, being essentially inert (moisture-resistant, no outgassing) and fire-resistant. Finally, and rather importantly, depending on the type of glass fibre fabric, it can be relatively inexpensive.

Several basic variables must be considered when selecting a woven glass fabric. Different glass compositions are available; for the purpose in hand, E-grade glass is preferred. Yarns are composed of continuous filaments, which guarantees a constant quality and thickness of the weave. The average filament diameter and the strand count can be chosen within a certain range; these variables will partly determine the total thickness of the weave.

For this application, a plain weave pattern is used. The fabric density differs outside the cell area: it is lower to save on fabric material where it is not needed, and higher to provide some covering of the connectors in the spaces between the cells, which prevents unwanted reflection of the sunlight by the connectors and contributes to the aesthetic appearance of the module.

Woven glass fibre fabric can be used with no finish; however, when larger openings are desired, it is useful to have some weave lock applied to the fibres to improve dimensional stability. The weave-lock material is selected for its chemical compatibility and for its ability to guarantee sufficient adhesion with the EVA encapsulating material used in the preparation of the solar panels. The mesh openings in the insulating layer are small with respect to the size of the contact points and of the ribbon connectors, but large enough for the solder to flow through

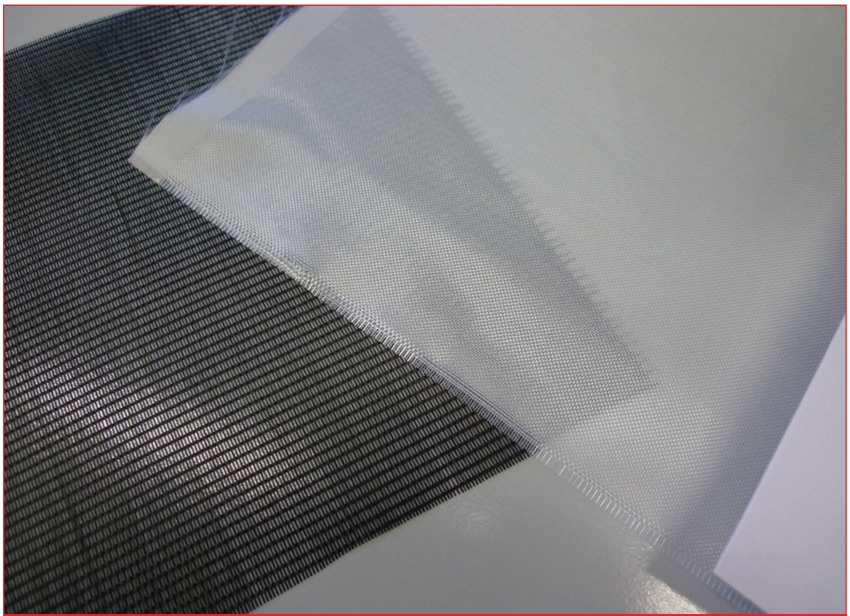

Figure 4. Examples of woven glass fibre fabric material (black version left, white version right) which can be used for the insulating layer.

Figure 5. Wide copper ribbons with preformed expansion bends.

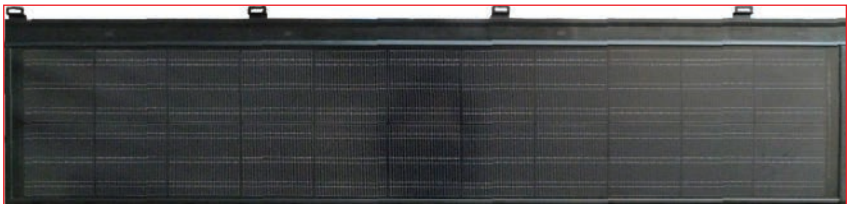

Figure 6. Photograph of the resulting modules.

	I_{sc} [A]	V_{oc} [V]	FF [%]	P_{mpp} [W]
Cells (class 1800 data)	9.21	0.62	76.8	4.41
Module average (of 8)	8.75	13.76	76.4	91.91
Best module	8.79	13.80	76.8	92.60

Table 1. Performance of the resulting modules.

the openings. The colour of the weave lock is also customized to produce a uniform appearance of the module after lamination. The glass fibre can be texturized to give it a denser and even more uniform appearance.

Step 4: Alignment of ribbons

The connectors are standard solderable ribbons, consisting of 80µm-thick and 6mm-wide strips of copper covered with a thin (9µm) coating of tin–silver solder to ensure optimal soldering. Expansion bends, as illustrated in Fig. 5, are preformed on the ribbons for relieving stress on the cells after the soldering step. The tinned copper ribbon connectors are aligned over each of the six rows of contact points, spatially separated by the fabric material from the back-side surface including the contact points.

Step 5: Soldering

The cells are heated in a semi-automatic solder tool with adapted solder heads, and an automatic contact soldering process is then applied on top of each contact point with light pressure to ensure good contact between the layers. Local pressure on each solder point is distributed by the ribbon and the underlying glass fibre tissue, thereby protecting the cell.

During this step, the solder paste melts and passes through the mesh openings in the woven fabric, while the connector and the contact points remain spatially separated by the fabric; this results in an electrical connection that penetrates the fabric only in those locations where solder paste was present. In places where no solder paste has been applied and a soldering step took place, the fabric will serve as an insulating material and as a spacer, thus preventing shunts and undesired electrical and mechanical connections, and remaining physically unaffected.

The temperature is set to avoid any melting of the solder on the connectors, but sufficiently high to promote melting and reflowing of the solder paste; this is possible since the ribbon's solder coating possesses a higher melting temperature than that of the solder paste because of the absence of Pb in the alloy. Since surface tension (and adhesion) of the solder on silicon and aluminium is very low, possible solder drop spills that would partly extend the silver contact pads retract within the confines of the silver contact pads, resulting in a self-alignment process and thus a reduced risk of shunts.

Step 6: Lay-up and interconnection of strings

Eleven identical cells are connected in series as described in the previous steps to form a string. The modules prepared here each consist of two strings. After these strings have been prepared, they are placed on the front-side EVA-lined solar-grade glass of a solar panel, and the individual strings are connected with end (bussing) ribbons. To finish the lay-up, the rear-side EVA encapsulant sheet and protective black back-side foil are then put in position. These two sheets have two punched holes to allow feed-through of the interconnectors to the junction box. This step is similar to a traditional lay-up of standard cell strings made of front- and back-side contacted solar cells.

Step 7: Lamination

During the subsequent lamination of the cell strings into a solar panel, the fabric, ribbons and cells are embedded in the EVA encapsulation material. The fabric provides additional dimensional stability to the encapsulation material in addition to reinforcement of the solar panel.

Results – characterization and reliability

In total, eight single-cell modules were prepared according to the above-mentioned process flow. Preliminary electrical evaluation tests on these modules showed a loss in fill factor of about 1% compared with the standalone cell. The dense fabric outside the cell area gave a uniform black appearance to the module after lamination. All measurements on the laminated modules were carried out under standard conditions [6].

> "The connection technology provides both excellent electrical insulation and electrical conduction."

A photograph of the modules is shown in Fig. 6; the performance of the best one is presented in Table 1. Although the data for the actual cells used is not available, the cell class performance data is included to give an indication [7]. The high value of 76.8% for the fill factor demonstrates that the connection technology provides both excellent electrical insulation (so a reduction in shunt resistance is avoided) and excellent electrical conduction (the increase in series resistance is minimized).

Reliability testing was also carried out on the modules. As an example, Fig. 7 shows the evolution of power and

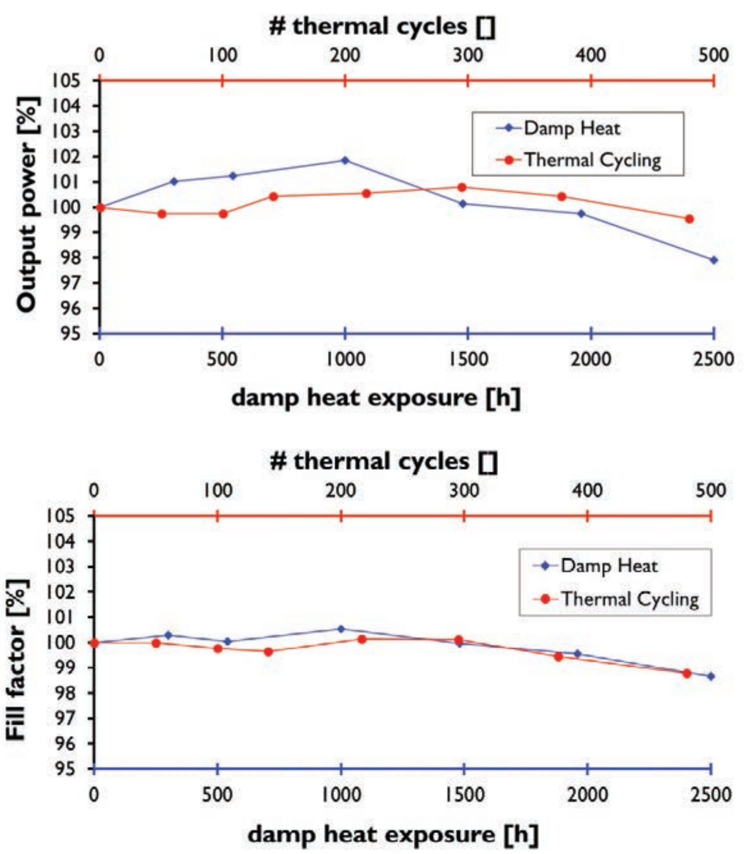

Figure 7. Evolution of power and *FF* for modules subjected to thermal cycling and damp heat.

Figure 8. Automated tabber–stringer system for back-contact cells, including paste dispensing, glass fibre fabric lay-up, hot air soldering, and EL testing of the fabricated strings.

FF of the average of two modules that were subjected to thermal cycling and of two modules that were subjected to damp-heat conditions. For reference, IEC standard testing specifies a pass/fail criterion of a drop in power of a maximum of 5% after 200 thermal cycles or after 1000 hours of damp heat.

The modules were also submitted for, and passed, full IEC certification testing [8] at Eliosys. This also indicates the promising potential of this technology in terms of the reliability aspect.

"The next step is upscaling and automation."

Conclusion and outlook

A concept for manufacturing modules from back-contact solar cells has been proposed and demonstrated. Considering the promising potential of this technology in terms of performance, cost and reliability, the next step is upscaling and automation. To this end, an automated tabber–stringer has been acquired and custom modified: the system is shown in Fig. 8. After hook-up and installation, initial testing will begin..

References

[1] Govaerts, J. et al. 2012, "An overview of module fabrication technologies for back-contact solar cells", *Photovoltaics International*, 17th edn, pp. 112–116.

[2] Solland 2011, Sunweb Module Datasheet, August.

[3] Eitner, U. et al. 2013, "Progress in HIP-MWT module technology", Presentation 5th MWT Workshop, Freiburg, Germany.

[4] Borgers, T. & Szlufcik, J. 2011, "Use of a uniform layer of insulating material in back-contact solar cells", Patent WO2012059534.

[5] Van Kerschaver, E. et al. 1998, "Solar cell and process of manufacturing the same", Patent WO1998054763.

[6] IEC 61853:2007, "Photovoltaic module performance testing and energy rating".

[7] Photovoltech 2012, DSM008 MAXIS BCT156AE Preliminary Datasheet, February.

[8] IEC 61215:2005, "Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval".

About the Authors

Tom Borgers joined imec in 2000, working on III-V detector technologies and developing a flip-chip approach for megapixel infrared sensors. He switched to the field of photovoltaics in 2008, when he began working for Photovoltech. His interests lie in back-contact solar cell concepts, specifically the development of module technology. In 2012 Tom joined imec's reliability and modelling group, and currently works in the Si PV group, focusing on module interconnection technology.

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Jef Poortmans received his degree in electronic engineering from the Katholieke Universiteit of Leuven, Belgium, in 1985, and his Ph.D. in June 1993. He is the director of the Solar and Organic Technologies Department at imec, and is currently director of the SOLAR+ strategic programme, which comprises all the PV technology development activities within imec. Jef has also been a part-time professor at the Katholieke Universiteit since 2008.

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