Current status and future potential of back-contact (BC) module technology

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ABSTRACT

This paper describes the technical concepts and current status of back-contact module technology. A back-contact module has the advantage of a higher conversion efficiency because of less shading of the front of the cell, fewer inactive areas in the module and lower series resistance in the interconnection. Aesthetically, back-contact modules are more attractive than standard modules. Furthermore, module manufacturing is gentler due to there being less cell handling during the process. The two main technical concepts related to back-contact modules – interconnector technology and printed circuit backsheet technology – are discussed in this paper. An overview is given of the production status of current back-contact module manufacturers to also show the significant potential of this technology in economic terms.

Why back-contact technology?

Module efficiency

The most efficient modules available on the market use back-contact (BC) technology. Sunpower has recently displayed modules reaching 20.4% efficiency powered by their current generation of 22.9% efficient Maxeon IBC (interdigitated back-contact) or BC-BJ (back-contact back-junction) cells.

What makes back-contact modules more efficient? Module efficiency is determined to a large extent by cell efficiency. By turning to BC technology, relative efficiency gains of 2–4% can be reached at the cell level, depending on the specific BC technology. This gain is mostly due to the fact that BC cells partially or totally avoid optical shading by front metallization: all contact pads for cell interconnection have been moved to the rear of the cell. However, up to 20% of relative module efficiency is determined by module technology, meaning cell interconnection, encapsulation and module design aspects. Overall, these effects lead to an efficiency loss of 10–15% from cell to module for conventional FBC (front-back contact) cells.

BC module technology can do better. Because of the rear contacts, cell interconnectors do not shade the cells and can be optimized to strongly reduce serial resistance losses in the string. They can also be optimized to use conductive material (copper) more efficiently than the conventional flat ribbons for FBC cells. By adjusting local conductive cross-section to the varying local current, leading to tapered cross-sections, 25% of the copper can be saved without losing power. This adapted increase of conductive cross-section can result in a 2–4% relative efficiency gain, attributable to the switch to BC technology.

Since the cells have all their contacts on the back side, the interconnection of strings can be moved more easily behind the cells, and the cell distance can be reduced by 1–2mm. This reduction of the inactive module area provides a relative efficiency gain of around 3–4% at the module level, since efficiency takes into account total module area.

Adding up all these effects – cell efficiency gain, reduced inactive area and reduced stringing serial resistance loss – leads to a relative module efficiency gain of approximately 10% in favour of BC technology. The relative module power gain only amounts to approximately 6%, since it does not profit from the reduction in inactive module area.

Module cost

At the cell level, switching to BC technology requires 2–3 additional process steps, for example laser drilling for MWT (metal wrap through) and EWT (emitter wrap through) technology or contact isolation. The related additional costs seem low enough to be almost matched by the gain in efficiency at the cell level. Consequently, the specific price in €/W remains relatively constant.

BC technology is seen as a means of introducing very thin solar cells into module production. BC module samples have been successfully produced using 120µm cell and conductive adhesives [1]. Because of the SMD (surface mounted device)-type process flow, the cells only need to be handled once or twice to get to their final position in the module. The use of special interconnectors and joining materials, again made possible by the rear-contact design, can reduce thermo-mechanical stress in the cell.

As soon as it becomes possible to manufacture very thin solar wafers and cells with satisfactory production yield, the associated cost saving can then be attributed to BC technology. Approximately 60–65% of conventional module cost is associated with the solar cell. At the module level, BC technology is not yet evident as a cost saver in terms of material costs, which are the largest share of the module manufacturing costs. Structured interconnectors are more expensive than flat wires, and in the PC approach (printed circuit on backsheet) it is not yet clear to what extent cost savings can be achieved by high volume production.

In module production, cost savings appear to be possible by introducing a high-throughput manufacturing line with a low footprint compared to conventional lines. A very important factor will be the production yield compared to conventional lines. The reduced cell handling in a BC module production line may help to reduce cell breakage and thus improve the yield.

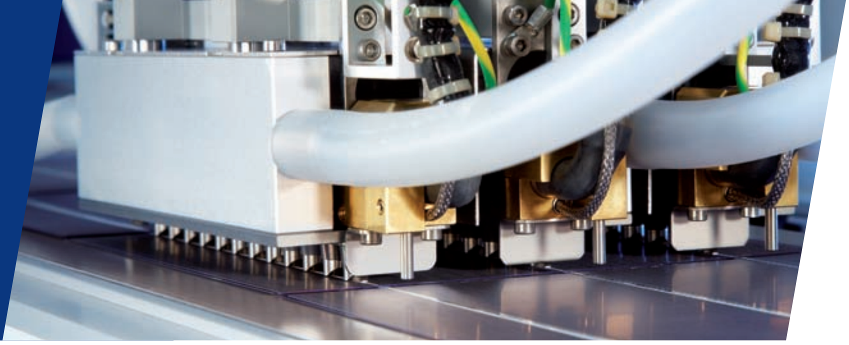
Module aesthetics

BC technology has been recognized as a candidate with a high potential for use in building-integrated PV (BIPV) [2]. The reasons for this are the strong reduction (or total lack) of metallic reflections on the cell, the strong reduction of inactive (white) area throughout the module and even the possibility of designing customer-specific metallization patterns on MWT cells that also consider aesthetic aspects. Maximizing efficiency has the side effect of minimizing visual interference.

Cell types and interconnection challenges

For the process of string production, the contact layout of the BC cell is critical [3]. IBC cells typically have their contacts located on two opposite cell edges (Fig. 1). The cell metallization itself has to carry an increasing amount of cell current over the whole cell length; this can limit feasible cell formats. An MWT cell only collects current locally at the cell level by contact pads, which are distributed evenly over the total cell area.

IBC interconnectors only have to bridge a small distance (approximately 5mm) in between cells (Fig. 2). They need to provide



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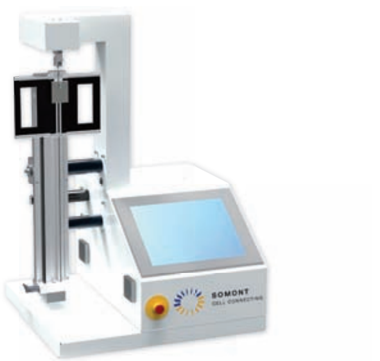

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mechanical stress relief in between cells against loads originating from temperature changes and module deflection. On cells with distributed contacts, the interconnector is supposed to collect the current from the contact pads and carry it towards the cell edge. The interconnector cross-section is critical for serial resistance losses. The interconnector design has to provide stress relief not only in between cells, but also in between contact pads on one cell. A tapered design adapts the cross-section to local current.

Power losses due to stringing series resistance can be significantly reduced by increasing the amount of copper per cell and optimizing the interconnector design (Fig. 3). In current MWT cell designs the interconnector that contacts the emitter pads needs to cross over the base metallization of the same cell, requiring an isolating layer. This layer may be either an isolating coating that is selectively applied to the solar cell by screen printing or an adapted encapsulant material.

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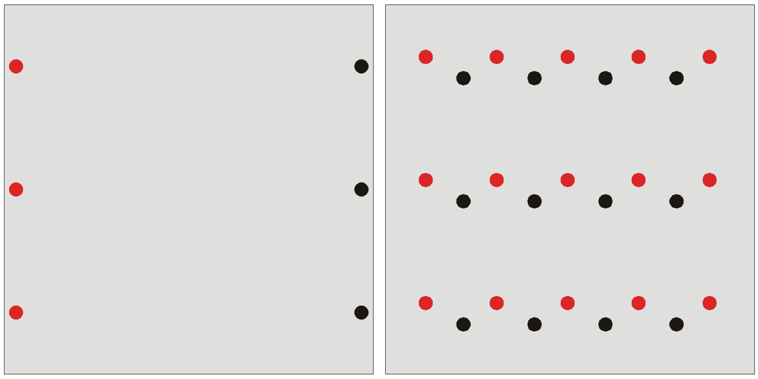

Figure 1. Schematic view of BC cells with edge contacts (left) and distributed contacts (right).

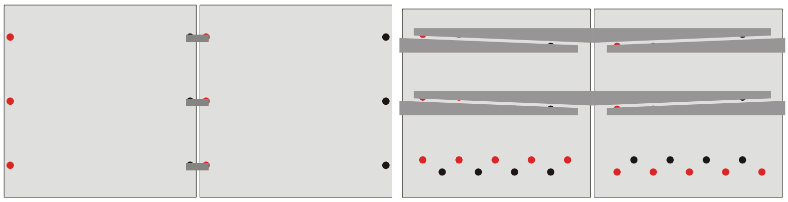

Figure 2. Interconnection schematic for cells with edge contacts (left) and distributed contacts (right).

Different designs of single and multiple bows have been proposed for stress relief [4]. Optimal design ensures a compromise between ohmic resistance due to bow length and mechanical stiffness. If MWT cells are interconnected with conventional flat ribbon wires and conventional soldering tools, the mismatch in thermal expansion between copper and silicon leads to cell bow. Additionally it is difficult to reduce serial resistance losses by increasing or optimizing the conductive cross-section. The metal foil can be structured to provide local stress relief and adapted cross-sections by using a punching tool. Masking and etching PC (printed circuit) strips or PC backsheets allows very flexible configurations [5,6,7].

Different strategies have been suggested for the interconnection process itself (Fig. 4). A pre-lamination joint formation has the advantage of enabling string quality control before irreversible lamination takes place. It requires a dedicated tool, as is the case with post-lamination joint formation. For the latter, laser soldering through the front glass has been proposed. In-lamination joint formation has the appeal of using the laminator additionally as a soldering or curing tool, but this usually requires a preliminary fixation of cell position with respect to the interconnector material and careful tuning of the simultaneous processes.

For joining, solder paste and conductive adhesives have been proposed. Adhesives are filled with silver particles, work out more expensive and provide a less satisfactory conductivity than solder joints. Their advantages include lower process temperature and lower stiffness, both of these properties helping to reduce mechanical stress on the joints and cells.

Reliability

Extensive research has been carried out to assess the reliability of BC modules. At the cell level, the laser-drilled holes and MWT laser contact separation may reduce cell mechanical stability if not properly executed. The mechanical stability of the contact pads also requires special attention.

At the module level, certification according to IEC 61215 and IEC 61730 is effectively mandatory for reliability and safety conformance. In practice, module manufacturers do not rely on these basic tests for new products; they use accelerated-ageing and outdoor-exposure tests that are more robust than those defined by the standard. Thorough testing will increase confidence in module

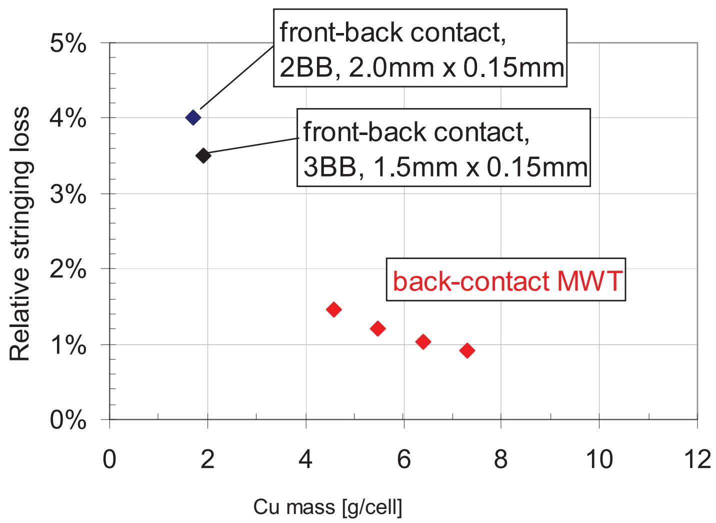

Figure 3. Calculated serial resistance power losses due to cell stringing, I_{mpp} = 8.3A.

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Interconnector material	Interconnection process	Joining material
structured interconnector	pre-lamination	solder paste
PC strips	in-lamination	conductive adhesive
PC backsheet	post-lamination	

Figure 4. Technology choices for BC cell interconnection.

reliability, but it is generally not possible to guarantee a module service lifetime from accelerated-test findings.

BC module technology introduces new interconnector designs, where mechanical and thermomechanical stresses require special attention. Critical tests include mechanical load and temperature cycling. If new materials are additionally introduced, the interaction needs to be studied especially under a damp-heat accelerated-ageing environment. Since there is as yet no long-term reliability evidence regarding any specific BC module technology apart from Sunpower, BC modules have experienced some difficulties on the path to commercialization.

> "BC module technology introduces new interconnector designs, where mechanical and thermomechanical stresses require special attention."

Manufacturing concepts

In principle, traditional pick-and-place assembly steps handling single cells and single interconnectors are feasible for producing BC modules. This is especially true for cells with edge contacts, where only one, relatively small, interconnector per cell is required. The vision behind BC module technology foresees a more elegant process, taking advantage of the SMD character of BC cells to speed up manufacturing. Eurotron proposes a system where the module is assembled sunny side up on a vacuum carrier and then flipped, together with the front glass, into a sunny-side-down position. This stack is then introduced into the laminator for adhesive curing and lamination. The following steps are included (Fig. 5), following layup and fixation of the PC backsheet on a vacuum carrier:

1. Screen printing of joining material (solder paste or adhesive)
2. Layup of a perforated encapsulant (2)
3. Cell layup
4. Layup of a front encapsulant (1)
5. Layup of front glass
6. Flip of entire stack

After the entire stack has been flipped to sunny side down, further processing, including joint formation and lamination, can take place.

Recently a process flow was proposed that requires only a single cell-handling step [4]. The module layup starts with the front glass and a specially structured encapsulant foil is placed on the glass. When vacuum is applied laterally, the structures allow the fixation of the entire cell matrix on the layup (sunny side down). The interconnector material is prepared on a separate vacuum tray and then flipped on the cell matrix. The process sequence of the one layup assembly (OLA) technology is shown in Fig. 6. It consists of the following steps, following layup and fixation of the PC backsheet on a vacuum carrier:

1. Layup of a structured front encapsulant (1) on the front glass
2. Cell layup and vacuum fixation
3. Layup of a perforated encapsulant (2)
4. Screen printing of joining material (solder paste or adhesive)
5. Flip of PC backsheet onto the cell matrix

After the stack has been completed, further processing, including joint formation and lamination, can take place. This sequence may be modified for the use of structured interconnectors not initially fixed to the backsheet. These interconnectors may be preassembled on a vacuum carrier, screen printed with the joining material and then flipped onto the cell matrix. After joint formation, the backsheet can be applied.

Current state of the technology

Interconnector technology

Achieving a module efficiency higher than 20% in production, Sunpower manufactures the most efficient modules available on the market. Their back-contact E20 modules use back-junction back-contact (BC-BJ) cells that have an efficiency of 22.4% and point contacts at the cell edges (Fig. 1). NREL confirmed a record module efficiency of 20.8%, with a fill factor of 77.9%. According to recent publications [8,9], a lot of effort has been taken to lower the power loss from cell to module (18.7% module efficiency in 2007)

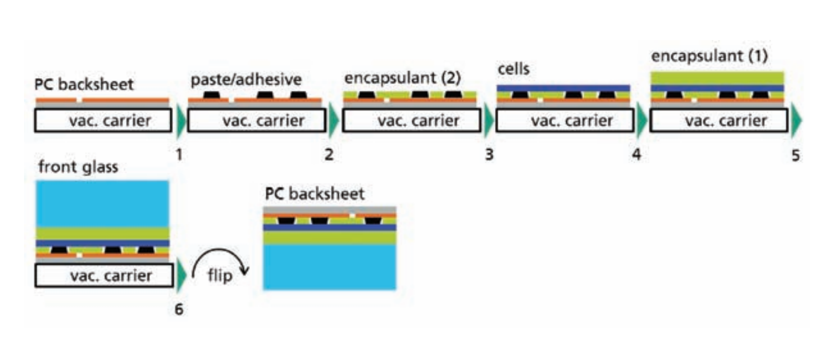


Figure 5. Eurotron layup concept.

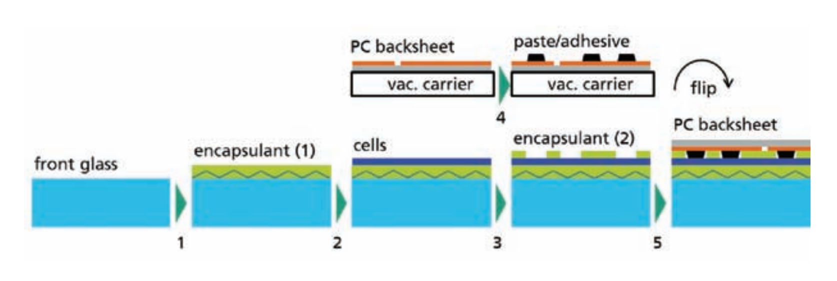
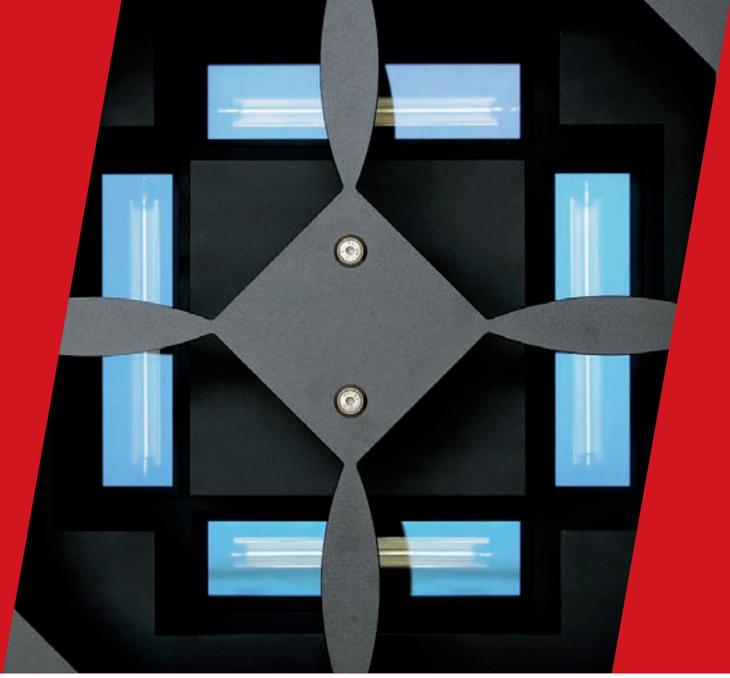


Figure 6. OLA concept.



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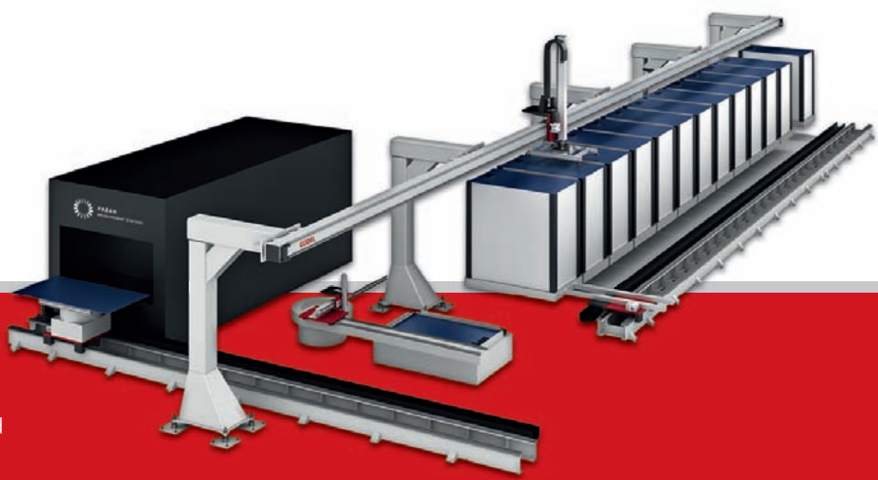

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and investigate the module reliability. Sunpower claims their modules to be long-term stable, showing no degradation in the field and under extended IEC testing. No PID (potential-induced degradation) has been observed. To date, 20MW of E20 modules have been installed, and the current production capacity is planned to reach 116MW in Q4 2011.

The ELPS technology of Canadian Solar is based on MWT cells and a stringing technique with ribbons [10]. For monocrystalline cells, efficiencies of up to 19.2% are reached, leading to module efficiencies in production of 16.2%. Their multicrystalline MWT modules are 15.5% efficient. Canadian Solar deems the concept of back-contact foils to be as yet unproven, while their approach is said to rely on proven materials. However, an easy switch to the conductive backsheet is possible and this manufacturer claims to have passed module certification successfully. Field tests are in progress and a target production capacity of 50MW has been set for the second half of 2011.

Fraunhofer ISE recently reported efficiencies above 18% for multicrystalline MWT cells and above 20% for multicrystalline Cz MWT cells [11]. With optimized structured interconnectors, fill factor losses from cell to module of the order of 1% (relative) have been measured on small modules. For demonstration purposes, MWT cells of 120µm thickness have been connected with lead-free SnAg solder. On account of the special interconnector material, the strings do not show any bow related to thermal expansion mismatches after soldering.

Printed circuit backsheet technology

In a joint development project with Schott Solar, Solland is about to commercialize MWT modules using the conductive backsheet approach. The cells are electrically connected to the conductive backsheet in a laser-soldering step after lamination. Module efficiencies of 16.4% (multi) and fill factor losses of 0.2–0.5% from cell to module have recently been published. Both companies see the potential for transferring the recent success of Schott with monocrystalline material to the MWT technique to achieve higher efficiencies. Regarding long-term stability, 60 modules have been deployed in the field since 2008, yielding results similar to standard crystalline modules: 1% degradation has been observed after IEC testing and 5% degradation after doubling the basic standard test sequences [12]. The pilot line has a capacity of 20MW and pilot production is currently being ramped up. In order to reach cost effectiveness fast enough, Solland is willing to license its technology. As a result, the generated economies of scale will primarily lower the cost of the conductive backsheet.

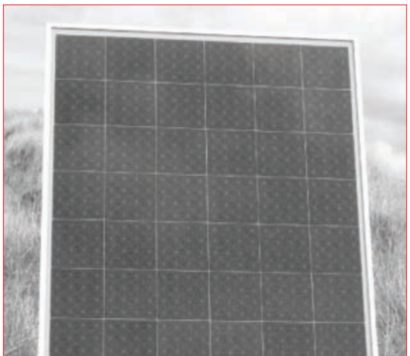

Figure 8. Module sample with MWT cells on a PC backsheet [1].

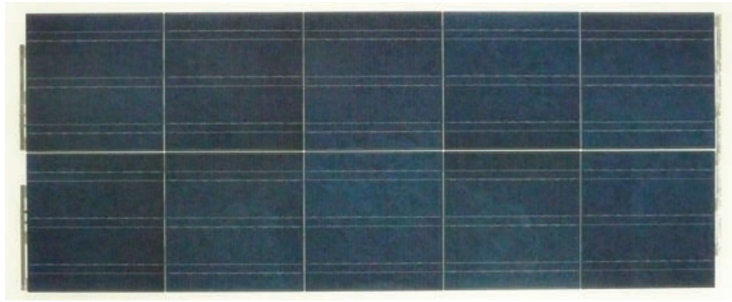

Figure 7. Module sample with MWT cells from Photovoltech and structured interconnectors, manufactured at Fraunhofer ISE.

"Reliability engineering focuses on the use of new materials and the adaptation of certification tests to better reflect degradation mechanisms seen for BC modules with conductive foils."

Current research activities at ECN focus on the module integration of cells with efficiencies above 20%, leading to a module efficiency above 19% (Fig. 8). Other issues are the use heterojunction modules and the transfer of microelectronic interconnection techniques to PV modules. The conductive backsheet concept is promoted in conjunction with conductive adhesives that cure during lamination. Reliability engineering focuses on the use of new materials and the adaptation of certification tests to better reflect degradation mechanisms seen for BC modules with conductive foils. The problem of a higher cost of the backsheet is expected to be solved as more suppliers enter the market. In 2010 ECN first reported the IEC-61215 certification of a type of MWT module manufactured with conductive adhesives and PC backsheets on a semi-automated Eurotron line.

Eurotron, the manufacturer of back-contact module production lines using the conductive backsheet technique, expects the backsheet cost to come down to 10–12€/m^2 in time. In Eurotron's cost scenario, standard FBC modules with a production cost of 1.18€/Wp are still more expensive today than the BC module concept at 1.10€/Wp. A production capacity of 300MW is expected to be operational by January 2012 and Eurotron plans to sell a cumulated production capacity of 1GW by the end of 2012.

Outlook

The potential of BC technology is impressive: a considerably higher module efficiency paired with thin-cell compatibility. Not surprisingly, cell and module manufacturers expect a market share of 40% BC technology by the year 2020 [13]. To facilitate this growth, material costs for BC cell interconnection need to come down or remain low. In the PC backsheet approach, cost reduction is expected to occur with market volume growth. In the structured interconnector approach, the punching step inevitably adds some cost to the simple coated copper foil.

A second factor that will promote growth relates to the expanding pool of experience and comprehensive data from modules exposed to outdoor conditions and accelerated ageing. An important step for proving module reliability has already been taken in the certification of the first types of BC module.

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Harry Wirth received a diploma degree in physics from the University of Freiburg, Germany, in 1995. He subsequently earned his Ph.D. from the École Polytechnique Fédérale de Lausanne (EPFL), and from 1999 he was in charge of the R&D group of a specialized insulating glazing manufacturer. In 2005 he returned to Fraunhofer ISE to set up the Photovoltaic Modules group and was also responsible for the installation of the PV Module Technology Center at Fraunhofer ISE. Since October 2010, Dr. Wirth has headed the new division of Photovoltaic Modules, Systems and Reliability, which is mainly engaged in the development, testing and monitoring of photovoltaic modules.

Ulrich Eitner studied technical mathematics at the University of Karlsruhe (TH). From 2006 to 2011 he worked in the field of thermomechanics of PV modules at the Institute for Solar Energy Research Hameln (ISFH) and obtained his Ph.D. from the University of Halle-Wittenberg in 2011. Since August 2011, Dr. Eitner has managed the Photovoltaic Modules group at Fraunhofer ISE.

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