The status and future of industrial n-type silicon solar cells

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ABSTRACT

According to the ITRPV (International Roadmap for PV), a large fraction of future solar cells will be n-type and rear-contact cells with the highest efficiencies and fabricated using low-cost processes. As the standard p-type silicon solar cell in mass production is completely optimized and has therefore reached its cost limit, it is currently very difficult for new solar cell concepts to be cost effective from the outset when introduced into production. Consequently, in the current market situation, the introduction of new solar cell concepts to the market is not straightforward. The only way to achieve this is to use the fully adapted standard processes employed in today's manufacturing lines and only upgrade them with a few industrially approved process steps – such as laser ablation and boron diffusion – in order to implement low-cost device structures with stable efficiencies well above 20%. This paper gives an overview of n-type cell concepts already present on the market and of promising technologies ready for pilot production; the latter were summarized and discussed at the 3rd nPV workshop in April 2013 in Chambéry, France. The consequences for module manufacturing, as well as for measurement techniques and for requirements in respect of new standardization for cell and module characterization, will also be discussed.

Introduction

In the last 10 years, the PV industry has had to survive three large crises: the feedstock crisis in 2005–2008, the world financial crisis in 2008–2009, and, the most difficult one so far, the large overcapacity of wafer, cell and module producers beginning in 2011. The last one is the most difficult so far and still ongoing; because of consolidation, only the fittest companies and most cost-effective technologies are surviving it.

Fig. 1 shows schematically the known learning curve for PV module prices. The plummet in price is due to sales that are close to, or even below, production costs in the struggle for survival. In 2013, module prices have now fallen to €0.50/Wp on average, so that – apart from the downstream players – actually nobody in the PV business today is making a profit. The period after 2014 is expected to be characterized by a continuous but slow decrease in module manufacturing cost, with the module price stabilizing for a certain time, enabling manufacturers to restore some profit margins. At the same time, balance of system cost is expected to experience a stronger cost reduction, resulting in an overall decrease in the cost of the installed PV system. Compared with the boom period lasting until 2011, characterized by continuous expansion of production capacities all along the value chain, it is now much more difficult to introduce new technologies to the market as the capability of cell producers to invest in the future drops to zero because of the lack of liquidity and of the persisting overcapacity.

At the moment, however, the situation is slightly improving, and the concepts that were popular two or three years ago are gaining interest again, because, after the crises, high-level companies have to be prepared to distinguish their products from standard mass-produced p-type products. This is possible by, for example, introducing n-type technologies that – thanks to the stable and high efficiencies – will enable a significant step forwards regarding the reduction in the cost of electricity (€/kWh) generated by PV.

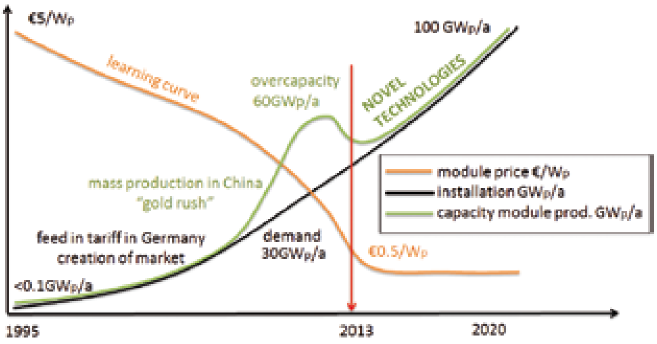


Figure 1. The development of demand, production capacity and module prices over the years and a forecast for the future.

> "The trend is moving towards ion-implanted cells, rear-contacted cells or n-type processes."

In order to significantly exceed 20% efficiency, the trend is moving towards ion-implanted cells, rear-contacted cells or n-type processes. Actually the combination of these three technologies will result in the most cost-effective and powerful device – an ion-implanted, n-type, rear-contacted interdigitated back-contact (IBC) cell with a potential efficiency greater than 23% in mass production. Provided that low-cost processes will be available, the addition of surface passivation by a-Si layers will further enhance the efficiency potential.

In the next section, the challenges and chances for the industrial implementation of n-type solar cell concepts will be considered. This will be followed by an overview of existing technologies, with a focus on diffused screen-printed devices; the specific requirements such devices have regarding suitable *I-V* measurements will be examined. Finally, useful advanced module technologies will be summarized and the future of n-type PV discussed.

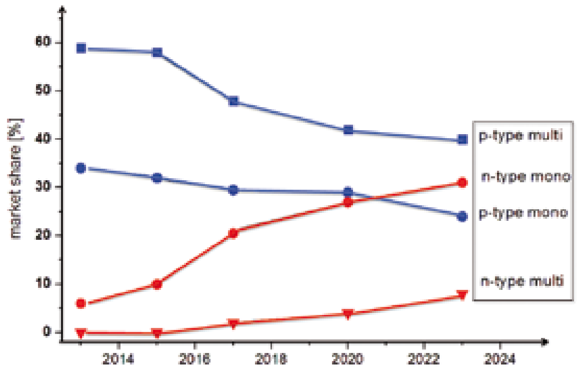


Figure 2. Predicted market share of various Si PV technologies according to ITRPV [2]. The data have been simplified as follows: 'p-type multi' includes 'p-type multi' and 'p-type high-performance mc-Si', while 'p-type mono-like' has been included in 'p-type mono'.

Challenges and chances for n-type cells

Challenges

- Wafer availability and price
- Homogeneous boron diffusion
- Silver consumption
- Dependence on few paste manufacturers

As regards the challenges for n-type PV technology in becoming the leading technology – not only from an efficiency point of view, but also in terms of production cost – an important issue up until now has been the higher sales price of n-type Cz-Si wafers than that of p-type Cz-Si wafers. One reason for this price gap is that certain n-type cell concepts currently implemented in industrial production require a very narrow resistivity range; in addition, some of them require wafers with rather high minority-charge carrier lifetimes (e.g. HIT – heterojunction with intrinsic thin amorphous layer). As the strong segregation effect of P in silicon leads to a larger resistivity distribution within the n-type Si crystal than within B-doped p-type silicon, the requirement of a wafer specification with a narrow resistivity range decreases the wafer production yield and consequently increases wafer cost.

Another important factor is today's small market share of n-type solar cells that prevents n-type Si crystal and wafer producers from benefiting from economy of scale on the same level as p-type manufacturers currently do. As more and more n-type-based cell manufacturing lines are expected to enter into production in the short and mid term (see section 'A look into the crystal ball'), the increasing production volume of n-type wafers will help to close the price gap. Recent news, such as the announcement by Comtec Solar of the construction of a 1GW/year n-type mono ingot and wafer plant in Malaysia (production start in January 2014 [1]), confirms this trend. In addition, upcoming crystal growth techniques, such as continuous Cz-Si pulling (CCz-Si by MEMC/SunEdison – technology from Solaixc, and HiCz by GTAT – technology from Confluence Solar) not only have the potential to enable production of monocrystalline Cz-Si at the cost of cast multicrystalline silicon, but also intrinsically feature the same production cost for n-type doping as for p-type doping, because of the narrow resistivity range the techniques allow for both types.

> "The market share of p-type mono and multi is expected to decrease, while n-type mono particularly will strongly increase."

The ITRPV [2] expects n-type mono to quadruple its market share from today's 5% to 20% in 2017, and to further increase it to 30% in 2023. Fig. 2 clearly shows this trend: the market share of p-type mono and multi is expected to decrease, while n-type mono particularly will strongly increase and, together with p-type multi, will dominate the Si PV market.

Another feature of almost all n-type cell concepts is the fact that the p^+-doped regions are formed by a boron diffusion and not by alloying of Al as in the case of a standard p-type Al back-surface-field (BSF) cell. Consequently, new types of screen-printing metal paste are required that, on the one hand, provide a low contact resistance when applied to the B-doped silicon, and, on the other hand, feature a good electrical conductivity when printed as fingers on, for example, the front-side B-emitter of a bifacial n-type cell. New types of paste for this purpose (in general Ag pastes with a small amount of Al) are now commercially available; however, further developments are required in order to allow the efficiency potential of screen-printed n-type Si solar cells to be fully exploited (see section 'The status of diffused and screen-printed solar cells'), and to reduce the Ag content of these p^+-contacting pastes. Initially, the need for this additional Ag/Al paste causes a greater Ag consumption per cell, leading to an increased Ag cost compared with standard p-type cells. Apart from reducing the Ag content of the pastes, reducing the quantity of paste used for the formation of the busbars, or even eliminating them completely (see section 'Module interconnection'), will significantly reduce the Ag consumption for n-type cells. If the increasing gap between n- and p-type cells in terms of stabilized efficiency is also taken into account, the Ag consumption in g/Wp (and consequently the cost in €/Wp) will further improve in favour of n-type cells.

Chances

- Higher efficiency potential (light-induced degradation (LID), metallic impurities, temperature stability)
- Higher energy harvest (higher sensitivity to low light intensity, bifaciality)

The challenges highlighted earlier are all being tackled by research institutes and companies involved in n-type solar cell process development; n-type technology therefore offers two important advantages, namely a higher *stabilized* efficiency and an increased energy harvest (more kWh/kWp) potential.

> "IBC and the HIT cell concepts both achieve the highest efficiency when using n-type Si wafers instead of p-type."

The potential for higher efficiency is based on the fact that the IBC and the HIT cell concepts – cell designs that are capable of achieving much higher efficiencies than any standard cell design – both achieve the highest efficiency when using n-type Si wafers instead of p-type. A high module efficiency reduces the costs related to the balance of system (BOS) of a PV installation. Consequently, if high efficiency does not come at the price of high module production cost, the cost of the installed PV system can be reduced. It is also important to stress that with increasing market share of n-type, the consideration of *stabilized* efficiency will gain more and more importance. Within the first few weeks after their installation in the field, standard p-type modules lose, because of LID, up to 2–3% of the P_{mpp} value at which they have been sold to the customer. As p-type-based PV modules nowadays represent more than 95% of the PV module market (or nearly 100% when considering just the 'standard' price segment), customers in the current situation have no alternative but to accept this initial power loss. As soon as more n-type-based modules not prone to LID become available, the LID susceptibility of p-type modules, from the point of view of the end-user, will translate into a higher module price (€/Wp) or into a lower energy yield and thus a higher cost of the electricity generated by the modules.

As pointed out and discussed in more detail in the section 'The need for additional measurement standards for bifacial structures', most n-type cells are intrinsically bifacial and can achieve an increased energy yield (kWh/kWp) both in monofacial (standard) and in bifacial module configurations.

Overview of n-type technologies

A comprehensive overview of n-type technologies can be found in Kopecek & Libal [3] – only the most important n-type cell concepts will be summarized here.

The very first solar cell, the 'Bell Solar battery' [4] created in 1954, was actually fabricated using an n-type Cz-Si wafer. The p^+- and n^+-doped regions, as well as the electrodes, were all located on the rear side of the cell in an interdigitated geometry: this was the first n-type IBC cell. Since then, the IBC concept has been used by many R&D groups in order to obtain record efficiencies using manufacturing process steps in the laboratory. Today, the IBC cells and modules produced by SunPower feature a module energy conversion efficiency of 21.5%, which is the highest among commercially available crystalline silicon PV modules. However, because of the rather complex process sequence, the production cost (€/Wp) is significantly higher than that of c-Si mainstream PV technology.

In second place in the efficiency ranking of commercial solar modules is another n-type concept: the HIT solar cell from Sanyo, now commercialized by Panasonic. In addition to the advantages of n-type cells described earlier in this paper, because of the heterojunction and the resulting high open-circuit voltages, the reduction of P_{mpp} with increasing module temperature is low for the HIT concept. Consequently, HIT modules can achieve a significantly higher energy yield (kWh/kWp) than standard crystalline silicon modules. Factors that have up until now contributed to a higher price (€/Wp) than standard PV technology are first – as already mentioned above – the need for very high quality wafers in order to take advantage of the excellent surface passivation by the amorphous silicon layer and thus to fully exploit the potential of the HIT concept, particularly in terms of open-circuit voltage, and, second, the high level of cleanliness of the wafers required during the HIT process sequence, which increases the cost for wet chemical cleaning steps.

For a long time, the HIT and IBC concepts (both meanwhile achieving over 23% cell efficiency in mass production) have been the only n-type cell concepts in industrial production – each concept being produced by a single manufacturer only. In 2009 Yingli started to industrially implement and further develop the n-Pasha cell developed by ECN. This bifacial n-type cell – with a boron-diffused front-side emitter, phosphorus-diffused BSF and

Company/Institute	Country	Name	Bifacial cell structure	Technology	Efficiency [%]	Reference
Yingli	China	PANDA	H-pattern	Diffused, SP	19.5	[7]
ECN	Netherlands	n-Pasha	H-pattern	Diffused, SP	20	[8]
INES	France	NN	H-pattern	Diffused, SP	20	[9]
ISC Konstanz	Germany	BiSoN	H-pattern	Diffused, SP	20	[10]
PVG Solutions	Japan	NN	H-pattern	Diffused, SP	20	[11]
Suniva	USA	NN	H-pattern	Implanted, SP	20	[12]
LG Electronics	Korea	Neon	H-pattern	Implanted, SP	20.5	[13]
Bosch Solar	Germany	iBiN	H-pattern	Implanted, SP	20.5	[14]
Hareon	China	NN	IBC	Diffused, SP	20	[15]
Samsung	Korea	NN	IBC	Implanted, SP (metal glass)	20.5	[16]
ISC Konstanz	Germany	ZEBRA	IBC	Diffused, SP	21	[17]

Table 1. Diffused and ion-implanted 6″ industrial n-type solar cells from different companies/institutes with screen-printed (SP) metallization and with two different geometries, both having a bifacial characteristic. (Efficiency values are rounded to 0.5% abs., as different measuring conditions were applied.)

metal finger grid on the front and rear sides – is commercially available in Yingli's PANDA modules.

The so-called PhosTop concept [5] is another category of n-type cells that is noteworthy. From the manufacturing point of view, it is the simplest n-type cell concept: the same process sequence as for standard p-type BSF solar cells is applied to n-type wafers to obtain an n-type solar cell with a rear-side Al-alloyed emitter and a phosphorus-diffused front-surface field (FSF). The particular advantage of the PhosTop cell concept is the fact that a standard p-type cell-manufacturing line can be used without the need for any significant equipment modifications. There are two reasons why this type of cell has not yet been implemented in industry: first, the rear Al emitter must be completely closed, so no Ag/Al pads can be located on the rear side and consequently standard soldering for interconnecting the cells within the module is not possible; second, being a rear emitter cell, this cell design requires rather high-quality wafer material with high minority-charge carrier lifetimes, making it difficult to achieve the lowest production cost. In addition, as various authors (for example Schmiga et al. [6]) have shown by numerical simulations, even when applying more-advanced techniques, such as a selective FSF, the potential of an industrially viable PhosTop cell with full Al rear emitter is limited to around 20%. Ultimately, because of the limited efficiency potential, it seems that today's higher cost of n-type wafers and the additional investment required for the module manufacturing line are not offset by the slightly higher module power output using the PhosTop cell design.

The status of diffused and screen-printed solar cells

In the authors' opinion, diffused and screen-printed n-type solar cells have the greatest potential to be cost efficient, as they rely on the standard p-type process which has been optimized in mass production. Many companies and institutes are therefore working intensively on such solar cells with two-sided contact geometry (similar to the Yingli PANDA cell) and with the IBC cell structure (similar to ZEBRA cell of ISC Konstanz).

Table 1 summarizes the solar cell concepts which have been presented, for example at the nPV workshops [7] and other PV conferences such as the EU PVSEC and IEEE PVSC, in recent years. The table shows that all solar cell concepts have efficiencies of about 20%, with the highest (21%) being achieved by the ZEBRA concept from ISC Konstanz. As ion implantation is beginning to enter the p-type solar cell market, and seems to be (in some cases) also cost efficient, some of the listed n-type concepts have implanted emitters as well.

It is obvious that these solar cells are limited by one of the process steps, which in this case is screen printing. The most important drawback is the recombination beneath the AgAl contacts to the B emitter. Measurements before screen-printing metallization show implied open-circuit voltages (V_{oc}), for example for the ZEBRA concept, of around 700mV, which is then reduced by 40–50mV to an actual V_{oc} of about 655mV because of metal-induced recombination (MIR) [18]. In order to increase the voltage, a deeper diffusion would be preferable, a softer metallization needs to be done, or something similar to passivated contacts has to be adapted in combination with screen-printed contacts. Efficiencies well above 22% would then be feasible for the IBC approach.

It is important that a more detailed measurement standard be agreed on: at the moment the kind of measurement chuck to be used for standardized measurements has not been defined. This topic will be discussed in the next section.

The need for additional measurement standards for bifacial structures

Bifacial solar cells are still thought to be only interesting to an exclusive niche market and are also considered to be very costly. Both of these impressions are false, since 90% of n-type cell concepts are bifacial anyhow (or can easily be made as such) as shown in Fig. 3. This opens up the possibility of using bifacial devices in bifacial modules and benefiting from the additional albedo (as glass–glass modules are now cheaper and demonstrate longer lifetimes). However, bifacial devices in standard monofacial modules also offer additional advantages, which have been demonstrated very effectively by Bosch [19] and LG [20] in high-power 60-cell modules, with P_{mpp} exceeding 300W.

Since the cells are bifacial and demonstrate higher efficiency, other measuring standards are needed: capacity effects begin to play an important role, and the conductivity and reflectivity of the measuring chuck will have a large influence on measurements, even if taken in monofacial mode (no additional light from the rear). Such devices can be also measured in bifacial mode, but this would be an article in itself, as there are many possibilities and challenges for such characterization. This topic will therefore only be touched on very briefly in the next section. Fig. 4 shows schematically what such measurements look like, with 1 sun 1.5AM applied to the front side. The amount of albedo collected by the rear in Fig. 4(a) depends on the nature of the surroundings; the chuck used in Fig. 4(b) depends on the kind of backsheet that is planned to be included in the module.

Figure 3. Cross sections and images of the most prominent n-type solar cells. Since both sides always have an emitter or a BSF/FSF, and as none of the sides has a fully metallized surface, the solar cells can be made bifacial.

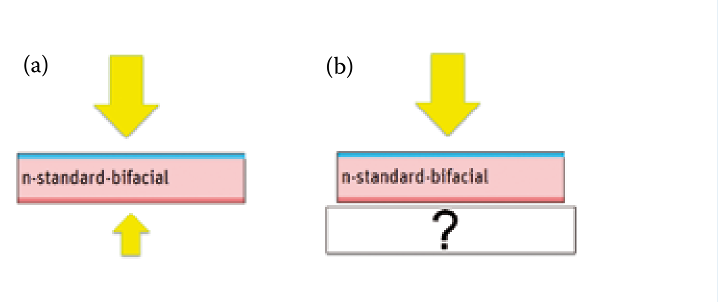


Figure 4. Schematic of the illumination of a bifacial cell in (a) bifacial and (b) monofacial modes. The unknown features are the illumination from the rear and the choice of chuck.

> “Other measuring standards are needed: capacity effects begin to play an important role, and the conductivity and reflectivity of the measuring chuck will have a large influence.”

Bifacial measurements of bifacial devices

Bifacial modules (glass transparent backsheet or glass–glass) with effective bifacial devices inside offer a huge potential for greater kWh harvesting. Because n-type devices are moving towards bifacial anyway, and thin glass is becoming more cost effective, the bifacial effect will surely be widely used in many installations in the future. Of course, the more reflective the ground or the surroundings, the more productive the bifacial effect: white flat roofs and installations on sand are therefore very good applications for boosting yearly power output without requiring any tracking.

Fig. 5(a) shows two possible ways of measuring bifacial cells in bifacial mode: 1) with one light source, two mirrors and filters (top); and 2) two light sources (bottom). The measured power gain is shown in Fig. 5(b) for different light intensities coupled into the rear side of a cell. When installations on sand are considered (reflectance of 40%), a power increase of 35% is expected; this means that standard 260Wp 60 6″ cell modules would have a performance similar to 350Wp modules (which actually do not exist at the moment). Such installations would be a good way of reducing the total system cost.

Monofacial measurements of bifacial devices

Like bifacial measurements, for which many measuring standards have to be agreed on, monofacial measurements can be also very complex, since other effects have to be considered as for standard solar cell measurements. The most important questions are:

1. What must the pulse length of the light flash be?
2. How should the chuck property be chosen (considering reflectivity and conductivity)?

In some cases, in order not to suffer from capacity effects, the flash pulse length even has to be chosen above 200ms, when V_{oc} is around 720mV (HIT and IBC). Otherwise, capacity effects of the measured solar cells will lead to inaccurate measurements of the efficiency. This must be checked before measurements are taken.

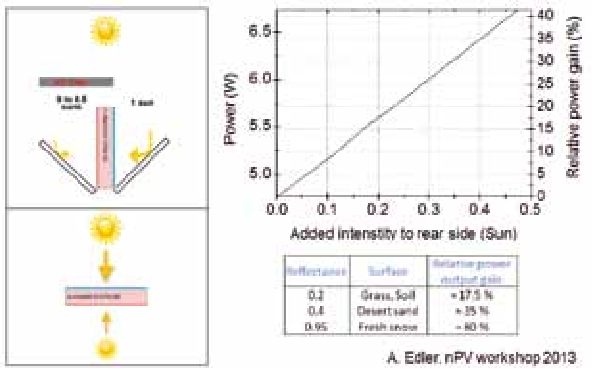
The properties of the chuck play an important role as shown in Fig. 6, where the internal quantum efficiency (IQE) is indicated for standard and bifacial p-type cells measured on a black chuck and on a white (reflective) chuck. A difference at long wavelengths between 1000 and 1200nm is clearly visible in the bifacial solar cells measurements taken on black and on white chucks. This is obviously due to the reflection of the chuck, leading to higher J_{sc} in the case of the reflective chuck.

Bosch Solar Energy has measured its n-type bifacial solar cells at FhG ISE using two different chucks depicted schematically in Fig. 7(a). The corresponding calibrated measurements are shown in Fig. 7(b) [21]. The measurement on the black, non-conductive chuck led to a cell efficiency below 20%, whereas for the reflective, conductive chuck it was above 20%. Bosch therefore proposed to use a white, non-conductive chuck in order to approximate the situation in the module where there is a rear side with a white backsheet. In this case the resulting efficiency would be 20.1%, as the current and voltage can be taken from the reflective chuck; however, since the fill factor *FF* in this situation is overestimated, the value for that has to be taken from the non-conductive chuck. Because such measurements are close to the module properties, the cell-to-module losses can easily be quantitatively estimated.

Assembly of n-type modules

Module interconnection

Just as with standard p-type cells, n-type cells with contacts on the front and rear sides, such as BiSoN and n-Pasha, can be interconnected by the soldering of copper ribbons – usually using fully automated tabber-stringer machines. The use of electrically conductive adhesives (ECAs) instead of soldering for connecting the ribbons to the cell is currently undergoing intense study, and this method can be applied to p-type as well as n-type cells. Gluing the ribbons has the advantage



Reflectance	Surface	Relative power output gain
0.2	Grass, Soil	~17.5 %
0.4	Desert sand	~35 %
0.95	Fresh snow	~80 %

A. Edler, nPV workshop 2013

Figure 5. (a) Possible bifacial measurement modes. (b) Power gain as a function of rear albedo.

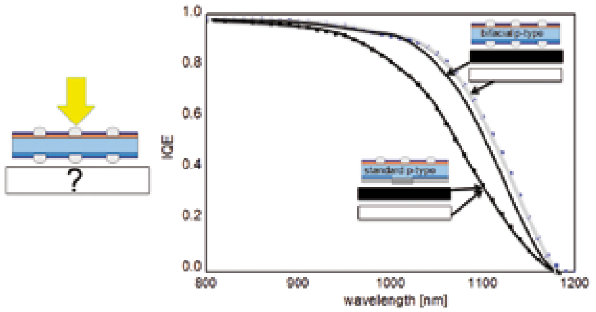
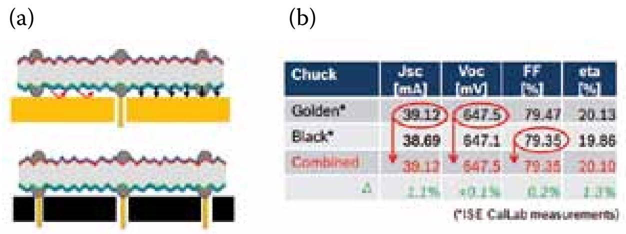


Figure 6. IQE for a bifacial p-type cell, measured with a black and a white chuck, and the same measurements for a standard p-type solar cell with full Al rear contact. The gain in short-circuit current J_{sc} for the bifacial cell, when using a white chuck, results from reflected light of wavelengths from 1000 to 1200nm.



Chuck	Jsc [mA]	Voc [mV]	FF [%]	eta [%]
Golden*	39.12	647.5	79.47	20.13
Black*	38.69	647.1	79.35	19.86
Combined	39.12	647.5	79.35	20.10
Δ	1.1%	+0.1%	0.2%	1.1%

(*ISE CalLab measurements)

Figure 7. (a) The reflective conductive chuck (top) and the black (non-reflective) and non-conductive chuck (bottom) used for measuring Bosch's n-type bifacial solar cells. (b) Measurements of these cells taken at FHG ISE [21].

of significantly reducing the formation of microcracks in the cells, especially when using wafers of thickness below 150µm – a thickness predicted by the latest ITRPV [2] from 2017 onwards.

The interconnection of back-contact cells can be accomplished using two different approaches. The first possibility is the use of conductive backsheets (CBSs) in combination with ECA for the interconnection. The CBS uses a known concept from the production of printed-circuit boards and is a laminate consisting of three functional layers:

1. Close to the cells, an isolating layer with openings for contacting the cells to the second layer.
2. A thin (e.g. 0.35mm) copper or aluminium layer, where the conductors for the two polarities are electrically isolated and structured in such a way as to create a series connection of the cells within the module.
3. An external layer made of polymeric materials (e.g. Tedlar), whose purpose is to protect the module under all possible climatic conditions in order to guarantee a long module lifetime.

The back-contact cells are glued using ECA to the conductive backsheet (with a layer of encapsulant inserted in between). The large cross section of the copper conductors (only 0.35mm thick, but with a width in the cm range) allows very low series resistances, leading to a reduced cell-to-module power loss. This technology is already in use on an industrial level for p-type metal-wrap-through (MWT) module assembly and can be directly applied to n-type MWT and IBC cells.

The second interconnection possibility is the soldering of copper ribbons using modified tabber-stringer machines (e.g. available from Komax). To reduce the additional mechanical stress and excessive bowing of the cells due to the fact that soldering takes place only on the rear sides of the cells, a soft ribbon (low yield strength) should be used. Another option for reducing the occurrence of microcracks is again the use of ECA instead of soldering. An important advantage of using standard ribbons for interconnection instead of CBS is that, in combination with a transparent backsheet, the bifaciality of the n-type cells can also be exploited at the module level, leading to a significantly increased energy yield (kWh/kWp(front)) and thus a reduced levelized cost of energy (LCOE – €/kWh).

An innovative module interconnection technique that can be applied to p-type as well as n-type cells is the NICE technology [22] from Apollon Solar: besides eliminating the encapsulant, this technology also replaces the backsheet by a glass pane. Such a glass–glass module has two advantages: first, it can be used in bifacial configurations; second, the replacement of standard backsheets by glass provides the best protection against climatic impact, allowing module lifetime guarantees exceeding 30–35 years.

Cell encapsulation

Apart from NICE technology, all n-type cell technologies have two important requirements with respect to the encapsulants. First, the encapsulant must be chemically compatible with the metal pastes used for cell fabrication as well as with the ECA. Second, advanced n-type cell concepts, in particular IBC cells, feature an excellent spectral response in the short-wavelength range (300–400nm); in order to transfer this efficiency increase to the final module, highly UV-transparent encapsulants are necessary. Promising candidates for meeting these requirements are ionomers, polyolefines and liquid silicone. Moreover, certain polyolefines have demonstrated a resistance to PID, for example when used in n-type ZEBRA modules [23]. When considering back-contact cells, the front-side encapsulant in any case can be thinner than in standard modules, leading to increased light transmission and reduced cost.

A look into the crystal ball: the future of n-type solar cells

As already noted, for many years the highest-efficiency c-Si solar cells have been processed on n-type silicon. New, lower-cost processes under development are being reported by many companies, such as Samsung, Suniva, Top Cell and Hareon among others. LG and Bosch, for instance, have demonstrated monofacial modules with 60 solar cells (6″ large) yielding $P_{mpp} > 300$Wp using bifacial n-type solar cells with H-pattern metallization on both sides. This result is in part a consequence of the additional advantage of reflection of the white Tedlar into the rear of the cell, leading actually to cell-to-module gains of up to 2% rel. Recently the construction of a 1GW n-type wafer factory in Malaysia was announced [1], and the n-Pasha consortium have begun planning a 100MW line in the USA for Nexolon [24].

> “More and more n-type technologies will enter the PV market in the coming years.”

The authors are confident that in the light of the steady improvement of the screen-printing pastes for n-type devices, the mass production of n-type wafers, the continuous progress in improving industrial processes for B-emitter formation, and, in particular, the high and stable efficiencies and high-energy yields, more and more n-type technologies will enter the PV market in the coming years. Since technologies that are based on established industrial process steps – as in the case of, for example, the ZEBRA IBC cell by ISC Konstanz – will substantially benefit from these developments, ISC Konstanz plans to transfer the ZEBRA technology to industrial production in 2014.

A new era of PV has begun in which adapted solutions for PV cells and modules will be introduced into the market, guaranteeing the lowest possible LCOEs and the longest module lifetimes for the respective applications. Manufacturers will thereby be given the opportunity to diversify their products away from the mass-produced commodity products such as the n-type technologies discussed in this article or through, for example, desert modules for hot and harsh climate conditions [25].

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