SOLARUNITED

THE GLOBAL SOLAR PV TECHNOLOGY & INDUSTRY ASSOCIATION

Global PV Technology & Industry Report

1st Edition - June 2016

Supported By:

BECQUEREL INSTITUTE

A Global Voice

The reach of technological innovation continues to grow, changing all industries as it evolves. In power generation, PV technology is increasingly playing a role in all processes of energy independence, from illuminating small remote villages to electrifying countries on free resources from the sun.

Technological advancements in PV will continues to contribute to services being taken out of the confines of labs and will become high efficiency mainstay energy devices.

With this technology revolution - there has never been a better time to be actively engaged. But there are many challenges that lie ahead that will require the industry to work together, and speak with a clear and impactful voice to create fair and competitive market opportunities for everyone.

SOLARUNITED's mission is to take Solar Energy to the next level to meet the energy demands of the 21st century by focusing on Quality, Reliability, and Technology.

Who We Are

Previously known as the International Photovoltaic Equipment Association (IPVEA), today we are **SOLAR**UNITED, now serving the mutual market interests of PV equipment technology manufacturers, module producers, project developers, financiers, consultants, service providers, law firms and other parties focused on the growth of solar energy.

SOLARUNITED is also a founding member of the Global Solar Council and Internationally **SOLAR**UNITED partners with groups, R&D Centers, and leading exhibition to help foster global information sharing and collaboration.

SOLARUNITED is continuing to grow and evolve to meet your changing needs, and it is through the active participation of our members that we are paving the path forward. We are providing more opportunities for engagement, networking, and delivering more value for your investment than ever before.

Join today—be a part of shaping the PV industry by becoming a member of **SOLAR**UNITED.

www.solar-united.org

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The Global PV Technology & Industry Association

SOLARUNITED, formerly known as the International PV Equipment Association (IPVEA), selected Intersolar Munich 2016 and the 32nd EU-PVSEC Conference to announce its transformation into a Global PV Technology & Industry Association.

While the PV industry and market have globalised in the last years, the need for a global association uniting the upstream part of the PV industry value chain has become more stringent. **SOLAR**UNITED intends to position itself as the only trade association focusing on Quality, Reliability, Innovation, and PV Technology. It is now serving the mutual market interests of PV equipment technology manufacturers, cells and module producers, project developers, financiers, consultants, service providers, law firms and other parties focused on the growth of solar energy. It aims at providing services to its members, facilitate the exchange of information between them and provide know-how and competence to the PV industry.

In order to reinforce its position as the only truly global PV technology and PV industry association, **SOLAR**UNITED has joined forces with several organisations in order to provide to its members the possibility to contribute and influence the development of PV technology globally.

- **SOLAR**UNITED officially announces their involvement in the new edition of the VDMA – ITRPV roadmap. **SOLAR**UNITED members will contribute actively to writing the most authoritative report on the development of the PV industry and technology.
- **SOLAR**UNITED will join officially the new European PV Technology and Innovation Platform (ETIP-PV), an independent body recognized by the European Commission as representative of the PV sector in Europe. **SOLAR**UNITED members will have the possibility to contribute to influencing European industrial and R&D policies through the ETIP-PV.
- **SOLAR**UNITED will officially launch during the Intersolar Europe / EU-PVSEC conference the first version of the Global PV Technology & Industry Report.
- **SOLAR**UNITED already announced the creation of several working groups aiming at involving the upstream and downstream part of the PV value chain into the improvement of quality and reliability of PV plants.
- **SOLAR**UNITED will further support the Global Solar Council as a member of the Executive and Strategy Committees.
- Additional initiatives aiming at gathering the global PV value chain will be announced in the coming months.

In order to support its new goals, the management structure of **SOLAR**UNITED will be upgraded. A triumvirate will ensure the management of the organisation from July 1, 2016. Bryan Ekus will be responsible for International Relations & Member Development, Bernhard Krause will coordinate the Management and Marketing and Gaëtan Masson on behalf of the Becquerel Institute will be in charge of content program development and strategy.

Eric Ast, President

Introduction

Bryan Ekus, Bernhard Krause, Gaëtan Masson

This report aims at presenting several points of view on the future development of the PV market and industry. Inline with the new strategy of **SOLAR**UNITED, it aims at providing an overview of current developments in several aspects on the PV industry and especially new and emerging technologies. Of course, much more could have been written on PV development and this report contains only some of the more interesting elements that are being industrialized now or that are heavily discussed within the industry.

First, this report looks at the situation of the global PV market and its main challenges in the coming years. Without entering too much into the detail of PV development, it highlights how PV could progress in the coming years, with many emerging countries completing the demand from the original markets.

Second, this report intends to give an overview of the direction that the PV industry is taking these days, with a focus on selected technology elements in almost all aspects on the PV value chain, from polysilicon, ingots and cells to modules. With regard to current development, the move to PERC is analyzed from the production point of view. The next steps in upgrading current production lines are detailed, starting from n-PERT and similar technologies. The potential to leapfrog to HeteroJunction is explained. Amongst thin film technologies, CIGS deserves a specific chapter given its potential. Other thin-film technologies might be studies more in depth in future versions of this report. Finally an outlook on perovskites, but also innovations in PV modules have been described. Bifacial cells and modules are considered as an innovation to be considered.

Last but not least, the report describes the activities that **SOLAR**UNITED has launched to involve more the upstream part of the PV value chain in ongoing discussions about the improvement of quality and reliability of PV power plants. The report highlights the role of the industry and illustrates the PID case as iconic of improvements that the industry might propose in the coming years.

Most contributions in this report involve specialists from different segments of the PV value chain, from equipment and material, to market and industry experts, and research centers from all parts of the world. It emphases how diverse the PV value chain has become and how the complexity of the current technology development is shaping the future of the industry.

Fig. 1: Expected evolution of PV cell efficiencies for most cSi technologies (ITRPV 2016)

Section 1: Market & Industry Development until 2020

Gaëtan Masson – Becquerel Institute

The PV industry remains a young and rapidly evolving industry using a technology that is being developed for decades. But in only a decade it has been multiplied by a factor 50, something uncommon in conventional industries but that the development of the IT industry in the last decades has also experienced.

A market that was, is, and will remain driven by public policies.

2015 saw 50 GW of PV being installed. Some additional GW could be counted if the methodology differs. Asia has taken the lead of the market and will strongly remain at this position in the coming years, reflecting naturally its share of the global population and richness. On the contrary to what happened some years ago when the market was driven by one single market, five markets are contributing significantly to the global PV market: China, Japan, the USA, Europe, and India. The rest of the global PV market can be considered as a sixth group with comprises the group of developed countries having already adopted PV (such as Taiwan, Chile, Korea, Australia, South Africa or Canada) and developing countries where PV is developing fast (Algeria, Philippines, Egypt, Mexico, or Turkey). The risk to see the PV market going down globally due to adverse policies in one of these groups is more limited than in the past, even if the situation of the first three markets remains policy dependent and could cause surprises.

A global history

The PV market cannot be detached from its industry and the other way around. Technology improvements and economies of scale are driving the cost down which raises the awareness about PV and pushes policymakers and developers to target new opportunities. Policymakers, through first tariff decrease and now mainly through competitive tenders are pushing the cost (and prices) decrease that pushes the industry to innovate and reduce its costs. As long as PV will not achieve competitiveness in all segments and countries with all sources of electricity, technology improvements will remain necessary to continue lowering the production costs, but also development and maintenance costs. In that respect, tenders have significantly contributed to highlight how competitive PV could become. And while tenders around 30 or 40 USD/kWh represent only a fraction of the PV market these days, they have shown the capacity of the PV industry to build on declining production costs to provide cheap electricity in almost on continents. The challenge might be today to bring the costs down further, not only for the most competitive but also for all market segments on all continents.

Costs and prices, and why we should be careful with the learning curve

At the time of printing this document, some tier 1 Chinese manufacturers announced costs starting at 0.37 USD/Wp, a continuously declining production cost. While all manufacturers cannot compete today with such low costs, they imply that the lowest threshold for reliable PV modules has established itself around 0.45 USD/Wp with a reasonable gross profit margin. Such low prices are out of the traditional learning curve for crystalline silicon PV and might lead to different interpretations of the curve. On the other side, less competitive manufacturers or producers of premium brand modules (with either an efficiency or technology advantage) experience costs decreases that are more in line with the learning curve. It might reflect a diversification of the PV industry in the direction of mass-products sold a super-competitive prices and premium products that will remain more expensive. In any case, the learning curve should remain considered with caution, as an interesting indicator, that must be corroborated with real technology improvements and effective economies of scale. In addition, the question of the possible switch, partial or complete, of the PV industry to new technologies shouldn't be neglected. The expected move to thin films technologies finally never happened, partially because of the intrinsic qualities of cSi but also because cSi was able to lower its costs faster enough to let little space to TF for growing. A large part of technology improvements that we see today are incremental improvements based on cSi conventional technology and doesn't require major changes in the production process to be produced. Others might play a role under condition of proving their ability to lower cost while providing significant improvements. In that respect, the challenge will be for cSi producers to continue lowering costs, bettering technologies to avoid the entrance of a low cost, high efficiency competing technology that would levelize the playing field.

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Towards a 100 GW annual PV market

We are not there and the industry might experience a new consolidation phase in the coming years. Whether most PV market forecasts until 2020 are announcing a market growth, the scale of that growth differs significantly according to the scenarios considered. The PV Market Alliance new scenarios until 2020 consider that the most probable scenario will lead to a growth that will not be large enough to absorb all capacities expansion announced, mainly from wafers to modules. If this were proven to become true, a new consolidation phase would start. This is even more expected that the quest for 10 GW-scale manufactures is ongoing. While the largest producer in 2015 shipped 5 GW, most tier 1 manufacturers will continue their production expansion to continue benefiting from economies of scale and stay in the cost race. New entrants have also announced their intention to grow fast or to develop vertically with high ambitions, which will increase the pressure in the coming months and years, leading to reduced margins, a possible new price war and a real consolidation (that never really happened, technology-sound manufactures being absorbed and integrated rather than closing).

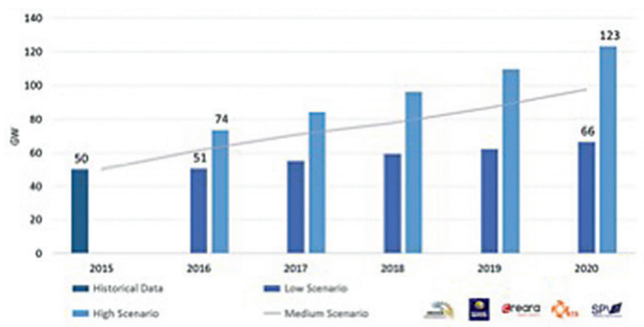


Fig. 2: PV Market Alliance's 5 years Global PV forecast

Niche markets

The quest for a 100 GW market in 2020 should also announce new niche markets. Technology niches such as Heterojunction or Bifacial modules or application niches such as BIPV might grow with a reasonable level of economies of scale in a 100 GW-market. In the same way, different applications in different markets, and especially under different climates might lead fast to ad hoc products being developed to cope with new quality requirements. Bankers and investors' job consists in evaluating the risk associated to their investments and PV is not escaping this analysis. Now that PV quits its infancy and has passed the 1% penetration globally and growth outside of its FiT-driven original markets, the question of the quality of PV installation becomes a key factor for its development. Under the concepts of bankability lies the simple idea that products and applications should deliver their promises, no less no more. With the uncertainty on revenues linked to publicly supported PV being slowly a question from the past, remains the question of the quality of installations and how technology improvements and installation and development best practices can guarantee PV a low-risk or risk-free investment.

Some conclusions

Almost all traffic lights are green for PV to become a mainstream electricity source globally. While the outcome of COP21 is still rather vague, the PV cost decrease and the rapid market expansion in countries that count will push the PV market towards close to 100 GW around 2020.

The industry expansion will continue while production costs might be reduced extremely fast thanks to capacity expansions and technology innovations. The rapid increase of production capacities by the market leaders is putting the pressure on other manufacturers to reduce costs and stay in the race. Technology improvements and new technologies will have enough space to develop in the coming years, while it is probable that the rather monolithic PV market could start to split in more technologies, more products for diverse applications, and cost-effective niche products.

Section 2: Summary of PV Technology Development

2.1. Summary of the International Technology Roadmap for Photovoltaic (ITRPV) 7th Edition

Dr. Jutta Trube, Dr. Markus Fischer, Dr. Axel Metz – ITRPV

ITRPV VDMA

The International Technology Roadmap for Photovoltaic (ITRPV) was initiated in 2009 by SEMI and since the 7th Edition VDMA is continuing the work with the active help of international contributors. The current version of the ITRPV covers the entire c-Si PV value chain from crystallization, wafering, and cell manufacturing to module manufacturing and PV systems. The complete document can be found at www.itrpv.net.

The ITRPV confirms that PV producers are continuing to track the historic solar learning curve of 21 % (Fig.1). The average crystalline silicon (c-Si) module prices declined from 0.62 USD/Wp in 2014 to 0.58 USD/Wp in 2015, corresponding to a manufacturing capacity of 39.3 GWp and 50 GWp respectively.

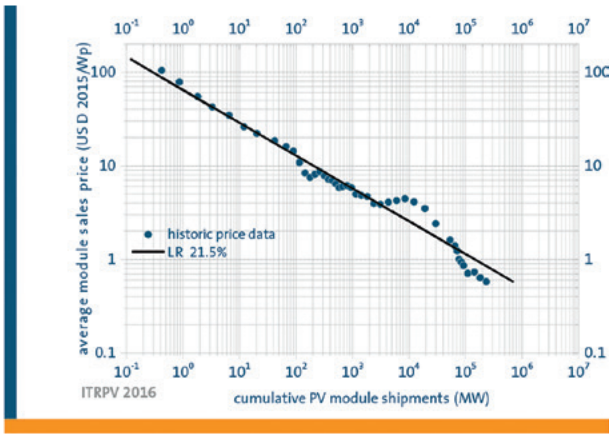


Fig 3: Learning curve for module price as a function of cumulative PV module shipments.

Silver paste is forecast to remain the dominant force in metallization in the foreseeable future, with copper only accounting to around 7 % of cell production in 2016. Lead-free pastes will be used widely from 2017 onwards. Silver usage per cell reduction is continuing, decreased from an average of 300 mg in 2009 to 110 mg in 2015 – a 66 % reduction, forecasted to 2026 a decline to 40 mg.

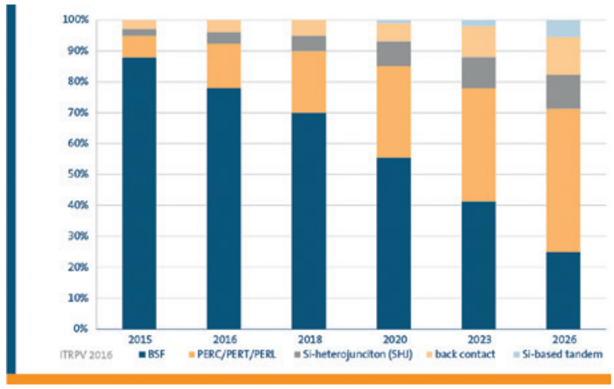


Fig. 4: Worldwide market shares for different cell technologies.

The passivated emitter and rear contact (PERC) technology is expected to increase market share to 45 % by 2025 (Fig.2). Heterojunction concepts are expected to increase share for niche applications, alongside IBC concepts, with Si-based tandem cells, presumably with perovskites, not appearing in the market until 2019.

On the efficiency side of the production equation, the roadmap predicts multi crystalline PERC cells to exceed 20 % efficiency on average by around 2020, and 60-cell multi modules 310 W.

Solar LCOE is expected to decline in step with PV cell and modules, with 2016 see a range of $ 0.044 to $ 0.09/kWh achieved, falling to $ 0.031 to $ 0.06/kWh in 2026 – for systems larger than 100 kWp and with a lifetime of 25 years.

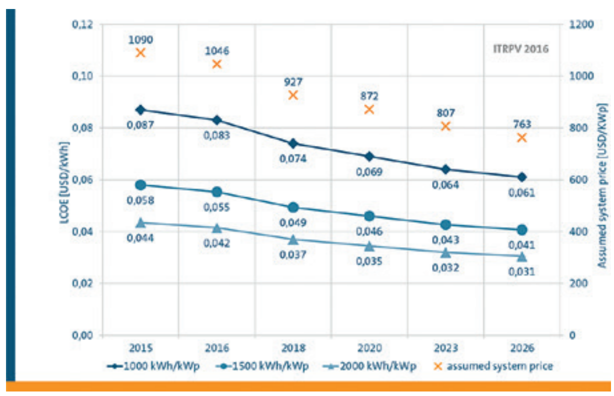


Fig. 5: Calculated LCOE values for different insolation conditions. Financial conditions: 80 % debt, 5 %/an interest rate, 20-year loan tenor, 2 %/an inflation rate, 25 years usable system service life

2.2 Recent Progress in Poly-Silicon Industry

Prof. Dazhou YAN – China Silicon Co. Ltd.

Development Situation on Modified Siemens Process

In China, a modified Siemens process is now the mainstream polysilicon production method. Based on its maturity currently all the domestic polysilicon manufactures rely on it.

Now, the new trends are to lower cost, enhance productivity, improve product quality, and reduce energy & material waste, within a commercial application.

Reduction Furnace improves Single Furnace Manufacturing Rate and markedly lowers Power Consumption by fine Design of utilizing Thermal Energy

Through computer simulation, the reduction furnace lowered power and material consumption by optimizing the layout of the feed ports.

By using, a design of miscellaneous nozzles builds a thermal field flow and material concentration is well distributed inside helps to produce high-grade pyknotic polysilicon rods with a smooth surface and even diameter.

At present, polysilicon reduction furnaces in China are either with 24 pairs, 36 pairs, 40 pairs, and 48 pairs of electrodes.

The electric energy consumption of a single-furnace of 5~12 tons of polysilicon production has been decreased from 120 kWh/kg-Si in year 2009 to less than 55 kWh/kg-Si today.

Moreover, comprehensive electricity consumption has been reduced from 200 kWh/kg-Si to 90 kWh/kg-Si around, which is a ratio of 55 %.

Advanced polysilicon reducing technology consumes electric energy less than 45 kWh/kg-Si, which is internationally accepted.

Along with further optimization, the comprehensive electricity consumption of the entire technique of a modified Siemens process is to be lowered to less than 70 kWh/kg-Si, which is a remarkable future technique developing in this industry.

Common Application of High Pressure, Low Temperature Hydrogenation Reforming

Almost without exception, all of the operating domestic polysilicon enterprises, including DAQO NEW ENERGY, ASIA-SILICON, RENESOLA, GUODIAN INNER MONGOLIA, LDK SOLAR, YICHANG CSG POLYSILICON, DUNAN have carried out High Pressure, Low Temperature Hydrogenation reforming to deal with the STC by-product.

Through reforming, they totaled 145 ton per year of additional STC, with a single equipment hydrogenating capacity of up to 100,000 ton + per year.

Using single high-pressure low temperature hydrogenating equipment in a larger scale with stable operation and lower energy consumption, effectively promoted the reduction of energy consumption and costs of polysilicon.

By-products of modified Siemens Process include STC, dichlorosilane, as well as others. By using the hydrogenation technique, STC mainly becomes raw material of TCS and returns to the system after purification. Dichlorosilane is designed by most factories to combine with STC in the presence of catalyzer to produce TCS through disproportionation and then return to the system after purification. This significantly decreased material consumption of polysilicon. Calculated from silicon consumption of per 1 kg of polysilicon, it decreased from 1.35 kg to lower than 1.2 kg, in a reduction rate higher than 10 %

Purifying System Optimizing and Comprehensive Energy Savings

With combination of high efficient TCS tray and filler, the differential pressure coupling rectifying and purifying system makes the high temperature material gas from one rectifying tower to heat the feeds come from the other tower.

Successful cases were also reported of series towers. By this means, vapor consumption of the tower bottom and circulating water of the tower top are drastically decreased. The energy consumption is lowered by 45 %~70 %.

Safety and Environment Protection

To produce 1 ton of polysilicon, there will be about 10~20 ton of by-product of STC during manufacturing. It's popular for the polysilicon manufacturers to make STC as raw material of polysilicon producing by hydrogenating into TCS and returning to the system for reuse.

It's also used to produce fumed silica, which is the government supported high-tech product.

Both above are efficient ways to comprehensively utilize the by-product to lower cost of polysilicon production.

In recent years, based on domestic enterprises technique development and intensive management, environment governmental department normalized online supervising, and the public enhanced environment consciousness, no polluting enterprise can survive nowadays. Those existing polysilicon producers are in clean and elegant conditions with material in closed circuits.

The problems of pollution have been resolved.

2.3 State-of-the-art in Silicon Ingot Casting Equipment and Technology

Dr. Christian Lehnert and Dipl.-Ing. Michael Hohmann, ALD Vacuum Technologies GmbH

Casting of multi- and mono-crystalline silicon ingots by Directional Silicon Solidification (DSS) is a key element in the production chain of solar cells and modules. The DSS process not only directly impacts achievable cell and module efficiencies but also yield, productivity and production batch size and determines to a certain extent the final cost structure of energy generation by photovoltaic means.

In this process the silicon feedstock is melted at temperatures up to 1500 °C inside a SiN coated SiO_2 crucible surrounded by a thermally insulated heating zone made from graphite felt. Subsequently, controlled silicon crystallization is initiated in the same crucible by either slowly upward movement of heating zone or opening the thermal insulation at the heating zone bottom and simultaneous cooling of crucible bottom by a cooling device placed underneath the heating zone. The process proceeds with crystallization, annealing and cool-down of the produced silicon ingot under inert conditions.

SCU (**S**ilicon **C**rystallization **U**nit) systems engineered and manufactured by ALD Vacuum Technology GmbH are among the most recognized DSS furnace types and widely applied for silicon ingot casting throughout the world. The SCU furnace design (cross section shown below) entirely meets the requirements for cost-efficient production of multi- and mono-crystalline ingots and is superior to other DSS-type furnace designs with respect to resulting ingot quality, productivity and operating costs.

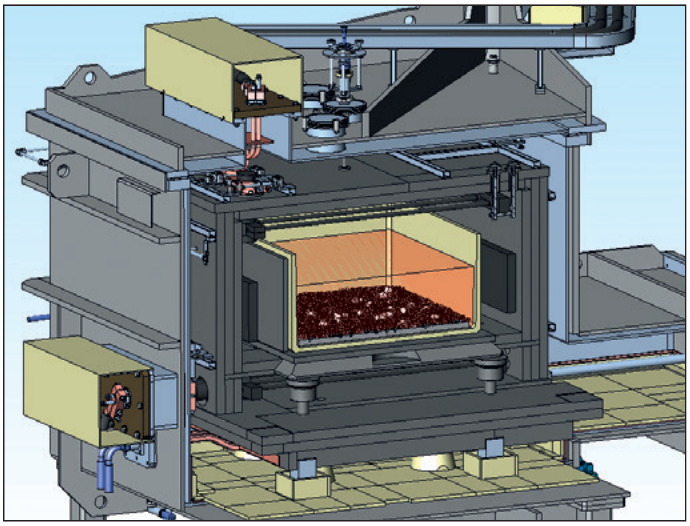


Fig. 6: SCU furnace design

The unique SCU design uses independent top, bottom and side heaters and an active cooling device consisting of water-cooled copper plate and system of independently movable insulation plates. By separating heating and cooling zones, the design enables precise control of all crystallization parameters, e. g. solid / liquid interface curvature, temperature gradient and heat flux, silicon seeding and melting as well as crystallization speed, important for casting of high-quality silicon ingots. The heater arrangement allows EM stirring of the melt with the possibility to adjust a variety of different traveling magnetic fields (TMFs).

DSS furnaces were used exclusively for multi-crystalline silicon ingot production for a long time. However, in recent years advanced silicon crystallization techniques were developed, namely **HPM** (**H**igh **P**erformance **M**ulti) and Mono^{2TM} (casting of mono-crystalline ingots using the DSS method, equivalents are: mono-cast, quasi-mono, mono-like) processes. Both techniques use in contrast to the conventional silicon crystallization process silicon seed layers promoting enhanced silicon crystallization and production of ingots with substantially improved crystal structure. While the HPM process uses multi-crystalline seeds resulting in high-performance multi-crystalline ingots, the Mono^{2TM} process uses mono-crystalline seeds resulting in silicon ingots with more than 80 % mono-crystalline fraction.

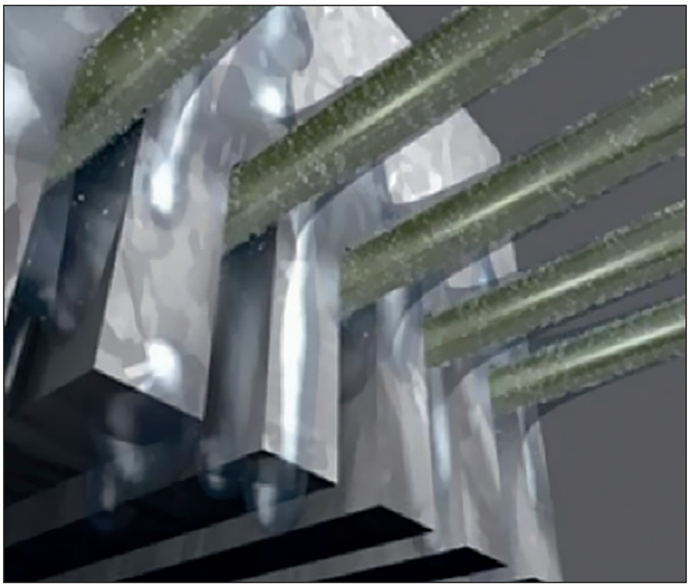
The same SCU furnace infrastructure used for conventional ingot casting is used for HPM and Mono^{2TM} ingot casting. Additionally, an automatic boundary tracker system used for detection of the solid/liquid interface position and improved process controls are applied to maintain the seed layer throughout the process and to enable reproducible production of HPM and Mono^{2TM} ingots. Application of seeded crystallization processes results in high-quality ingots enabling efficiency gains of approx. 0.5 % (HPM) and 1.0 % (Mono^{2TM}) on solar cell and module level. However, the lower quality of conventional casted ingots is partly compensated by lower production costs (no seeds, higher yield, shorter cycle time, higher productivity).

Over the years DSS furnaces were up-scaled to produce larger silicon ingots and to reduce the specific ingot production costs. While G4 and G5 ingot production was most common in the past, nowadays the majority of systems installed throughout the world enable the production of G6 ingots.

ALD's latest SCU models have an annual output of about 15 MWp and are designed for production of G6 ingots with 800 kg weight, 1000 mm edge length and 360 mm height (picture beside shows G5 / G6 silicon ingots produced with SCU systems). The use of optimized silicon feedstock even enables the production of taller G6 ingots with up to 1000 kg weight. The next generation of DSS furnaces for production of G8 ingots with more than 1500 kg weight has been engineered and is introduced on the market now.

2.4 Wafering Technologies Status and Perspectives

Dr. Nabih Cherradi – Desert Technologies



At the heart of every solar panel are silicon wafers. At it starts, the wafers manufacturing benefits from the semiconductor industry where the multi-wire sawing process was well established as proven technology. The process is based on a single wire passing in many hundreds of windings around a set of guide rolls to create a wire web. The wire moves continuously in a single direction at speeds of around 20 m/s. The bricks are forced down onto the moving wire web while abrasive slurry of polyethylene glycol (PEG) and silicon carbide (SiC) particles is being homogeneously applied to the web in front of the brick. The wire and the carrier fluid transports the abrasive particles to the brick, where the forces from the wire lead to a three-body abrasion process between the particles, the wire and the silicon brick. The conversion cost from the bricks to the wafers is the second high cost after the encapsulation process. Moreover, the major cost is mainly due to the consumables use, the kerf loss that represents about 50 % of the pure polysilicon used to make a wafer and the overall throughput.

Since the development of solar energy and the panels that drive the systems, three main routes to cost saving have been followed: the reduction of the materials usage that was improved from over 30 g/Wp in the early 2000 to less than 6 g/Wp today, thanks to thin wafers and thin wire. The wire saw technology was also improved allowing high throughput from few hundred to several thousand wafers/hour. The aqueous solution that represents the slurry, it's more and more recycled. Today we regenerate the slurry with less than 10 % of bright new slurry. Nevertheless, in the race for cost reduction, different new technologies merged. The most mature one is currently, an evolution of the proven slurry based wire sawing technology. The diamond wire sawing technology proposed by Meyer Burger among others. Since a couple of years, it's continuously gaining market share. It's advantages are multiples and from different point of view. Economical: the slurry is replaced by a diamond wire that generates higher output through a very fast cutting speed, the wafers doesn't need the deep and long cleaning process/detergents usage etc… Technical: no more slurry management. Moreover, the diamond wire process is environmentally friendly

Aside, other technologies are still either at pilot line level like the 1366's Direct Wafer™ process which is a one-step, kerfless wafer-making technology that has the potential to revolutionize wafer manufacturing. By delivering higher quality "drop-in" replacement multicrystalline wafers with unique surface features. The semi-continuous, high-throughput process eliminates silicon waste, resulting in a more powerful, low-cost wafer.

The continuous wafer synthesis technology developed by Fraunhofer CMI is based on crystal growth by mean of CVD process as well as the Twin Creeks' proprietary Hyperion process, is based on a beam of hydrogen ions that bombards a thick disks of crystalline silicon after heating in furnace a thin layer of 20 µm of silicon is peeled off the surface of each substrate. Both technologies can produce very thin wafers with no loss of silicon. However, these technologies are still at laboratory level and need further development before their industrialization. With the expected market development, capacity increase is needed and will probably open opportunities for new and innovative technologies with high potential of cost reduction especially the 'one step process' ones.

2.5 Achieving Increased Performance with PERC Technology

Dr. Christian Buchner – SCHMIDT Group

PERC technology is for sure one of the recent hottest topics for solar cell manufacturers. It has been extensively discussed on all recent conferences and shows and after all, it has found its way into mass manufacturing. Today high efficiency mono and multicrystalline cells and modules are commercially available from different suppliers.

Mono based modules have even passed the magical barrier of 300 Watt for a 60 cells module. The main topics in all presentations and discussions mainly focused on either the differences and potentials of the two main passivation technologies Al2O3 vs. Oxynitride or the different Al2O3 deposition methods PECVD vs ALD.

However, the manufacturing reality shows many more issues to solve in order to achieve real high efficiency. Besides using the right emitter design and related pastes to run the right firing temperatures that will not destroy the passivation again, proper cleaning and polishing of the rear side is essential. Taking a look at the landscape of PERC producers show that the leading ones in terms of efficiency are seeking new tools for junction isolation, rear polishing and cleaning.

Due to the outstanding performance of the recent advancements in wet tools manufacturers are able to achieve the best passivation result their particular passivation process can deliver. Having achieved this, a cell performance loss analysis shows that now the rear side is not limiting anymore as it was with a standard Al-BSF.

Now the front side is back in focus since it is limiting efficiency and exactly for this reason equipment providers are forecasting an extremely increasing demand for the selective emitter technology, which is the only proven manufacturing method using an ink-jetted mask followed by a wet chemical back etch. Supported by modern pastes for fine line printing which commonly also has an increased number of fingers on the front electrode etched backed emitters can go up as high as 160Ω/sq without sacrificing fill factor, but supporting efficiencies on mono PERC cell over 21%. Besides the efficiency advantage, another advantage of this process is that the emitter underneath the finger is still broad and low sheet resistance region, which extremely eases paste and firing parameter selection.

Having adjusted the front again with selective emitter leading manufacturers offers a second solution for boosting PERC to its full power. Taking a closer look to the rear side again brings attention to the bus bars. Although commonly quite small due to padded bus bar designs used today still in sum the rear bus bar is quite an area that shows increased recombination velocities due to insufficient passivation. An easy solution for this is a system, which replaces the rear bus bar screen printer that applies a thin tin-layer on top of the aluminum to provide a solderable busbar. Such the rear can be fully covered with Aluminum and no passivation disturbance by the typical Silver/Aluminum busbars, which typically contacts the Silicon rear directly, is introduced.

Summarizing the above, SCHMID offers three important solutions to achieve the maximum efficiency in a PERC manufacturing line, all proven in mass manufacturing and easy to upgrade.

2.6 Is PERC The New Standard?

Dr. Marco R. Huber, SINGULUS TECHNOLOGIES AG

After the introduction of screen printed contacts in 1975 [1], a twenty year lasting development of modern solar cells accomplished an important milestone by enabling mass production. An industrial standard, the so called Aluminum Back Surface Field (Al BSF) solar cell was defined and should outlast for more than four decades. The production of solar cells (1977's worldwide capacity equaled to 500 kW) stepped into learning curve striving to become more and more cost effective. Thus making photovoltaic energy conversion attractive for terrestrial applications, in addition to powering of space crafts, which had been the only driver until then.

Several routes of further developments were pursued. One aimed mainly to reduce or completely eliminate the shading of the front contacts, leading to cell architectures like Metal Wrap Through (MWT) [2], Emitter Wrap Through (EWT) [3] and Back Junction Back Contact (BJBC) [4] which transferred bus bars, front grid and the pn-junction, respectively to the cell's rear. All these approaches suffered from disproportional increase of the production flow's complexity and as of today, their share of total crystalline Silicon (c-Si) solar cell manufacturing lies in the single digit region [5]. A significantly different way was the transition from a diffused junction towards the so called Heterojunction (HJT) solar cell [6]. Surface passivation, junction- and BSF-formation by deposition of intrinsic and doped thin amorphous Si (a-Si) layers in combination with above mentioned BJBC technology finally resulted in today's champion (single junction) conversion efficiency of 25.6 % [7]. Nevertheless, HJT requires production equipment which in some steps differs significantly from the existing one and furthermore, some installed production tools will become needless. Therefore the technology does not support upgrading strategies of existing c-Si cell production. HJT will be an option for newly starting solar cell manufacturing that targets high efficiency applications on limited space or in high solar radiation regions, because the temperature coefficient of HJT is superior to the one of standard cells [8]. Besides that, several companies, formerly producing limited successful thin film a-Si modules consider justifiably the further use of installed deposition equipment by switching the production to HJT. In those cases, the upgrading model may work well. Market share of HJT is approximately 4 % (several hundreds of MW) today and due to the above described, is forecasted to gain around 10 % by 2026 [5].

Australia's University of New South Wales drove the solar cell development towards replacement of the Al-BSF by a dedicated, dielectric rear passivation layer. Their first approach was the Passivated Emitter and Rear Cell (PERC) [9], followed by the Passivated Emitter and Rear Locally Diffused cell (PERL) [10]. The latter achieved a conversion efficiency of 24.9 % which manifested the world record for two decades on the cost of a highly complex and expensive laboratory production procedure. Therefore finally the Passivated Emitter and Rear Totally Diffused cell (PERT) [11] was introduced as a more cost effective alternative to PERL, more suitable for mass production.

The smartness of the PERC concept is based on the full utilization of existing, well proven manufacturing equipment which needs to be extended by just two more steps: Deposition of the rear dielectric layer to reduce rear contact recombination losses (dominantly realized by Plasma Enhanced Chemical Vapor Deposition of Aluminumoxide, AlOx). This step can be combined in one vacuum deposition tool along with the front side anti-reflective coating. Prior metallization the electrically insulating rear passivation layer needs to be locally opened, which is typically done by laser ablation. Thus one laser tool is required additionally. Polishing of the rear (surface reduction) is beneficial for the PERC performance and is normally integrated into existing wet chemical processes, e.g. Phosphorous-silicate glass removal. During fast firing process a local Al BSF is formed in the region of the contact openings, giving PERC the synonymous name local Al BSF.

In 2014 the Institute for Solar Energy Research Hamelin (ISFH) reported a record PERC efficiency of 21.2 % [12] on Czochralsky material (Cz). In early 2016 an average PERC efficiency of 21.4 % in industrial mass production was reported [13], i.e. the benchmark established by research institute was transferred into industry within short period. Degradation problems, especially on Cz-PERC, that occurred further down the value chain have been reported to be solved [14]. Another upside potential of PERC is the availability of a cost saving bifacial layout, which is achieved without additional process steps, by simply applying an Al finger grid to the cells rear, which is aligned to the laser ablation pattern, instead of a full area print [15].

Our cell production cost calculations (including Si wafer) reveal 0.282 €/Wp for Cz PERC and 0.285 €/Wp for Al BSF cells on Cz [16]. Thus already on cell level, PERC is advantageous over Al BSF and usually such a lead increases when the cost calculations are driven forward to the final stage of levelized cost of electricity. Other cost calculations, published elsewhere confirm this tendency. In 2016 PERC production is on the 2nd rank with approximately 15 % market share versus still over 75 % for Al BSF. These proportions are predicted to change to almost 50 % PERC and 25 % Al BSF within the coming ten years [5].

PERC also offers a good starting position for future rounds of productivity increase in the industry. One logical candidate for an evolutionary progress were PERT solar cells, offering the possibility to use n-type base material without light induced efficiency degradation and the chance to go for bifacial module concepts. Depending on the final PERT production scheme (a broad variety is under development and discussion currently), PERC equipment can be used widely for this transition, just few production steps are required additionally and a further cost/Wp decrease is achievable [16].

PERC has grown a mature process, based on proven production technology with lower cost per Wp compared to Al BSF today. It offers a good base for further evolutionary-like developments. To cut the story short: Is PERC the new standard? It will be in a few years.

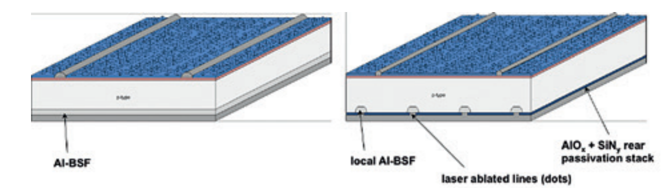


Fig. 7: Comparison of cell architectures: Al BSF (left) and PERC (right).

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2.7 MWT Technology: Ready to Start Mass Production?

Dr. Fengming Zhang - Nanjing Sunport Power Corp.

Currently several PV cells and module technologies are available on the market and a lot of new technologies are developed in labs. The quest for increased performance of PV cells is challenging all of those module technologies when it comes to electrical resistance. Since the internal module resistance is increasing with the square of the current, modern cell types require more conductive materials. This is not a problem as such meanwhile when the conductive material is positioned at the front of the cell, it generates shadow and reduces the performance of the solar cells. Many solutions have been explored to solve this problem, including wires, but at the end of the day, the shadow effect remains. As a result, most currently existing and new module technologies show a cell-to-module power loss of 1 to 5 %. The cell-to-module power loss is calculated as the percentage of difference when the sum of Pmpp of the individual cells is compared with the Pmpp of the module.

In order to solve this problem, several options have been considered, such as MWT cells that are detailed here. Metal Wrap Through (MWT) technology ensure the electrical connection of the cells at the rear-side, eliminating the need for conductive material on the front.

It has also been demonstrated that due to the stress-free connection between cells, degradation of module power caused by the stress and micro-cracks in conventional ribbon-connected modules does not exist any more. Therefore, a higher electricity output can be obtained.

Moreover, although MWT technology is not working in combination with the traditional H-type cells, these cells however can easily be converted to MWT cells. This conversion generates benefits for the cell producer, since it increases the cell performance and reduces the consumption of silver paste. Today, the MWT technology is compatible to PERC, black silicon, HJT etc.

Nanjing Sunport Power Corp., Ltd (abbreviated as SPP) has now finally transferred this technology into mass production, with a GW-scale production capacity, which might accelerate its development in the coming years.

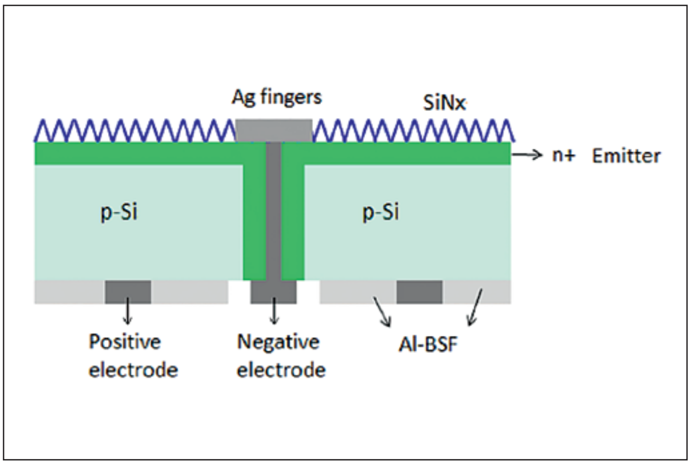

Fig 8: Cross-section structure of MWT cell (SPP)

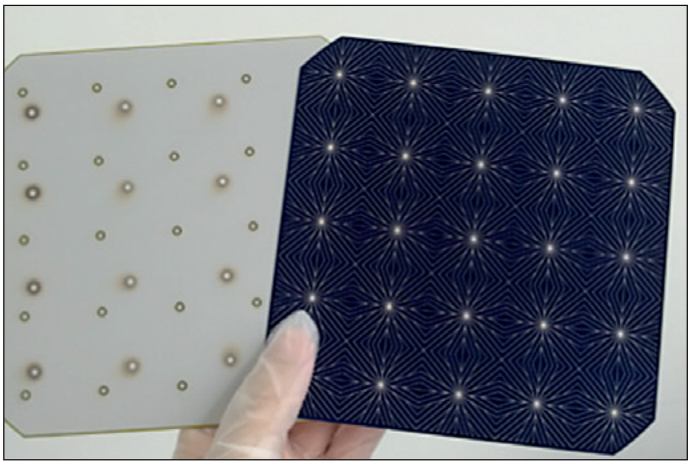

Fig. 9: Front and rear sides design of MWT cells

2.8. Bifacial Solar Cell Technology

Jochen Rentsch – Fraunhofer ISE

The majority of currently installed industrial crystalline silicon solar modules consists of solar cells fabricated on p-type silicon substrates. The cell architecture of these cells is predominantly represented by the so-called aluminium back-surface field (Al-BSF) solar cell and, to date with a significantly lower market share, the passivated emitter and rear (PERC) cell with local rear-side contacts.
Both Al-BSF and PERC cells generally feature full-area metallisation on the rear side. Hence, the majority of solar modules "only" utilizes the irradiation impinging on the front side of the modules to generate electricity. However, it has been shown that the albedo of the surroundings that leads to irradiation also impinging onto the rear side of a photovoltaic (PV) module or cell can be significant with maximum values up to about 60 % [1]. If this extra illumination due to the albedo of the surroundings can also be converted into electrical output power, the performance ratio PR – current definition: PR = the ratio of the actual yearly energy yield to the energy calculated from the rated output power1 and the yearly irradiation on the module front side - of these modules will significantly increase. For this purpose, two requirements need to be met: (i) The utilized solar cells need to be bifacial instead of monofacial, i.e., light can enter the solar cell from both sides, and (ii) the utilized modules need to feature a transparent rear side which can, e.g., be realized by the use of transparent backsheets or glass/glass modules. Transparent backsheets are commercially available, e.g. [2-3], and several companies have launched products featuring a glass/glass module, e.g. [4-5]. However, the main motivation for the use of glass/glass modules has so far been cost reduction potential and suspected higher reliability [6]. On the cell side, bifacial solar cells have been researched for a long time - for an overview, refer to Ref. [7]. More recently, PERT-like (passivated emitter, reartotally diffused [8]) structures featuring a grid on the rear side and, therefore, allowing bifacial operation, have gained increasing attention. One prominent reason is the suitability of the PERT cell structure for the realization of industrial cell structures on n-type silicon substrates. When being assembled into modules, an increase in energy output of around 10 to 20 $\%_{rel+}$ [9] compared to monofacial operation has been reported for bifacial modules, utilizing rear-side irradiation due to the albedo of the surrounding. Some solar cell and module-manufacturers have started to advertise their products to support bifacial operation and/or report increasing R&D efforts in this field, e.g. [10-12]. Other companies offer products with cells in principle capable of bifacial operation, without heavily advertising these bifacial features to date and incorporating those cells into modules with opaque backsheets [13-14]. Hence, both solar cells supporting bifacial operation and bifacial modules are, in principle, available for industrial production.

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1) Currently, the rated output power is given in units of "Watt-peak", and, in general only considers monofacial illumination.

2.9 Silicon Heterojunction Technology

Stefan Kern – Meyer Burger Global AG

Wafer-based silicon photovoltaic (PV) production has only changed slightly in the past forty years. The standard concept comprises p-type silicon wafers, fired contacts and encapsulation. Cost reduction is necessary if PV has to survive without feed-in tariffs and be competitive with grid electricity costs.

Therefore the levelized cost of electricity (LCOE) is one of the primary metrics for the cost of electricity produced by both utility scale and distributed power systems. The fastest path to lower LCOE is to introduce high efficiency solar cell concepts like the heterojunction technology (Si-HJT). Heterojunction cell technology combines the advantages of mono crystalline silicon (c-Si) solar cells with the good absorption and the superior passivation characteristics of amorphous silicon (a-Si) known from a-Si thin film technology using readily available processes and materials.

The structure of a Si-HJT cell is simple and its core is the thin intrinsic a-Si layer deposited between the c-Si wafer and the doped layers which is the key to achieve maximum performance. The skillful deposition of an intrinsic a-Si layer results in reduced interface state density and surface recombination current (J0 ~1 fA/cm2) and hence decreased surface recombination losses. The relatively straightforward Si-HJT production process takes place at low temperatures and requires fewer production steps compared to other high efficiency designs, which is economically attractive as it results in significant energy cost savings.

An important technological advantage of Si-HJT cells is the excellent surface passivation of a-Si which enables high open-circuit voltages and high cell efficiencies. The superior temperature coefficient of TC = -0.2 %/K ensures higher energy yield during module operating.

As previously mentioned, low temperature processing (< 250 °C) saves energy during manufacturing, prevents bulk degradation and allows the use of thin wafers. Integrated development throughout the PV value chain (diamond wire wafering, heterojunction cell technology and SmartWire Connection Technology (SWCT)) guarantees the maximum performance of HJT systems.

Already today HJT systems deliver higher kWh/m² compared to other technologies as shown in the first figure below, and this especially in the case of bifacial modules. In combination with the low manufacturing costs, this translates into reduced LCOE as shown in the second figure below. Moreover, we are at the beginning of Si-HJT mass production and further improvements are foreseen. The use of thin wafers, the reduction in manufacturing costs and performance improvement at the cell and module level will bring the cost of electricity generated by Si-HJT systems at a close to unbeatable low level.

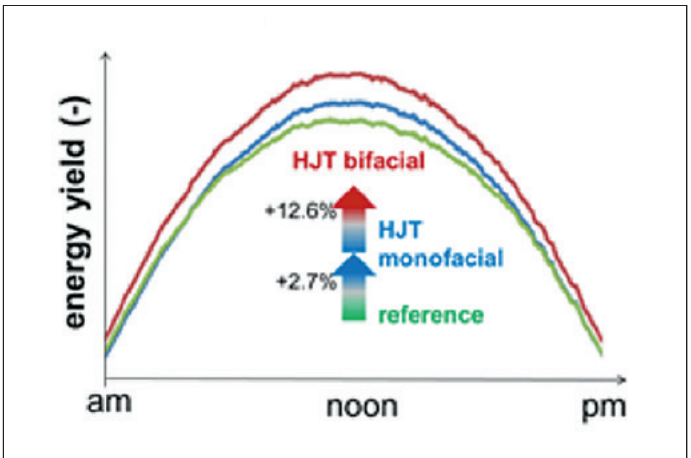

Fig. 10: kWh/m² generation of monofacial and bifacial Si-HJT systems vs. homojunction technology.

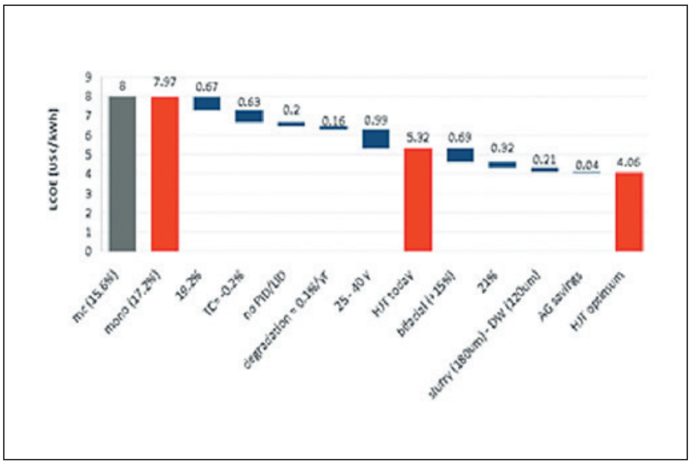

Fig. 11: LCOE from homojunction technologies to already available Si-HJT and to future Si-HJT systems.

2.10 CIGS Thin-Film Solar Cell Technology

Declared dead – or why the CI(G)S Thin-Film Solar Cell Technology is Experiencing a Renaissance

Bernhard Krause – MetaCom GmbH

Photovoltaics (PV) today are dominated by crystalline silicon (c-Si) technology. The markets talk about upgrades for PERC/PERT or the next level of cell technology: Heterojunction.

But during the last weeks we could realize that CIGS (Cu(In,Ga)(Se,S)2) again became interesting and new projects had been announced. Solar Frontier (1), the world's largest CIS solar energy solutions provider, announced that it has commenced commercial production of its 150 MW CIS Tohoku fab, located in Japan's Miyagi Prefecture. Construction of the plant began in 2014 and was completed 2015 when ramp up of new production lines began. Solar Frontier said that the Tohoku fab can now produce CIS solar panels "of the same grade and higher" as the firm's 900 MW Kunitomi plant.

CNBM is the Chinese state-owned enterprise that has recently announced plans to build PV module factories in China with more than 15 GW of annual production capacity. Born as a building materials company, CNBM in 2014 acquired German CIGS manufacturer Avancis, which has brought its expertise to the Anhui CIGS fab, which will cover a total of 55,000 square meters once first phase is completed in 2017. During SNEC contracts for the delivery of manufacturing equipment had been signed with SINGULUS TECHNOLOGIES (2) and von Ardenne for two 300 MW CIGS plants. CNBM announced the plan to expand its CIGS production facilities to 3.0 GW of capacity. SINGULUS TECHNOLOGIES will provide with new Production solutions for selenisation as well as sputtering and evaporation the key productions steps for the manufacturing of CIGS solar modules. With Shanghai Electric another Chinese giant invested in CIGS technology. Shanghai Electric will leverage in future its resources to help Manz (3) in developing technology in key segments, including CIGS thin-film solar technology.

CIGS – Efficiencies and characteristics

PV modules with CIGS absorbers are very effective in converting light directly into electricity. They are presenting record efficiencies of more than 22.6 % in R&D (ZSW, Stuttgart) and for production size modules of about 16.5 %.

In contrast to crystalline solar cells, for the CIGS technology large glass panels are used as base material and coated with relatively thin alloys of copper, indium, gallium and selenium or sulfur (CIGS).

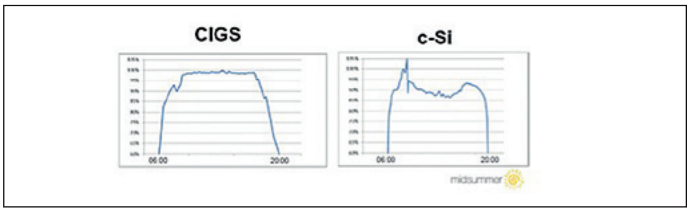

Fig. 12: Real life measurements in June 2014

Compared with the crystalline solar cells, the thin-film solar modules only slightly lose their efficiency in case of low lighting conditions or very high temperatures, i.e. the thin-film solar modules already generate power in the early mornings and in the evenings and therefore offer cost benefits for the generation of photovoltaic electricity. Loss of power during clouding is also mitigated to a large extent. Moreover, due to their optically more attractive surface, they can be set up on roofs and faces of buildings as a means of design. This combination makes CIGS one of the most sustainable solutions for renewable energy sources.

Electricity provided by CIGS is competitive

In a white paper about CIGS (5) published by the end of 2015, it was announced that today´s CIGS production costs are comparable to crystalline Si. The report explained (the figure shows the present status and the effects of learning by further scaling and upgrading module efficiencies), that CIGS has just started the learning curve typically seen for comparable thin-film technologies.

News CIGS facilities have the potential to yield total cost of ownership of 0.40 US-$/Wp even at productions capacities as low as 150 MWp/a.

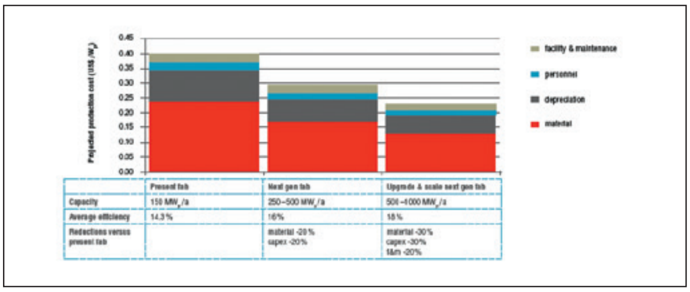

Fig. 13: Projected CIGS production cost using presently available technology and leveraging further cost reduction potential (5)

Conclusion

Today, CIS or CIGS technology is the thin-film technology with the highest levels of cell efficiency (ZSW (6) at present: 22.3 %). The specific advantages of the CIGS technology in terms of production and performance of the modules open up new market opportunities. This results in a low level of material and energy use during production. In principle, this makes energy payback times of less than a year possible.

The aesthetical advantages of CIGS modules with a beautiful, pleasant surface complement this.

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[3] Manz
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[5] www.CIGS-PV.net
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2.11. From Lab to Fab, the Status on Perovskites

Martin A. Green – Australian Centre for Advanced Photovoltaics, University of New South Wales

Recent rapid reductions in costs have assured photovoltaics a major role in future energy supply, making it one of the hottest topics in the energy field.

Within the photovoltaics field itself, the hottest topic over recent years undoubtedly has been the organic-inorganic lead-halide perovskites that have emerged quickly to become one of the most exciting and rapidly advancing topics within materials science. Although serious impediments to practical use remain, the sheer size and diversity of the international laboratory effort being brought to bear on the technology give encouragement that solutions, if available, will be found.

The most impressive laboratory gains have been made with energy conversion efficiency with values as high as 22.1% independently confirmed for small area cells (0.1 cm²) with values not appreciably lower at 19.7 % confirmed for larger 1 cm² devices. There is much interest in tandem cells on silicon and CIGS where even higher efficiencies up to 28 % have been claimed, but not independently confirmed.

The main impediment to commercial exploitation remains the poor stability of the devices. Most perovskite cells degrade dramatically in performance over a period of days or weeks even when encapsulated and not subjected to particularly severe environmental stresses. Although steady progress is being made in improving this aspect, there are still enormous improvements in stability required before a commercial product could be launched. Quantum leaps in this area rather than the present incremental gains would seem to be required.

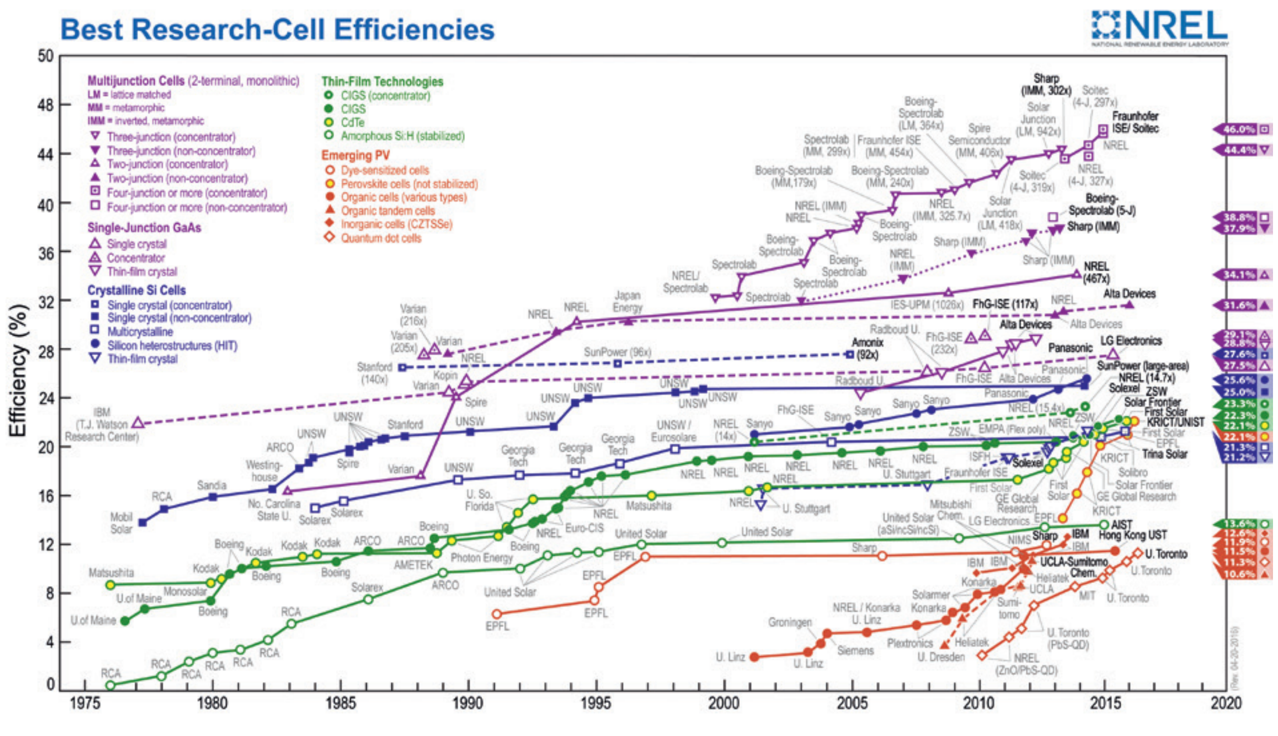

Fig. 14: NREL Best Research-Cell Efficiencies – 2015 (Perovskites in yellow-red dots)

2.12 Module Efficiency Boost: HJT & Connection Innovations

Stefan Kern – Meyer Burger Global AG

Three to five busbars, heavy silver fingers, a standardized coating process and glass/backsheets modules have long been the benchmark in photovoltaics. But those days are coming to an end. Innovative technologies for coatings and cell connections now enable up to 329 watts per module. Welcome to a brief history of records.

It was recognized early on that shorter fingers on solar cells minimize electrical resistance. As a result, the number of busbars was increased from two to three, even five. This brought about a significant reduction in energy losses. The same approach is also taken by the SmartWire Connection Technology (SWCT) from Meyer Burger. Here, busbars are replaced by up to 18 fine copper-based wires on both sides of the cell.

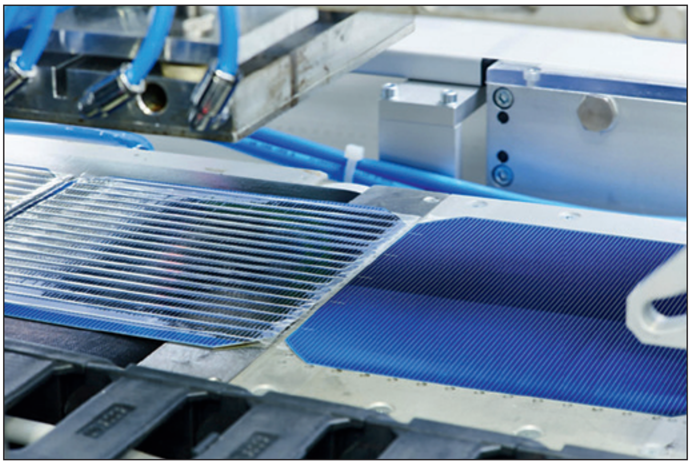

Fig. 15: Dense contact matrix replaces heavy busbars: Cell connecting station for SmartWire Connection Technology. Courtesy Meyer Burger.

This SWCT results in a dense contact matrix which reduces the electrical resistance dramatically. This is reflected in the module performance, which is up to 6 % higher than with three-busbar technology. This boost in performance can also be attributed to decreased shadowing. The round copper wires retain more light in the solar cell, and significantly less light is reflected back. The effective wire shading averages only 70 % of the wire diameter.

The low silver consumption is likewise record-breaking. Because busbars have been eliminated entirely, a 60-cell module needs less than 2.4 grams of silver. In addition, the wires do not require soldering, as in busbar technology, so that there are significantly fewer cracks. With SWCT, the wires melt together with the film and the cell surface in the course of the lamination process, which takes place at much lower temperatures. Moreover, the dense contact matrix prevents the negative impacts of micro cracks. SWCT is compatible with all kind of cell technologies such as PERC, PERT and Heterojunction.

The history of records would not be complete without a mention of Heterojunction Technology. It combines the advantages of mono-crystalline silicon with the outstanding passivation properties of amorphous silicon, as is well known from a-Si thin-film technology. This approach lifts cell efficiency to a new level: Heterojunction starts at around 22 %. Particularly striking is the unique temperature coefficient of TC<-0.25 %/°C compared to -0.43 %/°C (and greater) for other technologies. Another important downstream benefit of combining HJT and SWCT technologies

is the significant reduction of light-induced or potential-induced degradation (LID or PID) effects. HJT cells have an extremely conductive ITO coating on both sides which electrically protects the cell in the manner of a Faraday cage, thus eliminating the possible efficiency loss of up to 2 % which would otherwise be occurred.

Ideally, the SWCT and HJT are combined with the glass/glass module technology. This new design passes on aluminium frames. In contrast, modules are equipped with thinner front glass with an anti-reflecting coating which has a positive impact on module efficiency and makes them known for their persistence.

Modules with Heterojunction and SmartWire Connection technologies are expected to feature lifetimes of up to 40 years. Their reliability properties have been certified by TÜV Rheinland (IEC 61215, IEC 61730, ANSI/UL 1703): the modules were subjected to shifting temperatures of -40 to +85° Celsius – every four to five hours. After more than 800 cycles, only a very small energy loss of 1-2 % could be detected. The damp heat test also delivered excellent results. After more than 4,000 hours at a humidity of 85 % and a temperature of 85° Celsius, there was no significant loss of energy.
Heterojunction and SWCT are revolutionizing photovoltaics.
The first step has now been taken, allowing the history of records to be continued.

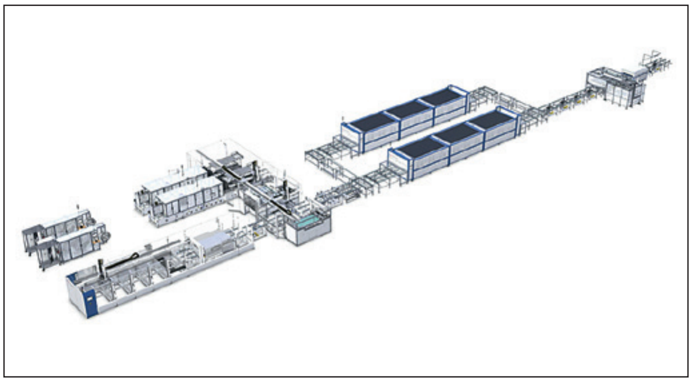

Fig. 16: Module production with SmartWire Connection Technology: Meyer Burger offers cost-efficient plug-and-play module production lines. Courtesy Meyer Burger.

2.13 The Expanding Role of PV Inverters

Lior Handelsman - SolarEdge Technologies

The PV inverter was originally named for its main function of AC-DC conversion, but as increasing demands are made on PV systems, the inverter's role has since expanded. This is similar to how cell phones were once mainly used to make calls, but today smart phones have numerous other capabilities. Functioning as the brain of the PV system, advanced inverter solutions are now responsible for a plethora of roles including, communications, monitoring, smart energy management, grid interaction, safety and more. As such, PV systems are becoming more advanced distributed energy power stations and open up a new world for smarter consumption.

Communication with the inverter is becoming a growing need for installers and system owners alike – whether for monitoring, remote access, or upgrading. The first link in the communications chain is from the module to the inverter. For instance, with SolarEdge power optimizers, the communications from module to inverter is conducted via Power Line Communication (PLC), so no special wiring is required. However, the link from the inverter to the cloud can be more complicated. There are multiple new strategies that can be embedded into inverters, such as Wifi, ZigBee, and cellular to allow for easy and simple communication.

In terms of monitoring, traditional string inverters provide limited access to information. String level or system level monitoring can indicate underperformance of the array, but little else. In order to inspect system issues, skilled technicians have to perform inefficient onsite troubleshooting on inverters operating under load and on DC lines at nearly 1500V. They connect expensive equipment to the arrays in an effort to 'sift through the tea leaves' of complex IV trace curves to detect issues. However advanced inverters, with module-level power electronics (MLPE), can track module-, string-, and system-level data on system production enabling greater resolution into system performance. With remote troubleshooting capabilities, these inverters can transform O&M from a manual, resource-intensive process to an automated, at-a-glance service.

To increase self-consumption with smart energy management solutions, the inverter is critical. While of course the quality of the actual battery is important, it is the inverter that is responsible for its functionality. For instance, you can buy a top-of-the-line guitar, but if you don't have a talented musician to play it, then it simply becomes decoration. In a PV plus storage system, the smart inverter controls when the PV is utilized, stored in a battery or transferred to the grid; and controls when the battery is charged, idle, or discharged to generate the maximum economic return.

Even without a battery, system owners can offset the impact of rate design and increase their self-consumption. One of the simplest ways for system owners to self-consume more is through load management - shifting consumption patterns to match peak PV production to loads such as water heaters, air conditioners, and pool pumps. As inverters already manage PV generation and consumption, it is a natural progression to integrate PV with smart homes and for the inverter to be the control unit. Advanced inverters offer load management control that can be coordinated with a homeowner's PV production.

Due to increased safety awareness in combination with evolving PV markets and proliferation of solar energy, safety regulations are being called for by fire authorities, insurance companies, and utility companies around the world. Experts in the fields of electrical safety, PV, fire safety, and insurance are working together to develop PV safety codes. The responsibility of meeting the new safety codes is mainly on the inverter. Inverter systems that include MLPE solutions are particularly cost-effective and successful at meeting these requirements as they can reduce DC voltage at the module level.

While this trend towards expanding the role of the PV inverter is putting a greater burden on the inverter and manufacturer, it is a necessary step in the advancement and proliferation of the solar energy. Just as in the past few years, inverters had to advance to address the larger role that they play in determining PV systems' bottom line and lifetime value, this new demand will be also addressed by the market through product innovation.

Section 3: Quality of PV Installations

3.1 SOLARUNITED's Quality Initiative

Laura Azpilicueta, Dr. Nabih Cherradi, Bryan, Ekus, Gaëtan Masson

Several attempts aiming to improve PV quality and reliability have emerged in recent years. But such initiatives do not comprehensively impact on the entire global value chain nor highlight the technological achievements made by state-of-the art PV plants. In that respect, **SOLAR**UNITED offers to capitalize on its unique position, global and technology-focused, to bring the PV industry as a whole one-step forward in terms of quality and reliability.

SOLARUNITED combines the strength of all parts of the value chain, globally, with a core of actors coming from the technology side of the PV industry: equipment manufacturers, materials, components providers, cells, modules and inverters manufacturers. This initiative intends to link the different sectors of the value chain, in order to ensure PV plant quality everywhere. The quality committee of Solar United has defined the following possible actions to be promoted within **SOLAR**UNITED's Quality & reliability of PV systems activities.

The first working group focuses on setting up recommendations for the downstream part of the value chain with regard to data collection from the field. It has been identified that the failures and defects in the field are causing performances losses that are uneasy to be identified in some cases. Several studies have so far studied and tried to identify the main causes of failures and the value their effect on the profitability of PV systems. Meanwhile the subject remains largely untapped.

- → **Write a white paper about requirements** from installers, developers and O&M companies in order to collect performance data, defects and failures in the field in a standardized way. This very first step should allow to define common reporting procedures that could be disseminated through downstream PV associations and global organisations. This paper will consist in a series of recommendations and possibly lead to specific training courses for inspectors.

- → **Propose the creation of a relevant database for PV performance** and defect in the field. **SOLAR**UNITED proposes to define the scope of such a database, together with experts who are already managing similar databases. The scoping of the database should identify which information must be logged in in order to provide information upstream and downstream.

- → **Call for data**: once the principle of the database guaranteed, this working group will identify which EPCs and O&M contractors could provide data.

The second working group focuses on the question of the impact of different climates on PV quality. It is now clear that the different climate on earth are affecting the lifetime and performances of PV systems in a different way.

- → **Write a summary paper** about the current understanding of climatic requirements. Such small report would synthesize the state of the art of climate impact on PV performances.

- → **The working group will propose recommendations** for the industry upstream and downstream, in order to better adapt the entire value chain processes including the choice of components. This might results in additional recommendations for testing, standards and components/system design.

Additional working groups will be proposed in the near future.

3.2. Failure in the field: Do PV Systems Reach Performances Expectations?

Gaëtan Masson – Becquerel Institute

Business plans of PV systems are built on performance expectations and foreseen degradation rates. But is the quality of the components and installations sufficient to guarantee the expected long term performance? This question is at the core of PV market development, and individual supplier responses appear to be insufficient in improving the confidence of the solar investment community. Achieving the expected level of quality should involve the entire PV value-chain, from the material and equipment manufacturers to the installers, and ultimately solar farms and plant operators.

From materials to PV plants producing electricity, the PV value chain is long and very often split between numerous actors. The components (modules, BoS, inverters) are in most cases produced by different companies, shipped, stored, sold, assembled and maintained by a range of companies that are not always equipped to communicate in the most efficient way. Of course vertically integrated companies reduce the number of players and developers ensuring the operation and maintenance of plants themselves are simplifying the transmission of information between all segments of the PV value chain. Increasing the reliability of PV plants requires to understand the root causes of defects. Defects identified in the field can be linked to power losses and therefore revenues losses as estimated in the figure below.

Faillures	Power loss [%]	Max power loss [%]
Hotspot	2,00%	20,00%
Delamination	1,00%	30,00%
Glass breakage	10,00%	50,00%
Soiling	10,00%	30,00%
Shading	10,00%	40,00%
Snail track	1,00%	8,00%
Cell cracks	1,00%	15,00%
Defective backsheet	1,00%	20,00%
Overheating junction box	1,00%	33,00%
PID = Potential Induced degradation	10,00%	70,00%
Failure bypass diode and junction box	33,00%	33,00%
Corrosion in the junction box	1,00%	33,00%
EVA discoloration	0,0%	10,0%
Theft of modules	100,00%	100,00%
Broken module	100,00%	100,00%
Damage by snow	100,00%	100,00%
Corrosion of cell connectors	1,00%	15,00%
Unsufficient theft protection	0,00%	100,00%
Improperly installed	5,00%	20,00%
Module damaged due to fire	100,00%	100,00%
Missing modules	100,00%	100,00%

Figure 17: Range of envisaged power losses due to failures

Source: Solar Bankability project – Technical Risks in PV projects – Report on technical risks in PV Project development and PV Plant operation – March 2016

The PID example developed below in this report is a perfect case of a combination of causes which can could benefit from a better coordination. But other examples such as micro-cracks in PV cells coming from transport or mishandling during the installation and not the only root causes of failure and performance losses. Once the failures linked to inappropriate practices during the transport, installation and maintenance processes have been identified, the failures linked to the components themselves can be analysed separately.

Analysing why PV plants are failing and whether these failures could be solved with appropriate technical measures would require a transmission band between the downstream and the upstream parts of the PV value chain. A standardized approach to identify, report and analyse failures in the field would be a necessary step to allow tracking failing components through a standardized traceability process. Under this conditions, the setup of a database of materials, components, products and installations would allow to gather field information, derive technology improvements and best practices for developers and installers.

3.3. Technology and Best Practices: The PID Case

Laura Azpilicueta – EVASA

In solar parks, solar panels are serially interconnected and, as a consequence, panels are frequently exposed to high potentials relative to ground. Such high potentials are known to create under certain circumstances a degradation of performances of the PV panel. This Potential Induced Degradation (PID) occurs when voltage potential and leakage current drive ion mobility within the module between the cells and other elements (e.g. glass, mount and frame). These ions, trapped in the cell surface, change the semiconductor's band gap and cause cell shunts. The ion mobility accelerates with humidity, temperature and voltage potential.

The PID effect is highly influenced by environmental factors (humidity and temperature) and acts at three different levels. Since relative humidity and temperature cannot be controlled, PID has to be counteracted at cell, module and PV System level. Improvements at system level can be ensured through installation best practices and for instance a better control of the grounding. We will focus here only on the components aspects and how technology improvements can contribute to solve the PID problem.

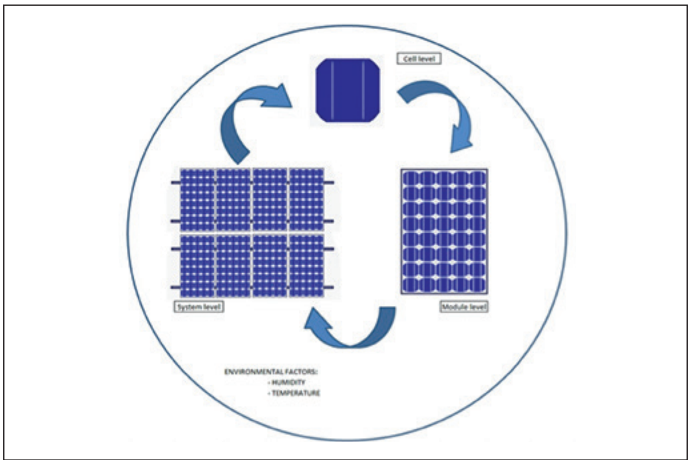

Fig. 18. PID involving cells, modules and PV systems

Component selection is one of the most important measures to counteract PID at module level. It is necessary to find appropriate material combination that minimizes leakage currents and carry out proper testing to assess durability of modules exposed to high voltage bias. Among different alternatives, EVA based encapsulants are most widely used due to their well established history of durability. Recently PID imposed to develop a new generation of EVA, tailored to offer higher dielectric properties and better window work, thus improving resistance against PID effect and better compatibility with other components. Such technology improvement is already available, with minimum costs and no significant changes in production process.

In order to verify whether the sensitivity to PID, tests required to qualify components and modules must involve voltage bias relative to module frame and temperature and humidity as accelerating factors. 2nd generation PID resistant EVA was tested using different kind of cells: standard and PID Free declared. Exposed at 60 ºC, 85 % R.H. and -1000 V during 96 hours (IEC 62804), EL pictures and I-V curves were checked and power degradation was negligible. Modules made with cells were measured under STC and Low Irradiance conditions (200 W/m^2). The figure below illustrates the average loss of power which was lower than 1 % with a new EVA generation.

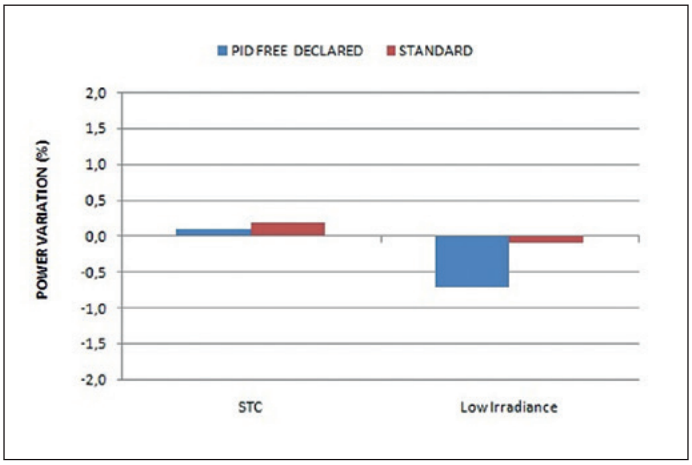

Fig 19. Average results at STC and Low Irradiance conditions for standard and PID Free cells

Insulation test (10.2) and wet leakage current test (10.15) were carried out according to IEC61215 after the PID test.

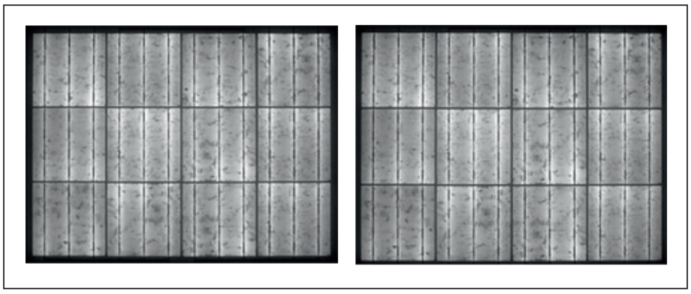

Fig. 22. Typical EL pictures at 100% ISC before (left) and after (right) PID testing20

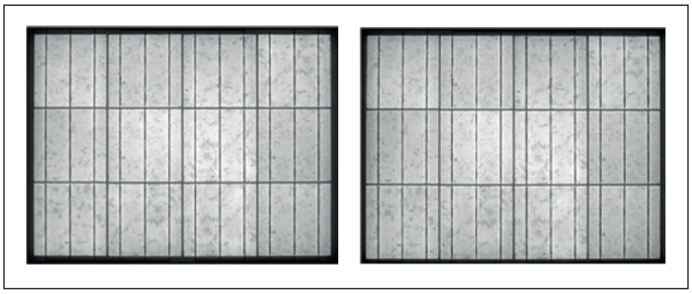

Fig 21. Typical EL pictures at 10% ISC before (left) and after (right) PID testing

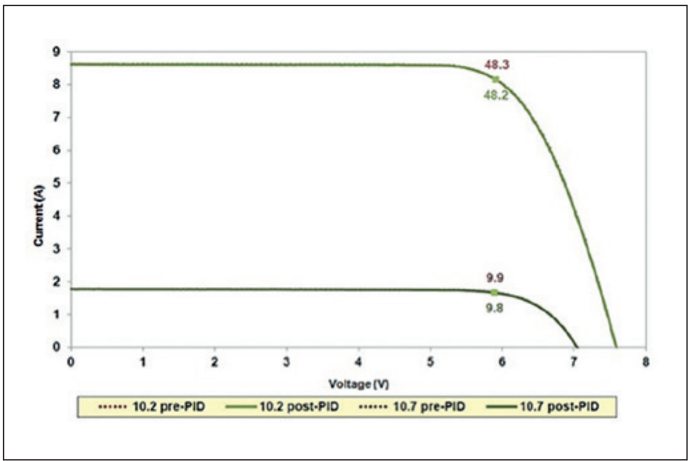

Fig. 24. IV curves at STC and Low Irradiation conditions before and after PID 22

Other procedures go beyond the IEC standard and apply more stringent conditions to increase the stress level and accelerate degradation. As example, standard 60 cell modules made with prone to PID multicrystalline silicon cells were exposed at 85 ºC, 85 % R.H. and -1000 V during 192 hours. All modules passed the test and average loss of power was lower than 1 %.

It is very likely that relative performance in the laboratory will be translated into the field, but tests don't reflect the behavior of the panels in the field and it is much too early to have comprehensive information of field performance. The problem will be completely solved when it will be proven that innovative materials, combined with best practices in installations will have completely eradicated the problem. This will not only require years of field data check but also the ability to follow carefully the behavior of products with the new EVA in the field.

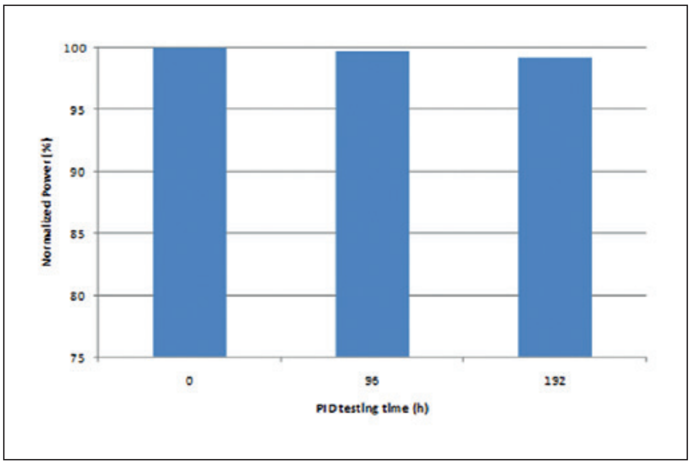

Fig. 23. Average loss of power up to 192 hours of PID testing






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Amazing solar photovoltaic technologies innovations just keep coming. Some advances come in the form of new revolutionary breakthrough technologies. While, others

are an evolution from the most currently used one. The articles presented in this magazine, review some promising technologies of different steps of the production of the solar panels. With the market size projections and the current production capacity, it's a good opportunity to think innovations….

On behalf of the editing committee, we would like to take this opportunity to thank all the authors for their valuable contribution sharing their expertise, taking the time from their busy schedule and responding within a very short notice. We appreciate very much your thoughtfulness and thoroughness in crafting these articles.

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