MEYER BURGER

Technological developments in module production

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Four examples of technological developments in production processes and measuring methodologies for solar module production

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ABSTRACT
In solar module manufacturing, three main processes can be distinguished: cell connection, lamination and testing/sorting. Each of these processes has a major impact on cell efficiency, solar module lifetime and module manufacturer turnover. It is therefore of the utmost importance that all the processes are correct, to get the most out of the cells and guarantee 20–30 years' lifetime. This paper describes novel technologies that are used in the module manufacturing process to ensure maximum module efficiency (electrical connection: Soft Touch and SmartWire Connection Technology) and lifetime (cross-linking density: non-disruptive X Link measuring method) as well as module manufacturer turnover (module testing: DragonBack® for high-capacitance solar technologies). All these technologies are ready for the highest efficiency c-Si cells (> 21% cell efficiency).

Connecting crystalline solar cells with discontinuous busbars on the rear using the Soft Touch soldering process

Joachim Ufheil

Crystalline solar cells in which the continuous busbars on the rear have been eliminated in favour of discontinuous busbars ('pads') are now increasingly common (Fig. 1). The objective is to economize on silver paste while also obtaining higher efficiency with a larger closed back-surface field. However, this presents some challenges for the soldering process. Since the aluminium coatings are up to 20µm higher than the pads, the question needs to be asked to what extent is it possible to completely (i.e. continuously) solder the pads on such cells if the silver paste to be connected to the cell connector is situated in a depression?

Figure 1. New cell design with pad busbars at the rear.

Ideally, there would be holders or soldering pins directly over the pads. Because of the variety of possible pad geometries, however, this would necessitate a number of different soldering heads, specifically adapted to each particular situation. In actual practice, it is not feasible to provide a separate soldering head for each cell type; hence, it is necessary to verify whether cells can always be soldered equally well using the same model of soldering head regardless of the geometry of the busbars. For verification purposes, test series were implemented with cells having different numbers and lengths of pads. A soldering head with 12 pins, which is the standard in stringer machines, was used in each case.

The objective was to obtain a continuous solder joint on each of the pads, which necessitates uniform heat input to the cell connector and especially to the border areas: this can be achieved using thermally decoupled soldering heads. With this new generation of soldering head, the temperature differences between the individual pins has been further reduced, and the high thermal capacity of the soldering heads ensures uniform heat input during the soldering process without any temperature outliers above or below.

The solder joints on the cells were implemented in each instance using the current standard material. Copper wire, which was shaped to have a rectangular cross section and coated with tin/lead/silver solder (62/36/2) to a thickness of 25µm, was used as the cell connector. A conventional isopropanol-based flux was used which contains adipic acid as its main active component. Only marginal changes were made to the soldering parameters compared with those for standard cells. The clock cycle and soldering temperature on

Figure 2. A Somont solder unit for two, three and five busbars.

the stringer were chosen to be nearly identical. In order to remain close to production conditions, cell strings consisting of ten cells were manufactured in each case in the test series.

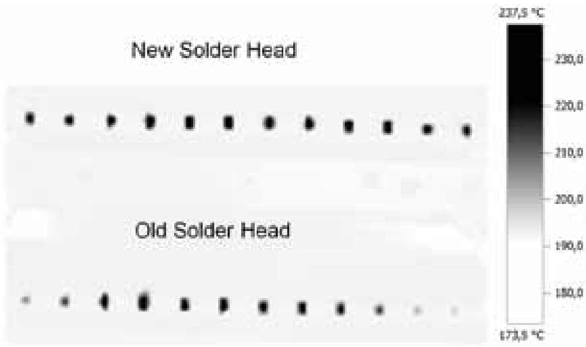

Figure 3. A thermal image, shown as a greyscale picture, for the new and old soldering heads. The temperature distribution has been almost completely equalized, especially in the border areas. This allows shorter soldering times as well as lower thermal stress to the cell.

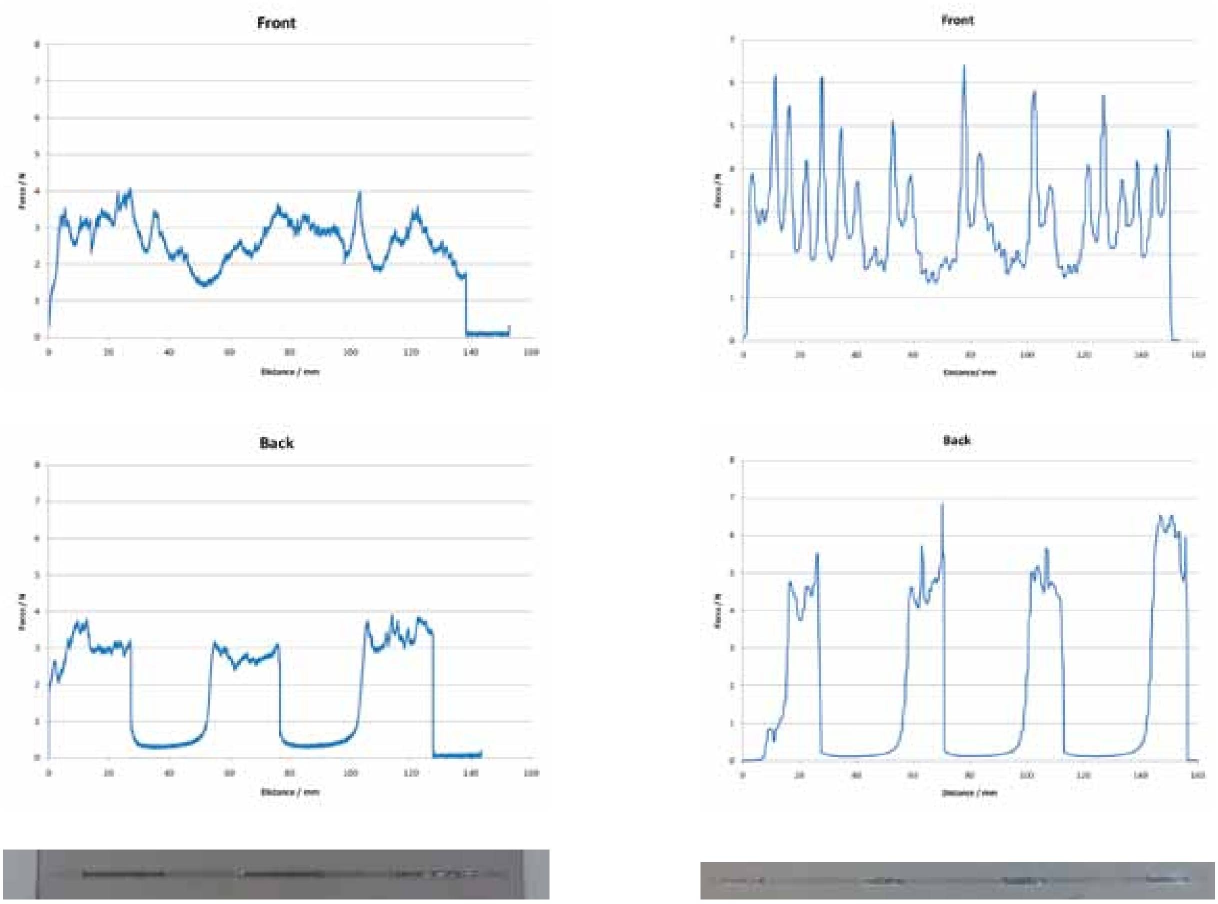

Figure 4. Peel diagram of the front and back ribbons and photo of the back side after the peel test: characterization of three pad (left), and characterization of four pad (right). Between the pads the force is zero.

No abnormalities were observed in terms of the melting of the solder during the soldering process. Depending on the proportion of adhesion surfaces on the top and bottom sides, the cell can exhibit bowing after the soldering process.

Individual cells were removed from the string and subjected to peel tests at 3mm/s at an angle of 180°: examples of the resultant peel diagrams are provided in Fig. 4. The forces plotted vs. distance on the peel diagram exactly replicated the pattern of the pad cells in the ideal case. For the aluminium paste, peel forces ranging from zero to small values were detected, depending on the cell. The forces on the different pads were highly dependent on the silver paste that was used. In both test series, however, peel forces of greater than 2N/mm^2 were measured.

On examination of the photographs of the cells after the peel tests, the first thing that could be observed was that the pads were almost completely soldered. Between the pads traces of the soldering process could likewise be visually identified, but these exhibited only insignificant adhesion forces. Good peel forces were also obtained on the front side. Note, however, that for the cells in the first test series, the busbar on the front side was continuous, whereas in the second test series, this particular busbar was not continuous.

Cells with pads on the rear side can be soldered in the same way as cells with continuous busbars on the rear side: no special modification of the soldering head is required for the pads. If there is a continuous busbar on the front side of the cell, a slight bowing of the cell will occur after the soldering process. The peel forces that are obtained on the pads are equivalent to those of a standard cell and depend on the prevailing soldering parameters and the silver paste that is used with the busbars.

SmartWire – The perfect path from solar cell to solar module

Marcel Blanchet

Today the majority of c-Si cells are connected electrically (stringing) using 2–3mm wide tin-coated copper ribbons, which are soldered onto the cell. This technology has been used since the very beginning of solar module manufacturing and is widely accepted on the market. Many companies have automated solutions for the stringing process, and the quality of the soldering process is very high. Nevertheless, there are some drawbacks concerning shading of the cell, impact of micro-cracks on module efficiency, and cost reduction potential in cell production. The SmartWire Connection Technology (SWCT) developed by Meyer Burger targets the disadvantages of the current busbar soldering method.

With SWCT every cell is connected using approximately 30 very thin coated copper wires on both the sunny side and the back side of the cell (Fig. 5), instead of using three to five wide copper ribbons. Busbars are therefore unnecessary on the cell; only the fingers are needed, which can now be as thin as 50µm because of the very short distance to the adjacent copper wire. On the back side of the cell no silver deposits for the busbars are needed because the wire has very good interconnection to the aluminium paste. This results in up to 80% reduction in the amount of silver required in cell production.

With a total of approximately 30 copper wires and 70 fingers per cell, a matrix of over 2000 contact points is created on each cell. This reduces the mean distance between the site of creation of electricity and the contacting point, thus reducing the serial resistance inside the solar module. A 10% higher energy yield (kWh/kWp) is possible compared to the best 3BB technologies. Moreover, micro-cracks have an insignificant effect on total module power, since the 2000+ contact points cover nearly every angle of the cell. By using SWCT, even a macro-cracked cell still remains contacted, resulting in a negligible impact on module power.

A further advantage of SWCT technology is the 3% reduction of the effective shading profile of the cell to 64% abs. of the total cell surface (Fig. 6). This equates to a 3% higher cell efficiency when cells are electrically connected

Figure 5. The wire foil is arranged on the solar cell.

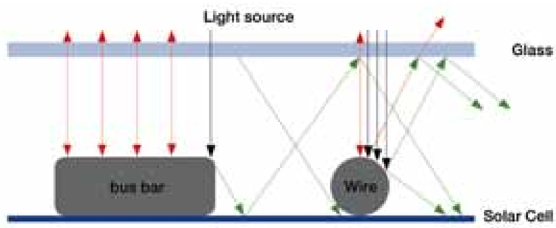

Figure 6. Reduced front wire shading and effective shading profile reduced to 64% [1].

Advantages of SWCT	Efficiency	Costs
No busbars needed on the cell	✓	✓
Up to 80% less Ag usage in cell production		✓
Lower serial resistance within the solar module	✓	
Improved energy yield by 10% compared with the best 3BB technology	✓	✓
3% larger active cell surface because of reduced shading A module with SWCT has up to a 10% higher energy yield (kWh/kWp) because of light trapping based on round wire	✓	
Higher reliability because of the number of solder dots, typically >2000	✓	
Better mechanical stability because of the mesh and wire foil; will be very tolerant to micro-crack suppression	✓	
Compatibility of SWCT with all types of wafer-based solar cell	✓	✓
Cells with rear-side aluminium paste will have a complete back-surface field (BSF), which will increase open-circuit voltage and cell efficiency		✓
Proven technology, with more than 200MW installed power		✓
SWCT is of particular interest when used together with the new Meyer Burger heterojunction technology (HJT) cells: here, the outstanding benefits of the two technologies, namely superior cell efficiency in conjunction with minimal transfer losses, combine to deliver a major customer advantage – the perfect path from solar cell to solar module	✓	✓

Table 1. Overview of the advantages of SWCT and the impact on the efficiency and manufacturing costs of a solar module.

Figure 7. Left: Solar module using 5BB technology. Right: Solar module using SWCT, developed by Somont [2].

using SWCT technology. Table 1 gives an overview of the advantages of SWCT and the impact on the efficiency and manufacturing costs of a solar module.

Aesthetic aspects are becoming more and more important in the installation of solar modules on roofs and facades. Since SWCT technology replaces the three to five wide ribbons with very thin and uniformly spread copper wires all over the cell, the appearance of the solar module is much more homogeneous. The cells, backsheet and contacting wires form a homogeneous black surface with a very thin grid of wires. From a distance of 5m, the wires are hardly visible, giving the impression of a homogeneous black surface (Fig. 7).

Somont sells the equipment needed for the automation of the SWCT manufacturing process, and 3S Modultec integrates the machines into a module production line. Both companies are members of the Meyer Burger Group.

An innovative measurement method for determining the cross-linking degree of EVA/glass/backsheet PV modules

David Rieder

Current measurement methods for determining the cross-linking degree of glass/backsheet modules have two major disadvantages: they are slow and they destroy the solar module under test. However, the degree of cross-linking is one of the most important quality characteristics of a solar module and needs to be measured both in a more comprehensive manner and by a method that is non-destructive. Fraunhofer USA, LayTec AG and 3S Modultec have now managed to integrate a non-destructive testing system into an existing laminator, which is capable of measuring the degree of cross-linking within about five seconds, thereby enabling statistical evaluation as well as a fast response to quality problems.

The lamination process

The purpose of the encapsulation process is to create a durable composite of materials protecting the sensitive functional units (cells and connectors) from external influences, and ensure electrical insulation and safety for the user. External influences include mechanical and chemical effects as well as moisture, UV light and ozone.

The quality of modern-day modules is monitored using a complete series of chemical and electrical tests. One of the most critical tests addresses lamination quality by determining the level of EVA cross-linking. The measured value provides insight into the quality of the lamination process and thus the quality and lifespan of the solar module [3]. Field measurements have shown that up to 10% of solar modules exhibit quality problems that can be traced back to deficiencies in the cross-linking process or the backsheet [4]. If the gel content is too low (< 75%), creep and/or delamination can occur. Moreover, water or moisture can penetrate into the module. If the cross-link density is too high, there is a risk of over-curing such that the EVA can no longer provide full protection. In view of all of these issues, more comprehensive measurement and quality inspection appear to be essential for solar modules.

Current measurement methods for determining the cross-linking value

The Soxhlet and differential scanning calorimetry (DSC) measurement methods are the most common techniques in use today.

Soxhlet

The Soxhlet method is a quantitative, chemical laboratory measurement technique used for continuous extraction of soluble contents from solids [5].

Advantages

- Mature technology, widely available and accepted

Disadvantages

- Destructive measurement method
- Chemical solvents required
- Manual measurement method
- Time-consuming test procedure (up to several days)
- Measurement and evaluation must often be performed by external labs

Differential scanning calorimetry

DSC is "a thermal process for measuring the quantity of heat released/absorbed by a sample during isothermal treatment, heating, or cooling" [6] (see Fig. 8).

Advantages

- Test procedure takes only a few hours
- No chemicals required

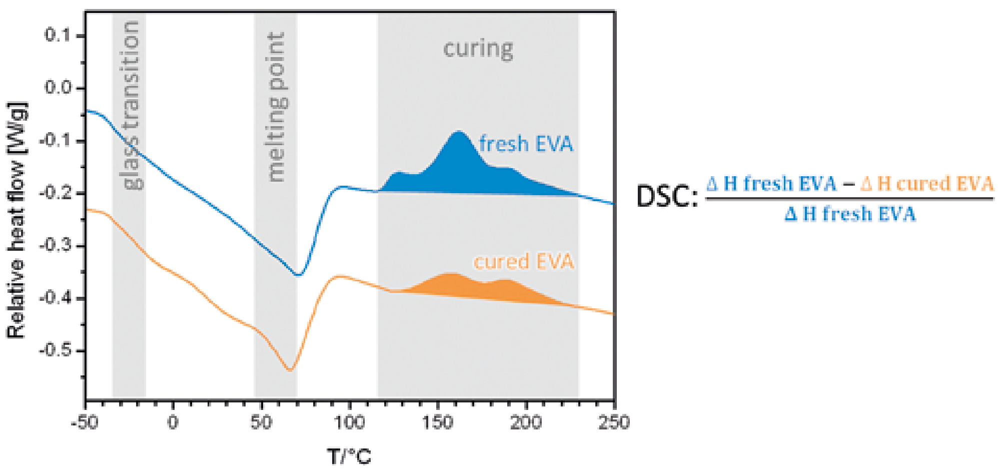

Figure 8. DSC measurement method [7].

Disadvantages

- Destructive measurement method
- Manual measurement method
- Correlation table required that can only be generated through prior destructive testing

X Link: A novel measurement method for determining the gel content

In cooperation with LayTec [7] and Fraunhofer USA, 3S Modultec (a member of the Meyer Burger Group) has now developed an innovative, non-destructive method for determining the gel content of EVA in-line. The novel technique offers decisive advantages over currently employed methods (see below).

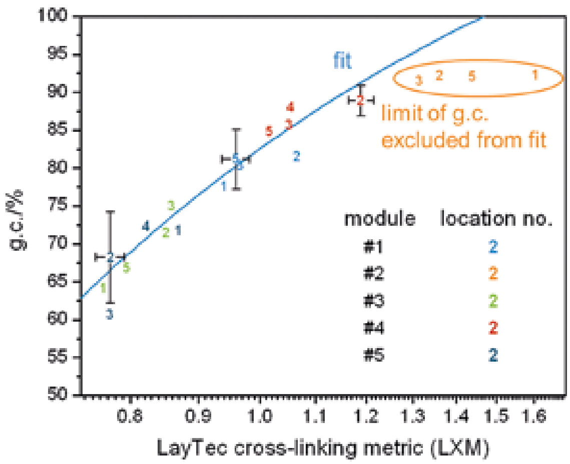

Figure 9. Correlation table comparison of the X Link and Soxhlet methods [7].

Measurement method and calibration

The X Link measurement method is based on sensing the mechanical properties of EVA that are correlated with the degree of cross-linking. Using a correlation table, the gel content can then be derived to allow a comparison to be made with the established Soxhlet extraction method. From these results, it is clear that the variance of the X Link measurement method is less than that of the Soxhlet method (Fig. 9). Moreover, it was possible to verify that the X Link procedure does not damage the cells (Fig. 10).

Advantages

- Non-destructive measurement method
- In-line and off-line measurement methods
- Automated measurement method
- 100% of modules can be tested
- Very short measurement duration (only approximately five seconds)
- No chemicals required
- Using laminators from 3S Modultec, the X Link measurement method can be integrated into the cooling press
- Usable for all glass/backsheet modules with cross-linking encapsulants

Disadvantages

- Requires a single calibration of each combination of EVA and backsheet (but there is an abundance of empirical data already available)

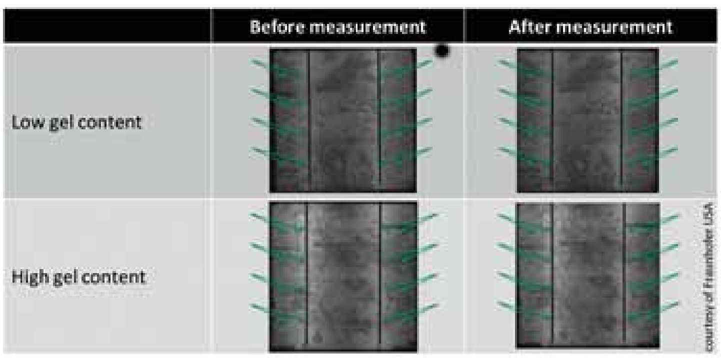

Figure 10. Electroluminescence images of a cell before and after measurement using the X Link method [7].

Figure 11. Set-up of a X Link off-line test station for small test samples and modules [7].

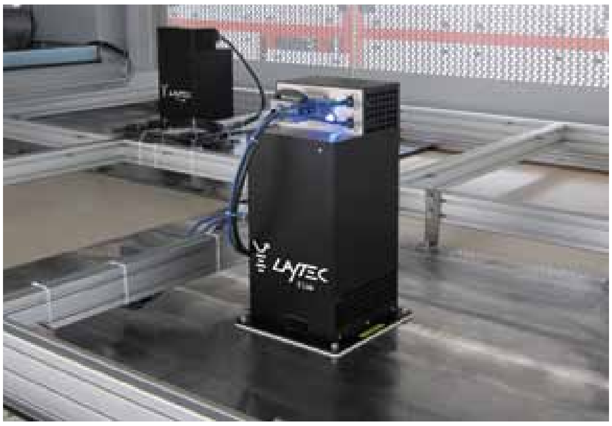

Figure 12. Integration of the X Link sensing head into the cooling press of a 3S Modultec laminator [8].

Practical application of the new measurement method

The measuring adapter can be used for either off-line or in-line measurements. Fig. 11 shows the set-up of an off-line test station. This set-up is suitable specifically for measuring solar modules or for applications in test laboratories.

In contrast, 3S Modultec has integrated the X Link measurement method into the laminator's cooling press, thereby enabling an in-line measurement of the cross-linking degree of solar modules for the first time (Fig. 12). The test set-up allows retrofitting all the existing laminators from 3S Modultec. The advantages are higher yield, lower risk of image loss thanks to more stringent quality control, and lower production costs with in-house testing. The measurement results are transferred directly from the test instrument to the SPS controller in the 3S Modultec laminator for storage and display on the screen. By using the PV02 interface, the measurement results are available to a higher-level manufacturing execution system (MES), such as FabEagle from Meyer Burger. In this manner, it is possible to measure the quality of every module and take action if necessary in order to ensure consistent quality (e.g. remove or reprocess the module).

X Link advantages

Higher yield

- Non-destructive measurement method
- In-line measurement allows immediate detection of process changes
- Simpler test procedure provides lower risk in case of new material combinations

Shorter ramp-up times

- Shorter measurement and evaluation duration allows faster process development

Module-based pricing

- Module-based quality assessment for more accurate pricing

Lower production costs

- In-house execution; no chemicals required
- Measurement results available immediately, so no quarantine necessary for new EVA batches

Optimized cycle times for the laminator

- Laminator cycle times can be optimized as a result of better and more accurate measurements of the cross-link density

Retrofit

- Upgrade possible for all existing 3S Modultec laminators

Bankability

- Manufacturers can deliver a complete track record to customers and certifiers for modules produced

Pasan DragonBack® – A dynamic solution for measuring the performance of high-efficiency PV modules

Corinne Droz

Advanced PV technologies that yield the highest efficiencies commonly exhibit high internal capacitance. Because of the slow response time, the electrical performance of these so-called 'HiCap' technologies necessitates modified measurement solutions. The traditional laboratory solution consists of a multiple-pulse measurement that increases the total measurement duration and allows the PV device to stabilize. However, a time-consuming measurement of this sort is not suitable for production. On the other hand, steady-state or 'long-pulse' light sources are not practical because of the higher total cost of ownership (TCO) and capex, and the poor light quality and temperature effect, resulting in low measurement accuracy.

The Pasan DragonBack® measurement methodology is based on a dynamic approach that models the voltage ramp with steps and overshoots according to the real internal capacitance of the module under test. This type of measurement can be performed within 10ms; as a result, an accurate measurement is obtained under $A^+A^+A^+$ light source illumination. P_{max} accuracy is within 0.5% or less compared with a reference multi-flash (MF) measurement.

Major challenges in high-efficiency module testing

Today's major challenge for the PV market and industry is to reduce the cost of PV electricity while maintaining a high level of quality. In order to achieve this goal, efforts are under way that involve the conversion efficiency on the one hand and the TCO on the other. This translates to the development of new PV materials with increased efficiency which must then be adapted to industry-oriented solutions for mass production at low cost.

New-generation PV materials with higher efficiencies commonly exhibit a highly capacitive effect that disturbs performance measurements when the conventional method is used. Such solar modules require a new approach for accurately assessing their electrical performance in production environments. The DragonBack® method, introduced by Pasan, is a solution that allows an efficient determination of the performance of highly efficient modules using an economical, high-quality pulsed light source.

The commercial value of a PV module is linked to its maximum power value (P_{max}) measured under standard testing conditions (STC). To determine this value, a solar simulator is used at the end of each module production line to test each individual module. The accuracy of this measurement directly affects the price for which the module can be sold and thus the manufacturer's profit.

The common way to assess a PV device's electrical performance is to continuously sweep the voltage applied to the device during illumination and record the corresponding current. Until now, the parasitic capacitance exhibited by any PV device due to electrical charges inside the semiconductor junction has been considered negligible, and performance measurements based on a flash light source lasting a few milliseconds (ms) have been very conventional. However, with the trend in PV technology shifting towards high-efficiency materials, this parasitic capacitance has increased dramatically and is therefore no longer negligible for performance measurements of a few milliseconds in duration. When a sweep is performed from 0V towards V_{oc}, the available current at the terminals is equal to the PV current generated by the module minus the current needed to charge the parasitic capacitance. When a sweep is performed in the reverse direction, the current is equal to the PV current plus the discharge current

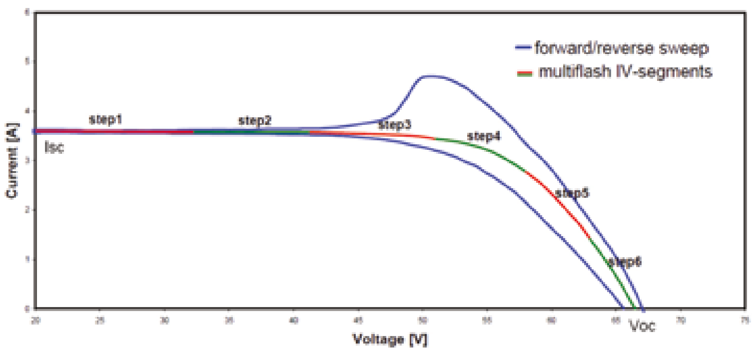

Figure 13. Forward and reverse I-V curves measured on a HiCap module with a linear sweep in a single 10ms flash (blue) compared to an MF measurement taken on the same module.

Method	Comments
Pulsed MF	Very accurate (used by reference labs), A⁺A⁺A⁺ light source quality, but time-consuming
Steady-state	High energy consumption and capex (high TCO), temperature effect
Pulsed 'long' flash	100–120ms not long enough for highly capacitive materials (~500ms necessary)
Average	Inaccurate P_{max}, real *I-V* curve is not the average of direct and reverse *I-V* curves
LED	Very poor spectrum quality (1 LED per IEC range!)
DragonBack ®	Low TCO, optimal tact time, very accurate and high-quality light source A⁺A⁺A⁺

Table 2. Comparison of measurement methods for HiCap modules.

of the parasitic capacitance. Consequently, P_{max} is either underestimated or overestimated (Fig. 13). To avoid such a measurement artefact, a time period up to 500ms, or even more, should be considered in order to obtain the correct power value. However, a long illumination time of this sort is not feasible with flash equipment, which must first ensure a high level of light quality (spectrum, uniformity) and stability.

The measuring procedure today

Until now, the methods available for measuring PV modules with high internal capacitance (HiCap materials, including heterojunction (HJT) devices) have not provided a satisfactory solution in terms of cost-effectiveness and accuracy. Because of the long response time of HiCap materials, the use of a pulsed solar simulator requires an MF measurement process in order to reduce the voltage ramp slope. Although this solution is the method of choice for accredited reference laboratories, which have the benefit of a high-quality light source, it does not suit the requirements of production lines, especially with regard to the cycle time.

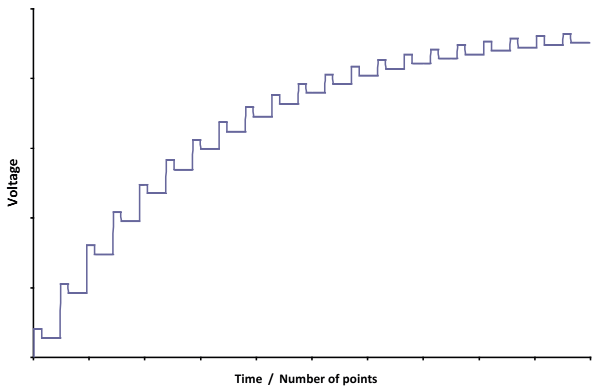

Figure 14. Typical DragonBack voltage ramp, including steps and overshoots.

On the other hand, steady-state testers could allow slow measurement, but this advantage would be rendered unfeasible because of several drawbacks of such machines: high cost, high energy consumption, low lifespan of the light source, poor light quality, and temperature effect impacting the measurement accuracy. Other proposed solutions include 'long' pulse equipment of up to 100–120ms; this, however, is not long enough to accurately measure HiCap modules, which typically require 200–500ms. Mean direct and reverse measurements have also been shown to lead to incorrect P_{max} estimates. Finally, the major drawback of the newly proposed LED-based testers is their very poor spectrum quality, which in turn has an impact on the measurement accuracy. Table 2 presents a comparison of measurement methods for HiCap modules.

The DragonBack measuring procedure implemented by Pasan

The DragonBack measurement methodology proposed by Pasan for highly efficient modules provides an option for module producers who seek a reliable, accurate and cost-effective measurement solution for advanced PV technologies. The most notable characteristic of this method is the combination of a highly accurate and highly repeatable measurement process for HiCap modules with industry requirements, including cycle time, low TCO and ease of use. Previously, the various proposed approaches for testing such materials were never able to satisfy the two main aspects, namely measurement accuracy and solution cost. In addition, this solution allows existing Pasan High^{LIGHT} tester equipment to be upgraded with the new process for measuring future high-performance technologies.

Using a 10ms single-pulse solar simulator, the DragonBack measurement method allows an accurate determination of the electrical performance (P_{max}, I_{sc} and V_{oc}) of HiCap PV modules in a production environment. The method is based on a dynamic sweep methodology that takes into account the specific capacitance of a given material. This adapted measurement technique overcomes the long stabilization time required by HiCap technologies.

Instead of applying a continuously increasing (linear) voltage ramp to the device, the DragonBack method applies a proper voltage profile, which consists of steps and adapted overshoots (Fig. 14). This results in faster charging of the internal capacitance and consequently diminishes the stabilization time. Accurate values for the *I-V* curve can thus be measured during a short illumination period. The distribution of the steps, as well as the specific shape of the step and overshoot, is adapted to each type of module on the basis of a prior measurement with which the capacitance profile of a representative module has been determined.

Fig. 15 shows the raw DragonBack applied and measured

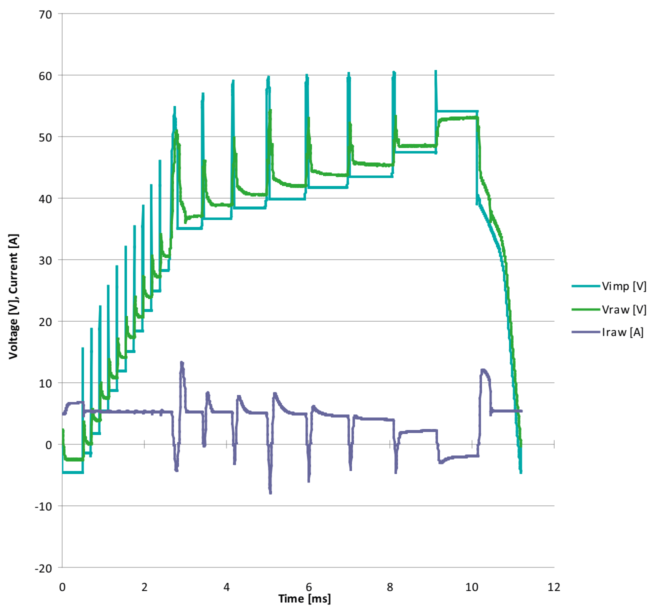

Figure 15. DragonBack applied voltage (blue), and the resulting measured voltage (green) and current (violet) for a commercial HJT module (type 1).

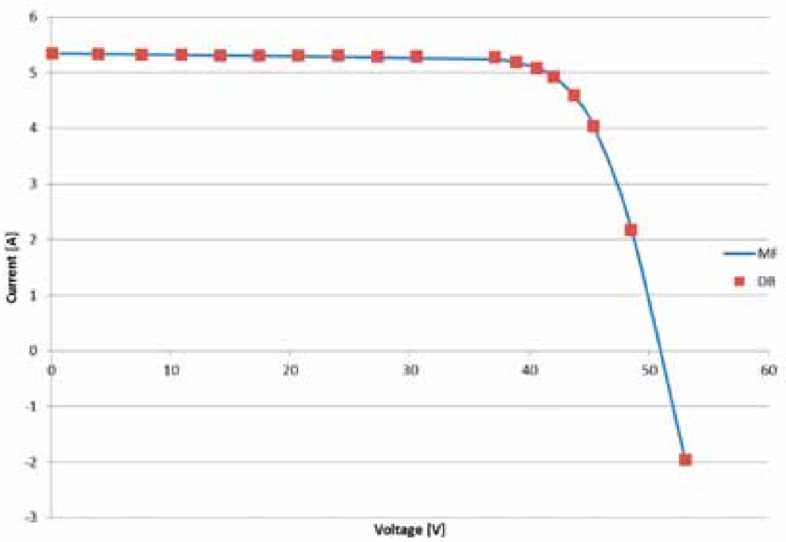

Figure 16. Comparison of the I-V curves obtained with the DragonBack method (red squares) and the reference MF measurement (blue line) for a commercial HJT module (type 1).

Module type	Producer	Typical max. capacitance	Number of points	Reference multi-flash results			DragonBack® results			Deviation		
				I_{sc} [A]	V_{oc} [V]	P_{max} [W]	I_{sc} [A]	V_{oc} [V]	P_{max} [W]	I_{sc}	V_{oc}	P_{max}
Commercial n-type cells	Yingli (Panda)	90µF	up to 30	8.94	37.32	243.18	8.95	37.29	242.97	0.05%	-0.08%	-0.09%
Commercial heterojunction type 1	Sanyo HIT type 1	350µF	18	5.34	50.91	207.43	5.35	50.91	207.01	0.07%	-0.02%	-0.20%
Commercial heterojunction type 2	Sanyo HIT type 2	700µF	10	7.59	43.16	245.67	7.59	43.16	246.86	-0.07%	0.01%	0.49%
Prototype heterojunction ultrahigh efficiency	R&R HJT	1mF	10	8.61	43.95	289.73	8.61	43.92	290.41	0.08%	-0.08%	0.24%

Table 3. DragonBack measurement results and a comparison with the reference MF method for different kinds of modules with various magnitudes of capacitance.

curves for a commercial heterojunction module (Sanyo HIT type 1). In Fig. 16, the stabilized *I-V* curve points for this measurement are compared with the reference *I-V* measurement obtained using the MF method. The DragonBack measured points are then fitted with a fourth-degree polynomial in the region of P_{max} and linear regression is used to extract I_{sc} and V_{oc}. As a result, the values obtained for the key parameters (P_{max}, I_{sc} and V_{oc}) are well within the 0.5% criterion as compared to the MF reference values (see second line of Table 3).

Table 3 lists the DragonBack measurement results obtained for different kinds of HiCap material. Experience has revealed that, with increasing device capacitance, the number of DragonBack stabilized points decreases, given an identical total measurement time of 10ms. However, for each kind of material and for all parameters, the deviation – when compared with the reference MF measurement – is comfortably less than 0.5%.

In conclusion, the DragonBack solution introduced by Pasan fulfils the need for an industry-oriented and cost-effective solution for measuring the power of highly efficient modules (which are consequently highly capacitive), taking into account production tact time, low TCO and measurement accuracy. An accuracy to within < 0.5% compared with a reference MF measurement has been demonstrated for several capacitive modules made from various technologies, when measured under a commercial $A^+A^+A^+$ Pasan 10ms light source with a 30s cycle time.

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