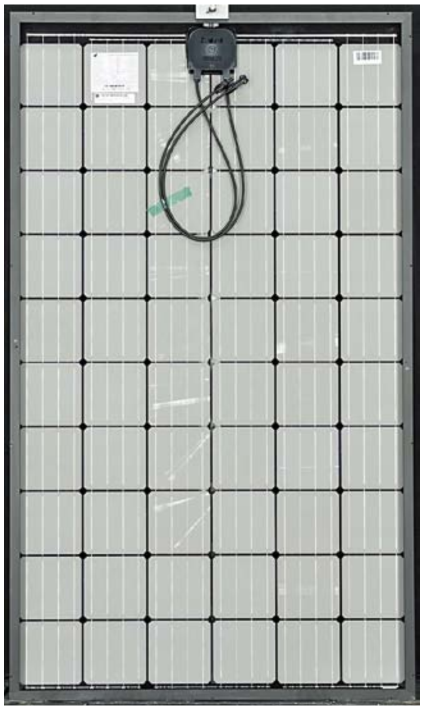
▶ On the test bench: The Excellent Glass/Glass 290PERC 60 module was the first to undergo PHOTON's rapid module test.



PI Photovoltaik-Institut Berlin AG (7)

Text: Anne Kreutzmann

A promising start

The first module to undergo PHOTON's rapid module test is a glass-glass module from Sonnenstromfabrik

Highlights

- Last year, PHOTON developed a rapid module test together with PI Photovoltaik-Institut Berlin with the intention of supplementing long-term yield measurements.
- The first candidate was a 290 W Excellent Glass/Glass PERC 60 produced by CS Wismar GmbH (Sonnenstromfabrik).
- The module passed all of the test categories, achieving fantastic results in most cases.
- One final test is still pending, however. Determining the module's susceptibility to PERC degradation was still ongoing when we went to press.

Germany-based Sonnenstromfabrik has its production base in Wismar. The company specializes in glass-glass modules, labelled Excellent Glass/Glass. Several different versions are available: with 60 or 72 cells; with transparent, white or black encapsulation material; with standard cells (mono or multicrystalline) or PERC cells. In addition, each version is available with or without a frame. The transparent, framed version of the 60-cell Excellent Glass / Glass PERC 60 module was put to the test here. This module is available with between 290 and 305 W of power; we tested the 290 W version.

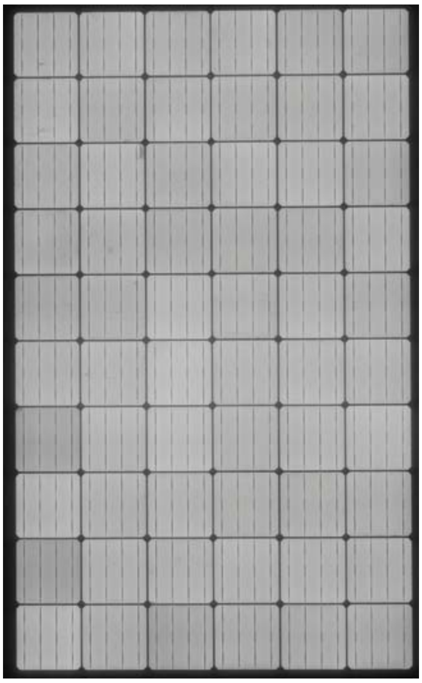
The modules were not procured on the open market, but rather provided by the manufacturer. Five modules were selected from a list

Overview of tests

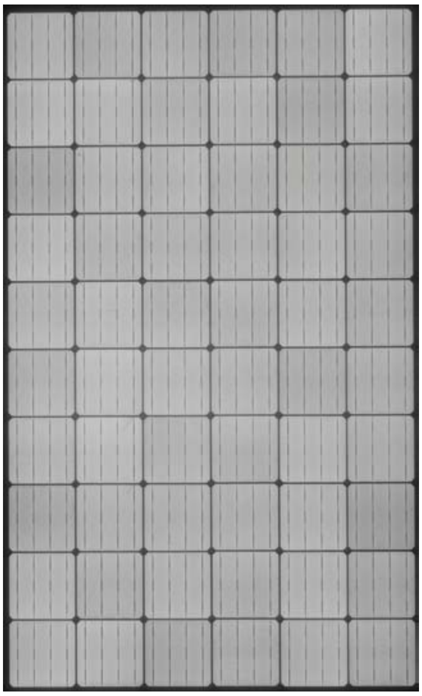
	Initial tests		Sequence I				Sequence II					Sequence III			Seq. IV
Serial numbers	Initial STC measurements	Initial EL analysis	LID	Low-light performance	PID (negative voltage)	PID (positive voltage)	Wet-leakage test	Dynamic load test + STC & EL	TC 50 test + STC & EL	HF 10 test + STC & EL	Junction box test	EL / STC under mechanical load	Peel test (EVA / glass)	EVA crosslinking test	LeTID (for PERC modules)
3353910	X	X					X	X	X	X	X				
3353912	X	X										X	N/A	X	
3353913*¹	X	X													
3353914	X	X	X	X	X	X									
3353920	X	X													in progress

*¹ Reference module

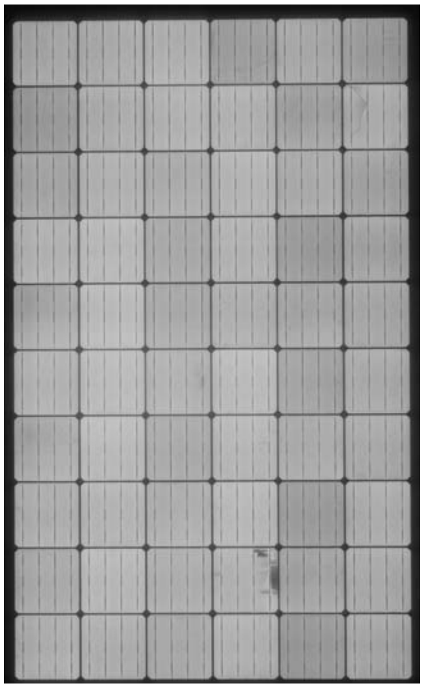
▲ Overview of test sequences: As the module tested was a glass-glass module, backsheet testing was not carried out this time. The PERC degradation tests were still ongoing when we went to print.



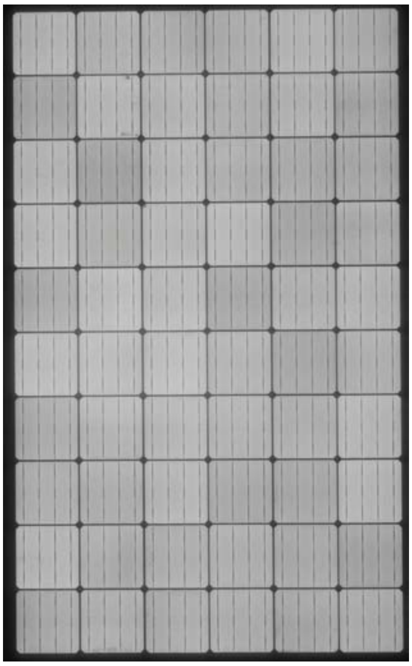
3353910



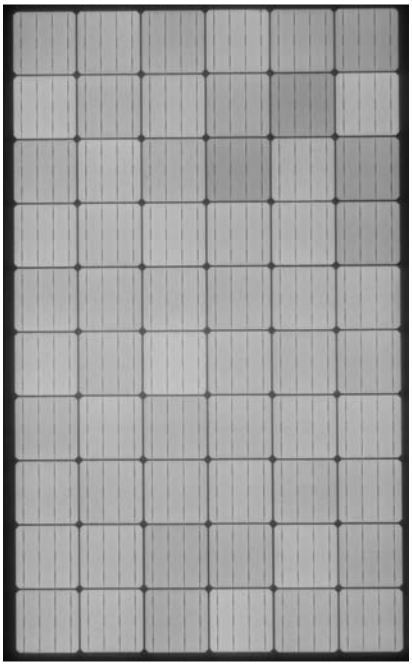
3353912



3353913



3353914



3353920

Evaluation of EL images taken before the start of testing

Serial numbers	Cells with micro-cracks	Cells with extensive microcracks	Cell breakage
3353910	2	0	0
3353912	2	0	0
3353913	3	0	0
3353914	1	0	0
3353920	0	0	0

▲ The electroluminescence analysis before the start of measurements showed hardly any abnormalities. Isolated microcracks appear, but cell breakage or extensive microcracks are not detected.

STC measurements before testing

Serial number	Test sequence	P_{MPP} / W	Abweichung	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %
Label info		290		32.26	8.99	38.83	9.58	-
3353910	Seq. 2	286.3	-1.30%	32.48	8.817	39.6	9.271	78
3353912	Seq. 3	286.8	-1.10%	32.5	8.825	39.6	9.312	77.8
3353913	Seq. 5	288.8*1	-0.40%	32.14	8.985*1	39.45	9.414*1	77.8
3353914	Seq. 1	285.7	-1.50%	32.45	8.803	39.49	9.313	77.7
3353920	Seq. 4	285.3	-1.60%	32.38	8.811	39.58	9.281	77.7

*1 Due to maintenance, this measurement was performed using different hardware, increasing the repeat accuracy to ± 1.6% (valid only when comparing data with this measurement). All remaining measurements have the specified repeat accuracy of ± 0.33%.

▲ Before testing begins, the most important electrical characteristics and power under STC for all five test subjects were determined. The values typically deviate by -1.2 percent from the values set out on the label, and that's within the range of measurement tolerances.

PI Photovoltaik-Institut Berlin AG

▲ Dynamic load test

of 50 serial numbers. Normally, there would be 200 serial numbers to choose from, but Sonnenstromfabrik pays particular attention to keeping low stock levels, so there weren't any more of this particular version available. The manufacturer didn't contact our editors to have its modules tested; our editorial team actually reached out to the manufacturer. As a result, based on the date of production, the module cannot have been produced specifically for the test – they were already finished before we got in touch. In addition, Sonnenstromfabrik signed an affidavit that the products tested are regular series products that have not been manipulated and are of average quality. And so, testing began.

Initial measurements

First of all, the modules' rated power was determined under standard test conditions (STC). All five modules have a power rating that is slightly lower than the 290 W recorded on the data sheet. At 285.3 to 288.8 W, however, the values are still within the measurement tolerance range of 2.9

Acronyms and units

STC	Standard test conditions
P_{MPP} / W	MPP power in W
V_{MPP} / V	MPP voltage in V
I_{MPP} / A	MPP current in A
V_{OC} / V	Open-circuit voltage in V
I_{SC} / A	Short-circuit current in A
FF	Fill factor in %
Δ% η	Chance in efficiency in %

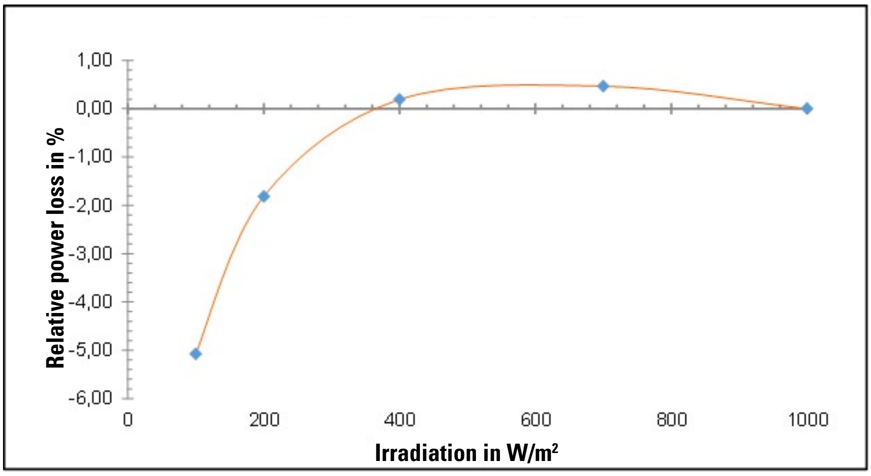
Light-induced degradation (LID)

Status	P_{MPP} / W	Deviation	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %
Initial	285.6		32.45	8.8	39.49	9.31	77.68
LID Cycle 1	283.8	-0.6%	32.22	8.81	39.53	9.3	77.21
LID Cycle 2	284.1	-0.5%	32.28	8.8	39.5	9.29	77.47

▲ The light-induced power decrease is minimal at 0.5 percent. Therefore, the power output remains fairly stable.

Low-light performance

Irr / W/m²	P_{MPP} / W	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %	Δ% η
1,000	284.1	32.28	8.801	39.5	9.285	77.47	0.0%
700	199.8	32.38	6.17	38.91	6.502	78.98	0.5%
400	113.9	32.21	3.536	37.99	3.726	80.45	0.2%
200	55.79	31.48	1.773	36.81	1.864	81.29	-1.8%
100	26.97	30.41	0.887	35.67	0.928	81.5	-5.1%



▲ Low-light performance takes a rather typical path, with a slight increase in efficiency around 700 W.

percent. This doesn't contradicts the manufacturer's claim that it only delivers products with a positive tolerance range. Measurement accuracy can be improved here if the spectral sensitivity of the cell is known, but that was not the case with this test. Therefore, based on PI Berlin's experience, typical values for the mismatch factor of PERC cells were applied.

Electroluminescence (EL) testing also went off without a hitch: though isolated microcracks are visible, there were no extensive microcracks or cell breakage discovered.

Test sequence 1

One of the modules was tested for light-induced and voltage-induced degradation (LID/PID); in addition, low-light behavior was determined.

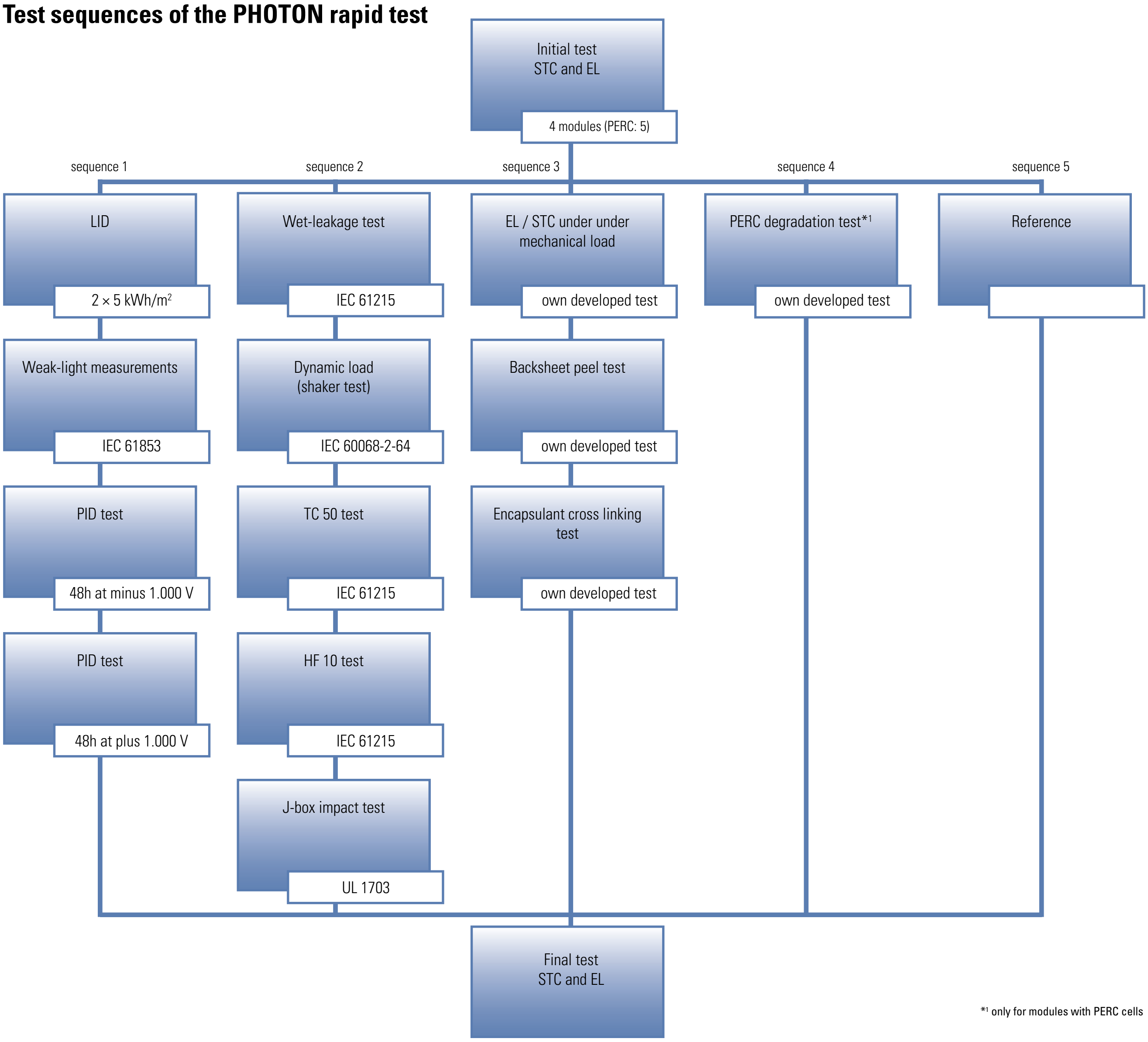
Light-induced degradation (LID)

The module was subjected to irradiation of 5 kWh per m2, after which the STC performance was determined again. This result was 0.6 percent lower than the initial measurement, which was slightly outside of the tolerance range for repeat measurements of 0.33 percent. Another cycle, again subjecting the module to irradiation of 5 kWh per m2, did not lead to any further changes. In fact, the measured STC output actually increased by 0.1 percent. Thus, the stabilized power of this module is only 0.17 percent below the output power, which is truly an excellent value.

Low-light performance

After stabilization, the low-light behavior was determined. This was carried out with irradiation levels of 100, 200, 400 and 700 W per m2. This test highlights whether a module is able to produce good yields even when irradiation conditions are bad. Reference measurements are taken under STC, so 1,000 W per m2. At 700 W, module output was 199.8 W, but efficiency increased by 0.5 percent, meaning that incident light is even more efficiently converted into electricity than at 1,000 W. At 400 W, the power dropped to 113.9 W, but

Test sequences of the PHOTON rapid test



▲ PHOTON's rapid module test is divided into three parts, or four if PERC cells are in play. One specimen does not undergo testing and simply serves as a reference module.

the efficiency was still 0.2 percent higher than at 1,000 W. At 200 W, however, the efficiency was 1.8 percent below the reference value; at 100 W, it was down 5.1 percent.

All of the values recorded are in line with the editorial team's expectations of a state-of-the-art module.

Potential-induced degradation (PID)

In order to determine any voltage-induced degradation, positive voltage and negative voltage are applied for 48 hours in each case. The voltage level corresponds to the maximum system voltage specified by the manufacturer – so, in this case, 1,000 V. The alteration in power output after both tests was 0.0 percent. The EL recordings show no deviation from the initial recordings. Thus, no susceptibility to PID was discovered.

Test sequence 2

The second test subject and its junction box were tested for electrical safety, then thoroughly shaken around. Any decrease in performance was then determined following humidity/freeze testing and thermal cycling.

Wet-leakage test

The module passed this test. The insulation resistance measured was 9,418 MΩ per m2; 40 would have been enough to achieve a passing grade.

Dynamic load test

While most of the modules will pass the insulation test, the dynamic load test, or shake test, is considered one of the toughest hurdles in PHOTON's rapid test. The dynamic mechanical load is intended to reveal structural weaknesses in the module design, including the use of thin embedding material or fragile solar cells. Pre-existing damage can be a real problem here, leading to significant, measurable reductions in subsequent tests.

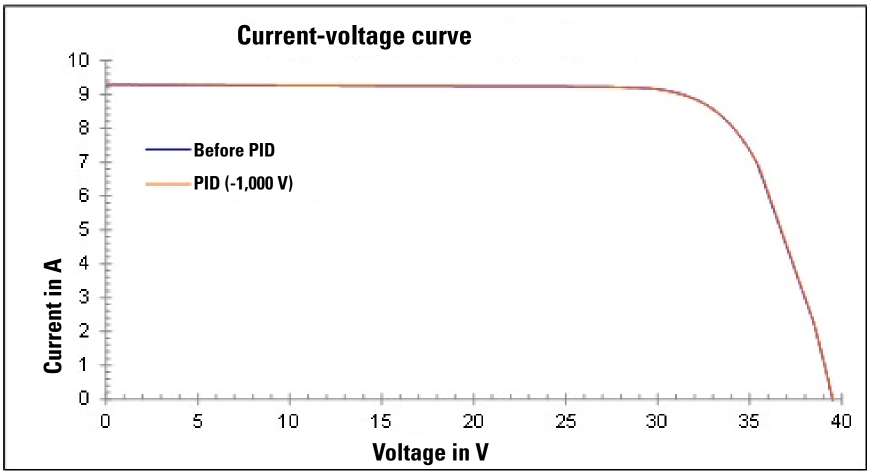
However, at least in this case, shaking the module did not harm the test subject measurably or visibly. Although the STC power measured after the test was 0.3 percent below the value recorded initially, it was still within the measurement tolerance range. Additionally, the EL recording showed no visible changes.

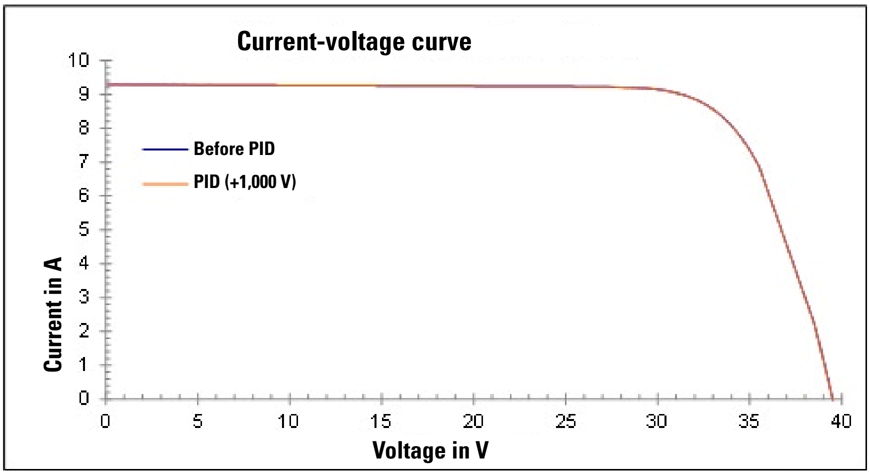
Thermal cycling

The subsequent temperature cycling test did not lead to any noticeable decrease in STC performance, with power down just 0.4 percent.

Potential-induced degradation (PID)

Status	P_{MPP} / W	Deviation	Change to EL image
Test with negative voltage			
Before	284.1		
After	284.0	0%	no
Test with positive voltage			
Before	284.0		
After	284.0	0%	no





▲ Voltage-induced power losses are not an issue for this module: The test shows no sign of susceptibility to PID.

Dynamic load test

Status	P_{MPP} / W	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %	Performance deviation from the previous test
Before	286.33	32.48	8.82	39.6	9.27	77.98	-
After	285.6	32.36	8.83	39.59	9.27	77.84	-0.3%

▲ After an hour of shaking, the module displays hardly any changes. The decrease in performance of 0.3 percent is within the range of accuracy for repeat testing. The electroluminescence images taken after testing show no abnormalities.

Thermal cycling test

Status	P_{MPP} / W	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %	Performance deviation from the previous test
Before	285.6	32.36	8.83	39.59	9.27	77.84	-
After	284.51	32.3	8.81	39.55	9.26	77.72	-0.4%

▲ Performance loss after 50 cycles of temperature cycling is minimal at 0.4 percent and is only slightly above the level of measurement accuracy set out for repeat tests of 0.33 percent.

Once again, the subsequent EL image showed no visible changes.

Humidity/freeze testing

After the humidity/freeze test, performance dropped 1.1 percent – and that's still a good value. The EL image showed no visible changes here either.

Junction box testing

The test subject passed the junction box test; the box remained undamaged.

Test sequence 3

The third module to undergo testing was initially subjected to mechanical stress and analyzed using EL. That was followed by destructive tests to determine the integrity of the laminate and quality of the encapsulation material. Glass-glass modules do not undergo the so-called peel test, which determines the force with which the backsheet can be peeled off.

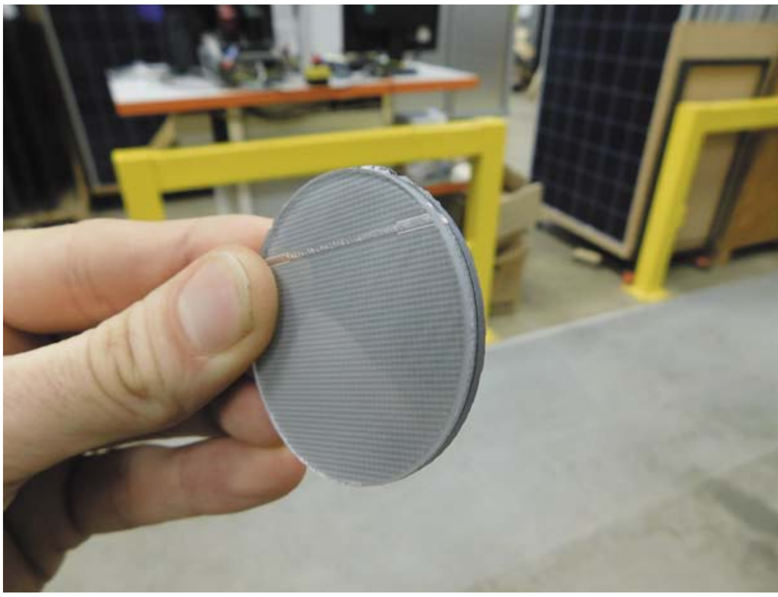
STC/electroluminescence under mechanical load

The module's STC power recorded under mechanical load deviated from the initial STC power by -0.1 percent. The EL imaging showed no visible changes.

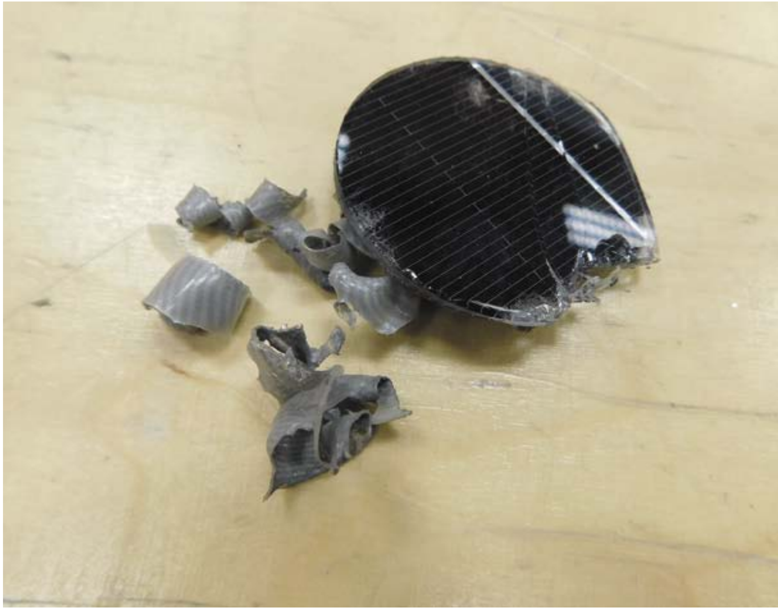
The result is not exactly surprising because the cells in glass-glass modules are encased in so-called neutral fiber – or at least that's the case when the glass on the front and back are the same strength and have the same level of elasticity. In this case, the cells are protected against tensile and compressive loads; bending the module has no effect.

EVA crosslinking test

Since low levels of crosslinking in the encapsulation material can lead to delamination or chemical-physical degradation – often recognizable by yellowing – a high degree of crosslinking is an important quality feature. The standard method for removing the EVA film is to pull off the backsheet. However, since the examined module has a glass-glass construction, a sample had to be cut out using a circular saw. Subsequently, the glass sides of the sample were destroyed and the EVA was removed from the back of the cell. The degree of crosslinking determined in two different positions was 85 and 86 percent. This value is in the upper range based on other research: Testing a total of 867 EVA samples from modules from different manufacturers, PI Berlin has reported crosslinking levels between 30 and 90 percent.



PI Photovoltaik-Institut Berlin AG (4)



▲ Taking an EVA sample from a glass-glass module was significantly more complicated than is the case with modules with backsheets. In order to reach the encapsulation material, a piece of the module was removed using a circular saw and the pieces of glass were carefully removed so as not to falsify the results.

EVA crosslinking test

Position	Degree of crosslinking ± measurement accuracy (%)
1	85 ± 2.1
2	86 ± 1.8

▲ The level of crosslinking of the encapsulation material is 85 percent, which is an acceptable figure.

Humidity/freeze testing

Status	P_{MPP} / W	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %	Performance deviation from the previous test
Before	284.5	32.3	8.81	39.55	9.26	77.7	
After	281.2	32.12	8.76	39.4	9.24	77.2	-1.1%

▲ The moisture/freeze test resulted in a slight drop in performance of 1.1 percent after 10 cycles. The electroluminescence images show no changes, which was also the case after temperature cycling.

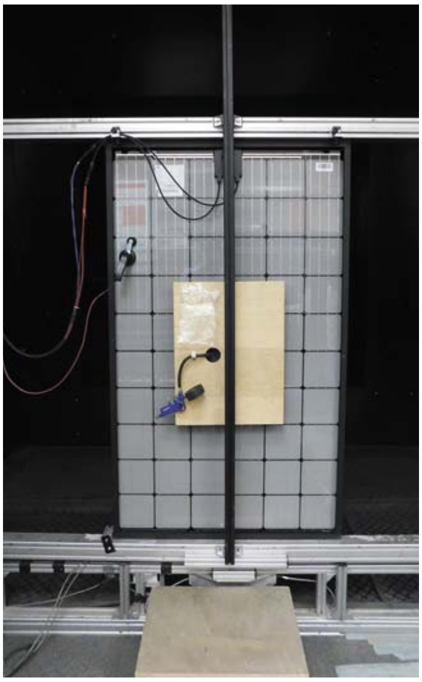
Manufacturer's comment

We are extremely satisfied with the results, except for the results of the initial performance measurements. Your results are about 1.2 percent lower than our measurements. During external measurements at Fraunhofer ISE and TÜV Rheinland, our modules achieved significantly higher power.

Performance under mechanical load

Status	P_{MPP} / W	V_{MPP} / V	I_{MPP} / A	V_{OC} / V	I_{SC} / A	FF / %	Performance deviation from the previous test
Before	286.82	32.5	8.83	39.6	9.31	77.79	-
After	286.46	32.4	8.84	39.64	9.29	77.79	-0.1%

▲ When tested under mechanical stress, the module is bent and the STC performance is determined; electroluminescence images are also captured. During this test, performance didn't decrease at all – the 0.1-percent drop recorded is within the scope of repeat measurement accuracy. The EL images do not highlight any changes when the module is no longer loaded.



PI Photovoltaik-Institut Berlin AG

▲ Electroluminescence images are usually taken without mechanical stress being applied. We aim to discover whether microcracks and other damage visible under EL are more pronounced under load. A special test bench was designed specifically for this test procedure.

PHOTON module test workshop

At our upcoming workshop, called PHOTON's module tests – results and outlook, we will outline insights gained from our tests up to this point. This will include results from long-term yield measurements and rapid testing started this year. An important component of this event will involve discussing the results and further developing evaluation criteria – so specific grading – which are intended to help end-users in their purchasing decisions.

Agenda

1:30-2:15 pm
Anne Kreutzmann, PHOTON
Presentation of PHOTON's module tests: Why we are testing modules and how we are testing them
Lars Podlowski, PI Photovoltaik-Institut Berlin
PHOTON's module tests: Overview of the results so far
Bernd Litzenburger, PI Photovoltaik-Institut Berlin
Comparing PHOTON's module test to other test procedures: Insights from different tests

2:15-3 pm
Florian Brahms, lawyer from Brahms & Kollegen
Effects of the PHOTON module tests on contract design: How can quality be legally agreed?
Radovan Kopecek, ISC Konstanz
Bifacial modules: What special features should be taken into consideration and how should test results be interpreted?
Giso Hahn, University of Constance (invited)
Beware of PERC cells: Current research on PERC degradation – light and elevated temperature induced degradation (LeTID)

3-3:30pm
Coffee break

3:30-4pm
Open discussion (all participants)
Moderator: Anne Kreutzmann
Further development of PHOTON's module tests: How can testing be improved while keeping costs stable?
What kind of rating system would be most helpful for customers?

Where Munich, Germany
When June 21, 2018, 1-4 pm (alongside Intersolar event)
Cost €120 (before tax), €99 for subscribers
Conference language German
Registration www.photon.info → Akademie → Workshop PHOTON Modultests (German website)

Program suggestions lab@photon.info

Test sequence 4

PERC degradation

Since the modules on the test bench this month use PERC cells, testing was also carried out to test performance-reduction issues associated specifically with this type of cell: light and elevated temperature induced degradation (LeTID). The underlying mechanisms are still being decoded by research teams and industrial players, which explains the lack of standardized testing.

Although one test subject was tested for LeTID issues as part of PHOTON's rapid test, the results are not yet ready for publication. This is attributed to the fact that the test procedure has to remain the same for all modules tested in the future – and they are yet to be definitively set. The test conditions presented in the September issue of PHOTON International anticipated using a temperature of 85 °C, but we have since come to the conclusion that better results can be achieved at 75 °C – thanks in part to numerous responses from the industry. The values for current supply have also been adjusted. This test will now be repeated on the reference module, which serves as a spare for these kinds of incidents; the results will be published in one of our upcoming editions. ●

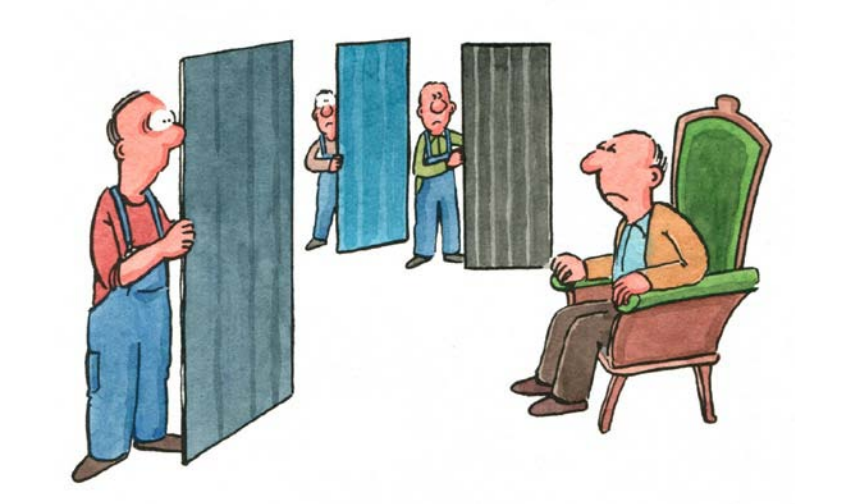
Overview of test results

Sequence	Test	Result	Notes
Initial	Visual inspection	Passed	No critical defects
Initial	EL analysis	Passed	No critical defects
Initial	Temperature coefficient	-0.40 %/°C	From datasheet
Sequence 1	STC & LID	-0.5%	Compared to P_{MPP} beforehand
	Low-light performance @ 200W/m²	-1.8 %rel	Relative power loss (related to STC power)
	PID (negative / positive)	0.0%	Compared to P_{MPP} beforehand
Sequence 2	Wet-leakage test	Passed	
	Dynamic load test	-0.3%	Compared to P_{MPP} beforehand
	TC 50 test + STC & EL	-0.4%	Compared to P_{MPP} beforehand
	HF 10 test + STC & EL	-1.1%	Compared to P_{MPP} beforehand
	Sequence 2 STC overall	-1.8%	Compared to P_{MPP} beforehand
	Junction box test	Passed	
Sequence 3	STC & EL under mechanical load	-0.1%	Compared to P_{MPP} beforehand
	Peel test (Glass/EVA)	-	Not applicable for glass-glass modules
	EVA crosslinking test	85%	Only EVA evaluable
Sequence 4	LeTID	**In progress**	-

▲ The tests carried out to date highlight the outstanding quality of the Excellent Glass / Glass 290PERC 60 module. However, one important examination is still pending: tests on PERC degradation take well over 6 weeks to complete, so the results will be published in one of our upcoming editions.

Further information
Contacts page 81

Rating test results



Gerhard Brunner / PHOTON Pictures

▲ Decisions, decisions: As soon as enough test results are available, a grading system will be put in place to inform customers about module quality.

PHOTON's rapid module test is intended to make it easier for future PV system operators to decide which modules to buy. Ideally, this could be achieved via a grading system that summarizes the results in school grades, such as A+ to F, for example. However, that kind of system assumes that everyone knows what an A+ grade module is capable of. As was the case with PHOTON's inverter test, our editorial team has decided to gather some experience first, and then propose a rating scheme later, which will be discussed at a workshop taking place in parallel to this year's Intersolar Europe event (see box, p. 52).

As a number of PHOTON's tests are based on existing standards, the failure criteria of those standards can be used to assess the corresponding results. These include:

Power measurements (STC)

Power measurements are taken at the beginning and at the end of non-destructive test sequences. The decision as to whether or not a module has passed the test is defined in the IEC 61215: 2016 MQT 19.1 standard.

Thus, a module is deemed to have passed this part of PHOTON's module test if the measured power under standard test conditions (STC) is within the rated power range specified on the module's label, taking the measurement accuracy of the solar simulator into account.

Wet-leakage testing

The standard for insulation tests is IEC 61215, chapter 10.15. A module is deemed to have passed the test if the measured insulation resistance multiplied by the module area is at least 40 MΩm².

Thermal cycling (TC 50 test) and Humidity/freeze testing (HF 10 test)

To pass the thermal cycling and humidity/freeze tests, the following must apply:

- No major visible damage may occur (defined in accordance with section 7 IEC 61215 Ed. 2).
- The output power measured before testing must not decrease by more than 5 percent.
- The insulation value must meet the same requirements as before the test began.

Junction box testing

The criteria for passing the junction box test are outlined in the US norm UL 1703 Ed. 3, section 30. The module is deemed to have passed the test if any fragments occurring are less than or equal to 6.5 cm². However, a module automatically fails this test if the damage to the junction box exposes live contacts, as this means there is no longer any protection in place if touched. ● ak

Participating in PHOTON's rapid module test

PHOTON's rapid module tests are open to anyone. That includes manufacturers, dealers, installers and plant operators – quite simply: anyone who is interested in a specific type of module. In order to take part in testing, clients have to cover the associated costs. However, we have endeavored to make keep these as low as possible. Rapid testing for a module with PERC cells costs €6,800 ($8,380) before tax, while all other crystalline modules cost €5,500 ($6,780). The results are available within 6 weeks.

A summary of the results is then published in PHOTON International. For those interested in more information than the short overview provides, a full test report spanning 50 pages can be ordered via PHOTON's website (www.photon.info → Laboratory → Module test → Rapid Test). It's also possible to place a non-binding pre-order for test reports before they become available. As soon as enough pre-orders are placed, these modules will be tested.

You could also approach us to suggest certain modules you would like to see tested. Our editorial budget also allows for testing third-party modules to provide a complete overview of the modules available on the market.

Modules are procured by PHOTON's editors to ensure that regular series modules are tested and not any that have been specifically produced or selected for the test. In order to exclude »golden samples,« modules will be procured on the open market if possible. The module manufacturer is then informed of the serial numbers before the start of testing and has 14 days to state why any of the products on hand may be atypical products that should not be tested. One reason, for example, would be if the modules concerned were actually sold as B-rated commodities, but that information was not clearly marked when purchasing onward.

If modules cannot be purchased on the open market because the module is very new or because retailers do not supply very small quantities, the module manufacturer has the option of sending the editorial team a list of 200 serial numbers of the desired module type, from which the editors can then select 4 (or 5 in the case of PERC modules). In addition, in this case, the manufacturer also has to take an oath confirming that the products provided are regular series products.

Before publication, the measurement results are provided to the manufacturer. If both parties agree that measurements were made correctly, the results are published. If there are concerns on the part of the manufacturer, it is the editorial team's responsibility to evaluate them and then to decide in regard to publication. The manufacturer's comment is an integral part of the report. ● ak

We look forward to your comments:
lab@photon.info

Outline of PHOTON's rapid module test

PHOTON's rapid module test allows for a quick and yet informative assessment of module quality. It reveals product defects and provides an outlook of expected performance decline due to degradation effects. Four samples of each module type to be tested are required, one of which serves as a reference module. For modules using PERC cells, another specimen is needed to test for PERC degradation specific to this type of module.

First things first: STC measurements and EL imaging

At the beginning of the test cycle, all modules are examined. A current-voltage characteristic curve is recorded according to IEC 60904-1 for all modules using a Pasan SS3b simulator. The light source used is a xenon lamp with a pulse duration of 10 ms (class A, according to IEC 60904-3). For high-capacity modules, several pulses are used in succession to achieve sufficient exposure time. Whether a module counts as high capacity or not is determined by recording the current-voltage curve in both directions. In high-capacity modules, the two curves differ. The simulator is regulated with a stabilized reference cell calibrated by Germany's Physikalisch-Technische Bundesanstalt (PTB) based on the World PV Scale Standard (WPVS).

The electroluminescence (EL) images highlight any damage to the solar cells caused during cell or module production or during transport.

Test sequence – module 1

After the electrical properties are determined, module 1 undergoes the following tests:

Light-induced degradation (LID) testing

With light-induced degradation (LID), modules can lose several percentage points of their original power output right at the beginning of their operating life. In order to measure the power loss occurring up until performance stabilizes, the modules on the test bench must not have prematurely aged.

Stabilization is carried out according to the industry standards IEC 61215-1-1-1:2016 and 2:2016. The module is connected to a resistor that holds it close to the maximum power point (MPP). Two rounds of exposure are then performed at 5 kWh per m^2. To carry out this test, a class C solar simulator with HQI lamps is used, the module temperature is maintained at 50 °C ± 10 °C, and irradiance is held at 800 to 1,000 W per m^2.

Low-light performance testing

Once the module output is stabilized, the low-light performance is determined. In addition to the current-voltage curve already recorded at 1,000 W, characteristic curves are recorded at irradiation values of 100, 200, 400 and 700 W.

Potential-induced degradation (PID) testing

With potential-induced degradation (PID), the voltage applied to a module causes power to decrease. The higher the voltage, the stronger the effect. To find out how susceptible a module is to PID, the maximum system voltage specified by the manufacturer is applied over 48 hours, both as positive and negative voltage. The module is exposed to a temperature of 85 °C and a relative humidity of 85 percent. Afterward, the current-voltage characteristic curve is recorded again within 4 hours and an EL image is created. The PID test is carried out in accordance with IEC TS 62804.

Test sequence – module 2

Module 2 is subjected to various stress factors that are intended to reveal production defects and the use of inferior materials:

Wet-leakage test

The wet-leakage test is carried out in accordance with IEC 61215. During the test, the module and plug are submerged in water to check dielectric strength. Except for the openings of the junction box, the entire surface is completely covered with water. The junction box itself is only sprayed with water. The short-circuited module connections are connected to the positive pole of a DC insulation measurement device, while the water bath is hooked up to the negative pole. In the case of framed modules, the water on the back of the module is also electrically connected to the water bath. During the measurement process, the maximum system voltage specified by the manufacturer is applied to the module – for a period of 1 minute for thin-film modules and 2 minutes for crystalline modules. Then the insulation resistance is determined.

Dynamic load test

During transport, solar modules are often subjected to considerable vibrations. Modules with cells that exhibit microcracking or for which the cells are not properly encapsulated can then sustain damage that leads to a significant loss in performance, particularly in connection with thermal stress. The dynamic load test is carried out according to an international standard used in the logistics sector, DIN EN 60068-2-64:2009-04. The test specs are based on military standard STD 810F. The test includes the use of an electrodynamic vibration generator (shaker). The modules are mounted horizontally on a pallet and exposed to vibrations at different frequencies for an hour. The broadband noise acts vertically on the modules and has a frequency of 5 to 500 Hz. With a high-quality solar module, this test should not lead to significant deterioration in STC performance, nor should any damage be visible in the EL images.

Thermal cycling

During the thermal cycling test in accordance with IEC 61215, the module is alternately heated to 85 °C and cooled to -40 °C, with each stage maintained for a period of at least 10 minutes. In contrast to the IEC test, the PHOTON rapid test only runs 50 cycles instead of 200 cycles. However, the test report records whether and, if so, by how much the STC performance has decreased during the test. The IEC certificate does not cover this type of grading, only specifying whether the module passed or failed.

In any case, extensive power loss of up to 5 percent would also be evident within 50 cycles. So although it's significantly shorter than the IEC test, the PHOTON rapid test could be considered to be more informative as it also reports limited power losses.

The question of what can be concluded from the power losses determined during the first 50 cycles on the further development of the module is particularly interesting. This question is answered by the lifetime test in the »PHOTON Silver Standard« (PHOTON International 10-2017).

Unsicherheit der Testergebnisse

	Relative error rate	Repeatability
Nominal power P_{MPP}	2.9%	0.33%
Open-circuit voltage V_{OC}	1.3%	0.12%
Short-circuit current I_{SC}	2.2%	0.13%

▲ Estimating measurement accuracy: The relative error rate always has to be taken into account when evaluating test results.

Humidity/freeze testing

The humidity/freeze test is also carried out in accordance with the specifications of IEC 61215:2016. In contrast to the thermal cycling test, the number of cycles has been adopted without change, remaining at 10 cycles. A temperature cycle consists of half an hour at -40 °C and 20 hours at 85 °C with humidity of 85 percent. This enables the resistance of a module to night frost, followed by hot days with high levels of humidity, to be determined.

Junction box testing

The junction box test is carried out in accordance with the US standard UL 1703 Ed. 3. A steel ball is dropped from a height of 1.3 m onto the junction box. If the damage this causes is severe enough to expose the contacts and there is no longer any contact protection, the module has failed the test. If not, it spends 3 hours in the climatic chamber at a temperature of -37 °C. The test is repeated and the junction box is checked again for damage.

Test sequence – module 3

Using module 3, the individual materials are examined. These tests are primarily destructive in nature:

Electroluminescence under mechanical load

This test has the same setup as the EL image does in terms of the currents applied and the camera used. As a special feature, however, the solar module is simultaneously exposed to mechanical stress. The test conditions are therefore largely equivalent to the conditions that prevail during system operation.

For this test, a lifting cushion between the rear of the module and a rigid plate is filled with compressed air, placed at a distance of about 20 cm. The critical factor in this case is the pressure in the cushion, as it determines the deflection of the module. However, since it is not possible to define a pressure value in bar that always results in a uniform deflection due to different sizes and strengths of solar modules, this value must be determined directly. To do so, a digital depth gauge is placed in the center of the front of the module by using a strut and is zeroed when the module is unloaded. The pressure in the cushion is then increased until the depth gauge indicates a deflection of ten mm. The depth gauge and strut are then removed and an EL image is produced. Its evaluation is based on the same procedure as for a mechanically unstressed test.

Backsheet testing

The test examines the connection of the backsheet to the remainder of the module and is performed in accordance with IEC 61730:2016, but deviates from the standard in positioning and evaluation. The test determines the force required to separate the film from the front glass and cells. This allows the strength of the interconnection to be assessed in relation to other modules. The more solidly the individual components are connected to each other, the lower the risk that they will separate from each other over the course of a hopefully long module service life.

EVA crosslinking test

The process of testing the degree of EVA crosslinking is based on IEC 62788-1-6:2017. The film normally used is made of ethylene vinyl acetate (EVA) and is available on the market in varying qualities. It is particularly susceptible to poor processing. Exceeding the storage period only slightly is sufficient to cause insufficient crosslinking in the material, making the entire module vulnerable to delamination. The test aims to uncover exactly these problems.

PERC degradation testing (module 4)

For modules with PERC cells, a fourth module is tested for PERC degradation. When PERC cells are used, not only is the front of the cells passivated, but also the back of the cells, which results in higher efficiencies. At the same time, however, these cells are also the most capricious of all the cell types and tend to suffer with performance losses that have not been fully understood so far. Current warnings are primarily based on information released by PERC cell manufacturers, who refer to their own measurements showing the corresponding degradation effects on competing products. At the same time, however, these manufacturers claim that they have the problem under control. The PERC test is designed to reveal how severe the problem actually is.

For this purpose, the module is energized in the dark at a temperature of 75 °C over a period of 1,000 hours, which is a little over 5 weeks. The amount of current applied is a twentieth of the short-circuit current specified by the manufacturer. At intervals of 168 hours, the current-voltage curve is recorded. ● ak