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MBJ Solar Module Judgment Criteria

Analysis criteria for solar module testing in the MBJ Mobile Lab & MBJ Mini Lab

Date: 10.11.2022 – Revision 5.0

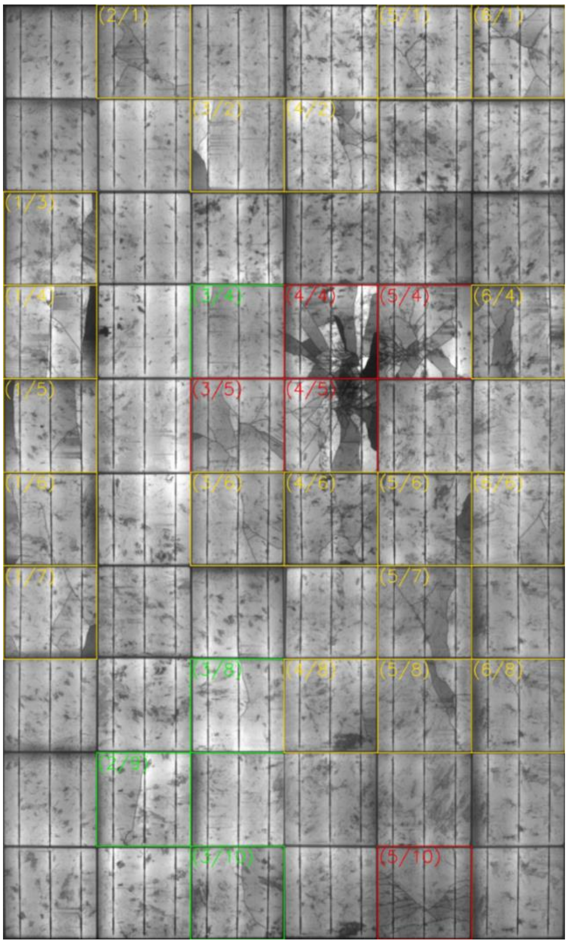
Foreword

This is the 5th revision of the MBJ Judging Criteria. The revision became necessary to adapt the assessment to the new PV module technologies, including the improvements in cell design, especially the multi-bus bar technology and the half-cut cell designs.

One main change is that non-critical errors can no longer lead to a rating lower than B. Another main change is the power classes are new defined. The visuals have been updated and some text passages have been revised.

Please note, this version can also be applied to older cell designs with two or three bus bar cells and full cells.

Compiled by MBJ Solutions GmbH and partners.



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1. Test methods and module quality classes

The actual condition and possible preliminary damage to PV modules are tested in the Mobile Lab or Mini Lab from MBJ Solutions GmbH by different test methods.

- Power measurement under simulated or approximated STC (ambient temperature or STC temperature) delivers reliable information about the PV modules electrical behavior.
- Electroluminescence testing is performed to check the panels for broken silicon–cells (“Micro Cracks”) which can be caused by forces applied to the PV modules front- or backside and could result in an irreversible power loss.
- Isolation and grounding test (if equipped) is used to test the electrical insulation of the panel. The test includes the continuity and insulation resistance measurement.
- Thermal imaging (if equipped) under reverse current can provide information about hotspots in the cell-area caused by damages up to defective bypass diodes or soldering issues in the junction box.

In order to guarantee an analysis standard for the PV modules inspection with the MBJ Mobile Lab or Mini Lab system for all operators, this document explains the analysis criteria for the four aforementioned test methods in detail.

2. Analysis criteria for the electroluminescence test

Green

Yellow

Red

Blue

Since the electroluminescence test in the MBJ Mobile Lab or Mini Lab is carried out in regard to the module's future power output, cell breakage (active or inactive) and micro-cracks are regarded as being identical. This assumption is based on the experience, that it is quite likely for a micro crack to become an active cell break in the future.

Active cell breaks often lead to a reduction in module power at the time of the test; these are then quantified by the separate power test in the sun simulator.

Cells are classified into the four following categories:

Green (minor): < 1% cell area affected

Yellow (major): >= 1% and <=10% cell area affected

Red (critical): > 10% cell area affected

Blue: (other EL abnormalities)

The relationship between the orientation of a crack/break and the power loss associated with the loss of active cell area is considered in more detail in the following pages.

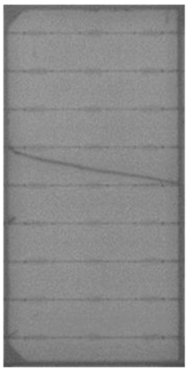
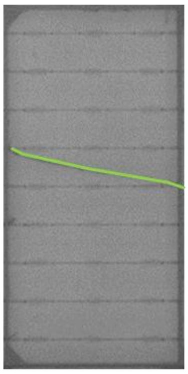
2.1. Minor cracks / cell breaks

Green

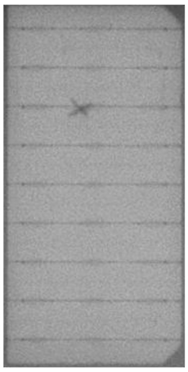
Inactive breaks should be marked green, since no power loss is expected. Other cracks and cell breaks are acceptable if they are not able to disconnect cell areas larger than 1 %.

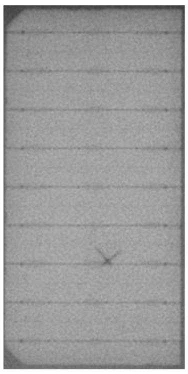
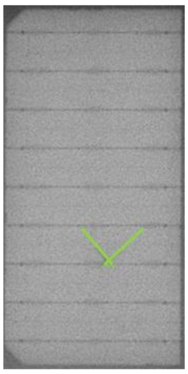
Nevertheless, the development of the cell crack should be noted, especially if there is already a tendency to a fanning out of the crack or to y-crack, in which case the cell may have to be classified as minor or major. Since this may not be able to be detected with the existing pixel resolution, if more than 10% of cells in a module are marked green, this is also a degradation criterion (see section 3.1).

A cell can only be rated as non-critical (green) if the number of non-critical cracks on the cell is less than the number of bus bars. Here, v-cracks are counted as two cracks and x-cracks as four cracks.

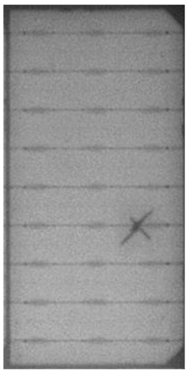
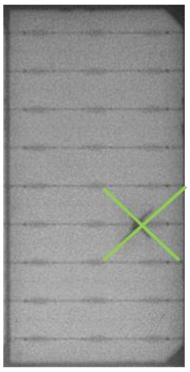
Single-Line-Crack	EL-Image	Marking
Description: The cell disruption runs in a straight line between the "bus bars".		
Judgement: A further expansion of the cell break is not expected. Possible cell area disconnection 0%.		

Y-Shape-Crack	EL-Image	Marking
Description: Diagonal micro crack with branching		
Judgement: A further expansion of the micro crack is not to be expected. Possible inactive area < 1%.		

X-Shape-Crack	EL-Image	Marking
Description: Single tiny cross or x-crack, that is slightly determinable as an x. Caused by punctual stress on the cell, e.g. punctual stress on the back sheet foil of the module.		
Judgement: A further expansion of the crack is possible, but the potentially disconnected cell area is < 1%.		

X-Shape-Crack	EL-Image	Marking
Description: Medium cross or x-crack. Location close to the bus bars in the middle of the cell.		
Judgement: A further expansion of the crack is possible, but the potentially disconnected cell area is < 1%.		

<table>
<tr><th>X-Shape-Crack</th><th>EL-Image</th><th>Marking</th></tr>
<tr><td><u>Description:</u>

Large cross or x-cracks which are easy determinable as crack or break. Location close to the bus bars in the middle of the cell.</td><td></td><td></td></tr>
<tr><td colspan="3"><u>Judgement:</u>

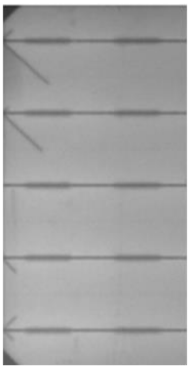
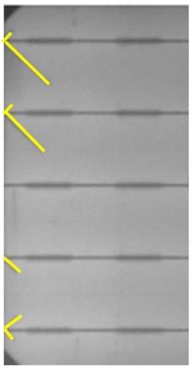
A further expansion of the crack is possible, but the potentially disconnected cell area is < 1%.</td></tr>
</table>

2.2. Major cracks / cell breaks

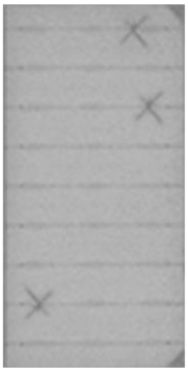
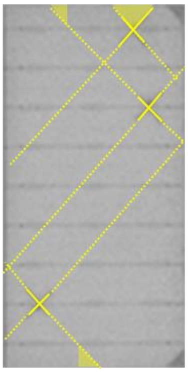
Yellow

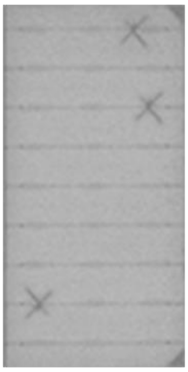
All cell areas that are disconnected or endangered of electrical isolation should be classified 'Major' or yellow, as soon as the disconnected or endangered cell area is between 1% and 10%. Cross-Crack-Lines caused by back sheet scratches should always be marked as Major, since a growth of micro cracks is likely. If there more cracks than bus bars it should be marked as major defect as well.

<table>
<tr><th>Multiple V-Cracks</th><th>EL-Image</th><th>Marking</th></tr>
<tr><td><u>Description:</u>

Multiple small cracks at the end of the busbars.</td><td></td><td></td></tr>
<tr><td colspan="3"><u>Judgement:</u>

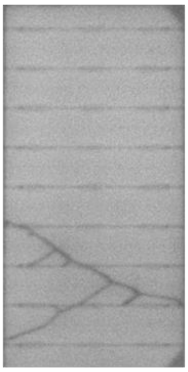
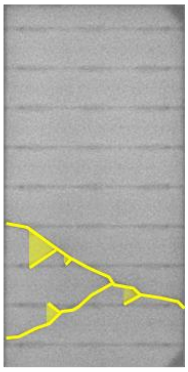
A further expansion of the micro cracks is expected. There are 7 cracks on a 5 bus bar cell. A loss of performance cannot be ruled out.</td></tr>
</table>

Multiple-X-Shape-Crack	EL-Image	Marking
Description: Multiple x-cracks close to the cell edge have a larger impact than x cracks inside of a cell.		
Judgement: A further expansion of the crack is possible and the potentially disconnected cell area could be more than1%.		

Multiple-X-Shape-Crack	EL-Image	Marking
Description: Multiple x-cracks on a cell can lead to potential disconnected cell area of more than 1%.		
Judgement: A further expansion of the micro cracks is expected. There are three x-cracks on a 5 bus bar cell. A loss of performance cannot be ruled out.		

Y-Shape-Crack	EL-Image	Marking
Description: The endpoints of the micro cracks are the "bus bars" and the cell edge.		
Judgement: A further expansion of the micro crack is not to be expected. Possible inactive area > 1%.		

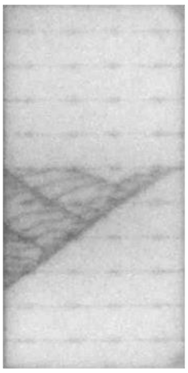
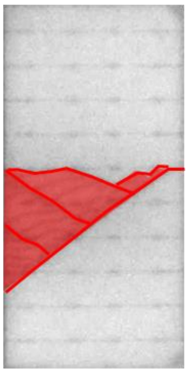
Cross-Line-Crack	EL-Image	Marking
<u>Description:</u> Cross crack lines caused by a scratch on the back sheet of the module		
<u>Judgement:</u> Critical, it’s unclear how cracks will propagate. Cell areas can be disconnected (as indicated). Possible inactive area > 1%.		

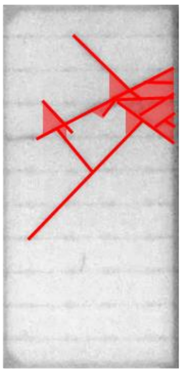
Dendritic-Crack	EL-Image	Marking
<u>Description:</u> Various Y-breaks between the 'bus bars'.		
<u>Judgement:</u> Breaks can potentially reduce the active area of the cell by more than 1%.		

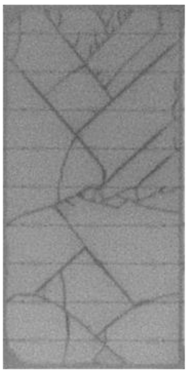
2.3. Critical cracks / cell breaks

Red

All cell areas that are disconnected or endangered of electrical isolation should be classified as very critical, as soon as the disconnected or endangered cell area is more than 10 %. Red cells lead directly to the classification of a PV module in the class C (see Section 4).

Branch-Cracks	EL-Image	Marking
<u>Description:</u> Branched cracks between the 'bus bars'		
<u>Judgement:</u> Possible cell area disconnection above 10%.		

Spider web-Crack	EL-Image	Marking
<u>Description:</u> Various cell brakes caused by mechanical impact e.g. hail.		
<u>Judgement:</u> These cracks can potentially reduce the active area of the cell by more than 10%.		

Spider web-Crack	EL-Image	Marking
Description: Numerous branched cracks in different size and location.		
Judgement: These cracks can potentially reduce the active area of the cell by far more than 10%.		

Dead cell	EL-Image	Marking
Description: Completely dark cell. Could be caused by soldering issues or extreme breakages		
Judgement: Inactive cell. Almost 100 % of the cell area lost and the modules output voltage could be reduced. We expect to see the effects in the IV measurement as well.		

2.4. Other EL abnormalities (without impact)

Blue

Defects which have occurred in the cell or module manufacturing process should be marked as EL-Abnormality as far as a propagation is unlikely. Since the power loss of the cell is already entered in the performance specified by the cell manufacturer, a further loss is not expected (sample images are shown in the attachment).

3. MBJ Module-judgment criteria for EL

3.1. Class A

Only PV modules with fewer than 10% as minor classified cells (green). The total of the marked cells may not exceed 10% of the cells. Cells classified as major and critical (yellow, red) are not allowed.

Less than 10% of the total number of a module are marked green

<u>and</u>

No cells are marked yellow

<u>and</u>

No cells are marked red

3.2. Class B

PV modules without very critical (red) cells and with no more than 10% critical (yellow) cells or more than 10% uncritical (green) cells.

More than 10% of the total number of a module are marked in green

<u>or</u>

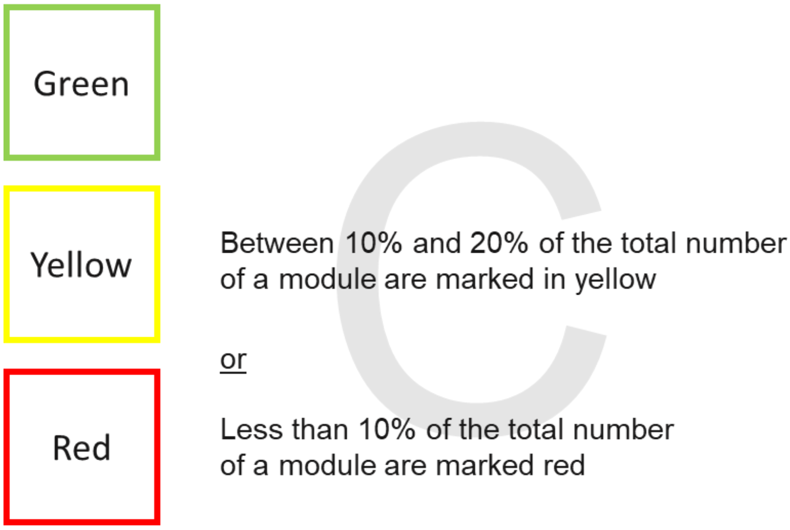
Less than 10% of the total number of a module are marked yellow

<u>and</u>

No cells are marked red

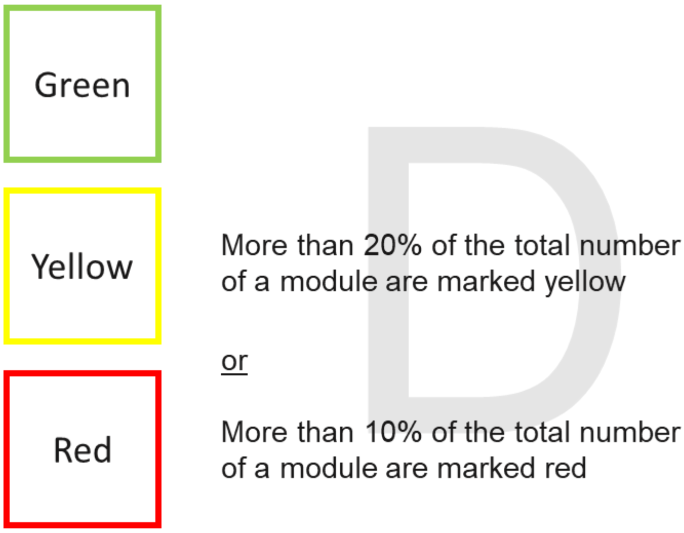
3.3. Class C

PV modules with fewer than 10% very critical (red) cells, more than 10% critical (yellow) cells or more than 20% uncritical (green) cells and in total less than 30% of marked cells.



3.4. Class D

PV modules with more than 10% very critical (red) cells or more than 20% critical (yellow) cells.



4. MBJ module judgment criteria for the power measurement

The sun simulator is used to measure the power of the PV modules. For the sorting into classes the manufacturer tolerances and the tolerances of the MBJ Mobile Lab or MBJ Mini Lab have to be considered. An example calculation can be found after the description of the classes.

Important to know:

The reference module has a major influence on the measurement uncertainty of the overall system. With a reference module of the same type as the modules to be tested, the measurement uncertainty can be reduced to 2%.

Class A	The measured power is above the panel manufacturer's warranted power.
Class B	Taking into account the negative measurement uncertainty, the measured power is above the power guaranteed by the module manufacturer.
Class C	Taking into account the negative measurement uncertainty, the measured power is below the power guaranteed by the module manufacturer, but does not deviate from it by more than 5%.
Class D	Taking into account the negative measurement uncertainty, the measured power is more than 5% below the power guaranteed by the module manufacturer.

4.1. Calculation Example

Warranty power	= 500W
Measurement uncertainty	= ± 3%
Limit value for the warranty power	= 485 W (incl. negative measurement uncertainty)

The resulting power classes are:

- CLASS A: Power MBJ@STC ≥ 500 W
- CLASS B: Power MBJ@STC ≥ 485 W < 500 W
- CLASS C: Power MBJ@STC ≥ 460.8 W < 485 W
- CLASS D: Power MBJ@STC < 460.8 W

4.2. Calculation Example with degradation

Nominal power	= 500W + 3% (only plus tolerance)
Initial degradation (first year)	= 3% = 15W
Linear degradation	= 0.7%/year = 3.5W/year
Warranted power after 2 years	= 500W – 15W – 3.5W = 481.5W
Measurement uncertainty	= ± 3% = ± 15 W
Limit value for the warranty power	= 467.1 W (incl. negative measurement uncertainty)

4.3. The resulting power classes are:

- CLASS A: Power MBJ@STC ≥ 481.5 W
- CLASS B: Power MBJ@STC ≥ 467.1 W < 481.5 W
- CLASS C: Power MBJ@STC ≥ 443.7 W < 467.1 W
- CLASS D: Power MBJ@STC < 443.7 W

5. MBJ module judgment criteria for High voltage and ground bond testing (optional)

The high-voltage test and the ground bond test are used to check whether the PV modules comply with the IEC/EN 61730-1 - 61730-2 approvals. Since this test is safety-relevant, there is only a pass/fail result.

Class A	High voltage test and ground bond test passed
Class D	High voltage test and ground bond test failed

6. MBJ module judgment criteria for thermal imaging (optional)

The focus of the thermal imaging lies especially in the so-called "hot spots". These small regions have a significantly higher temperature than the rest of the module. Thermal imaging is an optional feature for MBJ Mobil Lab and MBJ Mini Lab.

Class A	Modules with a temperature difference of conspicuous areas and the average temperature of < 5°C.
Class B	Modules with a temperature difference of conspicuous areas and the average temperature of > 5°C and <= 15°C.
Class C	Modules with a temperature difference of conspicuous areas and the average temperature of > 15°C and <= 30°C.
Class D	Modules with a temperature difference of conspicuous areas and the average temperature of > 30°C.

Hotspots can be caused by different types of issues inside a cell, by defective cells in the whole module or by electrical issues in the junction box.

7. The overall module judgment

The resulting overall module judgment will be the worst judgment of the four test methods. Means the worst class the module was judged to at electroluminescence, power measurement, high voltage testing and thermal imaging.

With these different tests, the modules can be divided into four quality classes:

Class A Superior quality	The performance is definitely above the promised performance and otherwise there are no abnormalities that could lead to a premature drop in performance.
Class B Good quality	The measured performance is above the promised performance, taking into account the measurement uncertainty, and the module shows only a few abnormalities that do not lead to a premature drop in performance.
Class C Insufficient quality	The performance is below the promised performance, even taking into account the measurement uncertainty, or the module has defects that can directly lead to a drop in performance.
Class D Poor quality	The quality of the module is bad. Either the performance is far below the performance promise, or there are significant quality defects (e.g. significant cracking, failed high-voltage test).

We can’t recommend to install Class C PV modules to avoid premature performance degradation. If Class C PV modules are installed, they should be grouped separately into strings that can be monitored and compared to "OK" strings.

Class D modules could lead directly to a reduction in generator output. These solar modules should not be installed under any circumstances.

8. Appendix

8.1. Appendix 1: Interesting facts about cracks and micro cracks

An intact solar cell shows no cracks and no dark area. The current flow is not interrupted. The solar cell has no power loss.

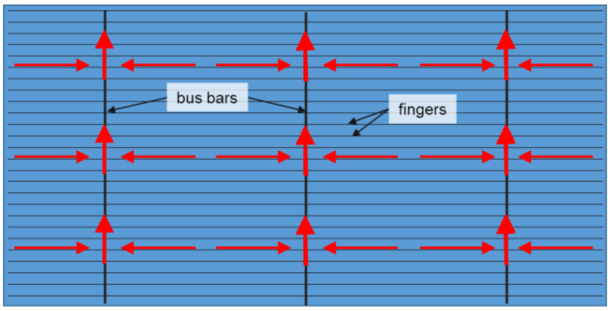


Figure 1 Current flow in an intact solar cell

A micro-crack through a silicon solar cell separates parts from each other, which are further connected via the contact fingers to the bus bar, and thus remain electrically active. Micro-cracks produce therefore no dark areas in the electroluminescence image. The luminescence remains homogeneous despite the cracks. Micro-cracks alone lead to not lead to a significant power loss.

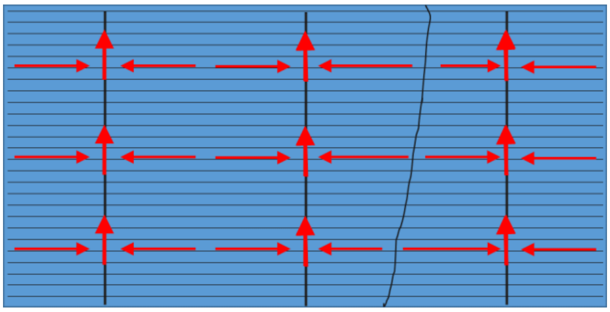


Figure 2 Current flow in a solar cell with an inactive crack

If a crack is located in the outer area of a solar cell can this lead to an inactive area with a remarkable power loss.

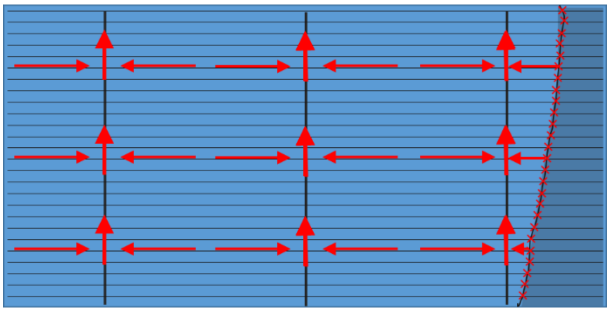
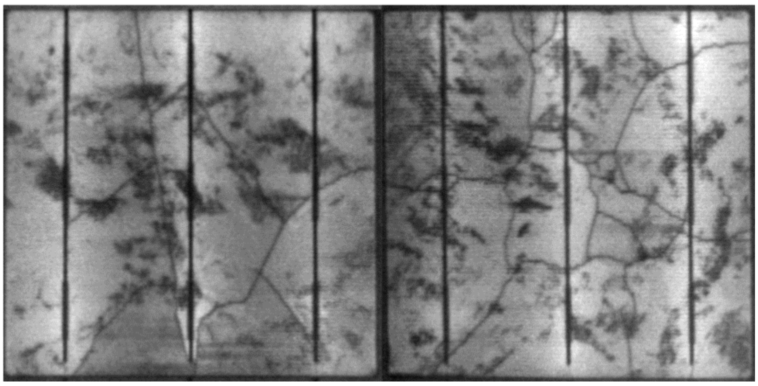


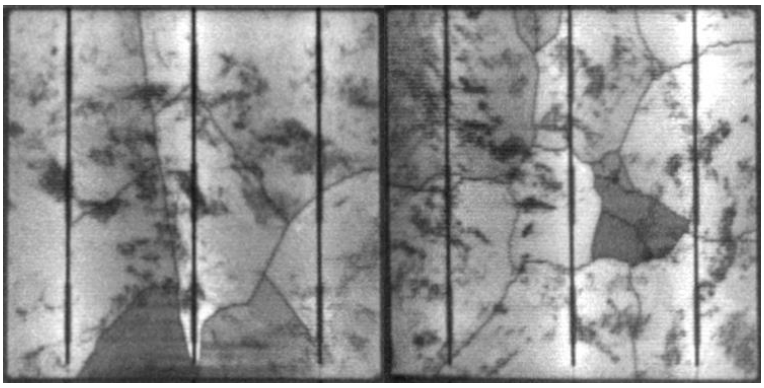
Figure 3 Current flow in a solar cell with an active crack

Micro-Cracks can turn into cell breaks by tearing the contact fingers (e.g. by thermal expansion) of two silicon parts, which are separated by a crack. The tearing of the fingers and thus the loss of connection to the bus bar leads to inactive cell parts. The breakage may not be immediately complete. It can begin with an increased contact resistance. The electrical connection may be interrupted temporarily, depending on the temperature or mechanical influences. The breaks are apparent through a lower luminescence on one side of the break, homogeneous or with a gradient depending on the location. Breaks lead in the worst case to completely dark (inactive) cell sections.

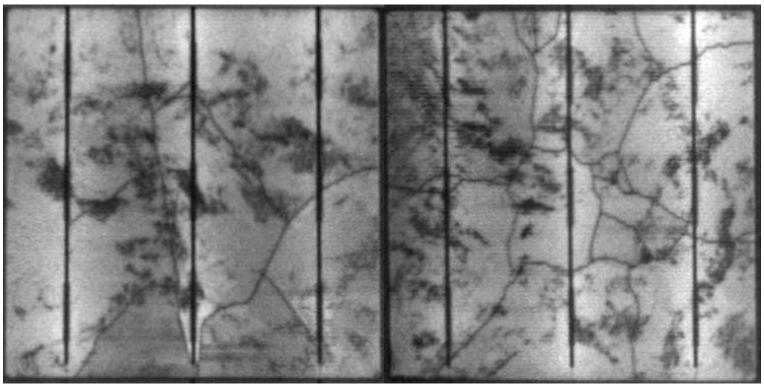
The following images shows how an inactive crack becomes an active crack through a temperature change.



1st capture, about 16 ° C

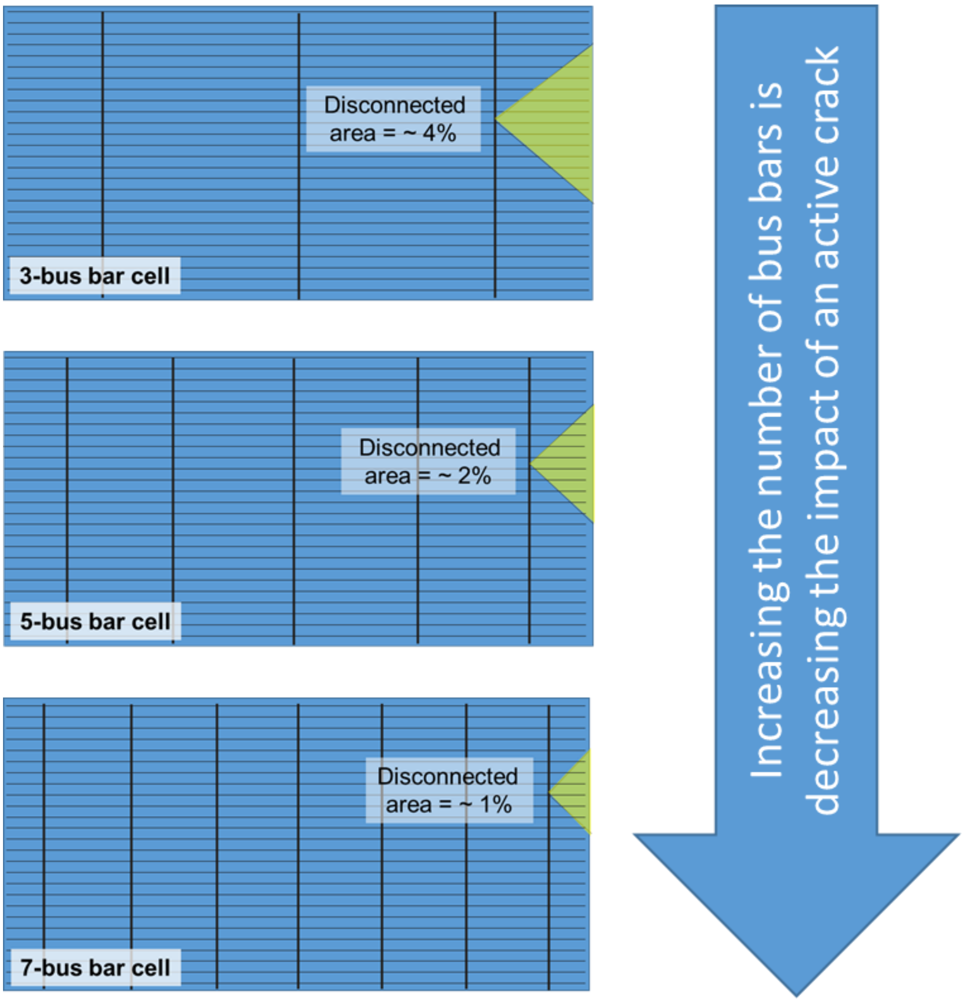


2nd capture, about 24 ° C



3rd capture, about 15 ° C

In the past years half-cut cells and the multi-bus bar technology was implemented. One of the advantages is that these improvements are reducing the risk of a power loss through cell breakage.



Nevertheless, the development of the cell crack should be noted, especially if there is already a tendency to a fanning out of the cell crack or to y-crack. The figures below are showing the effect of the growth of micro cracks.

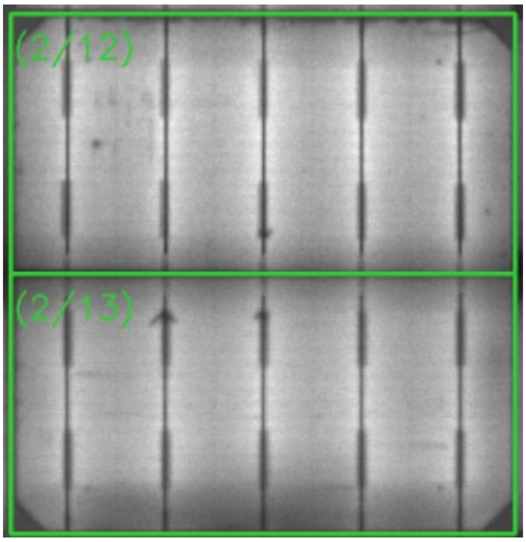


Figure: Small cracks before installation

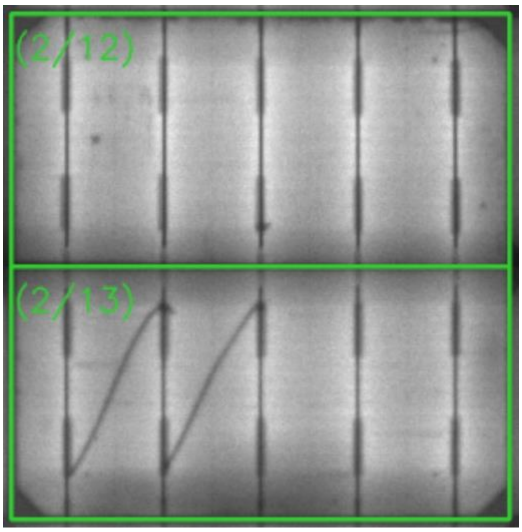
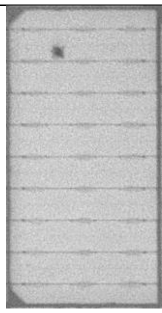


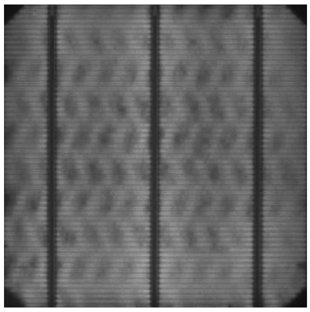
Figure: Grown cracks after one year

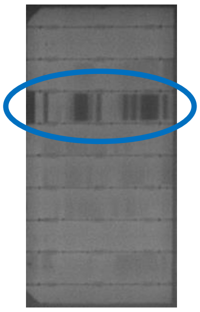
8.2. Appendix 2: Other EL abnormalities (without impact)

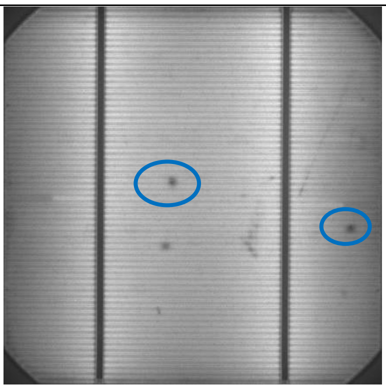
Blue

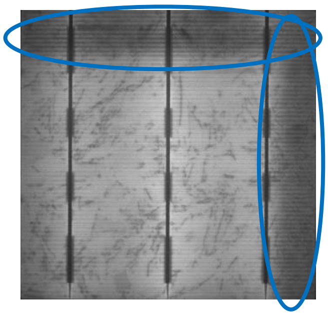
Defects which have occurred in the cell or module manufacturing process should be marked as EL-Abnormality as far as a propagation is unlikely. Since the power loss of the cell is already entered in the performance specified by the cell manufacturer, a further loss is not expected.

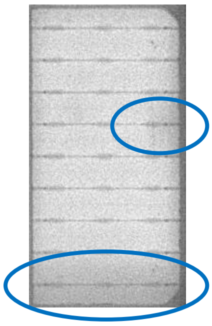
Dark areas (clouds)	EL-Image:
Description: Cloudy area with a lower luminescence. Created during the firing process by a temperature gradient from the cell center to the cell edges.	

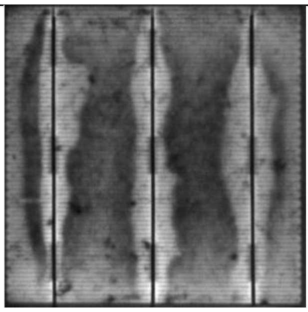
Chain pattern	EL-Image:
Description: Local areas with a lower luminescence. Printed into the cell by the conveyor belt caused by an inhomogeneous temperature distribution.	

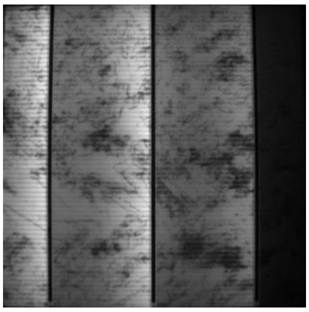
(slight) Grid finger interruptions	EL-Image:
Description: Area of a grid finger with a lower luminescence Failure during the screen-printing process causes interrupted or non-existent grid finger.	

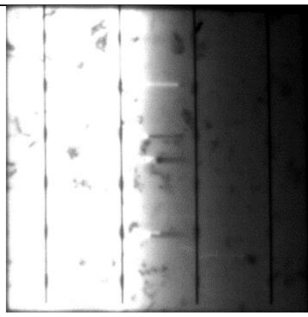
Shunts	EL-Image:
Description: Points with almost no luminescence Could be caused by direct contact of the grid finger to the cell base, defect in the pn-junction etc. Verifiable only with the Lock-In thermography or EL under reverse bias	

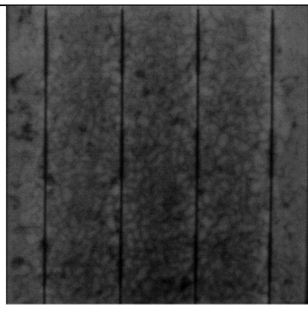
Ingot edge piece	EL-Image:
Description: Lower luminescence on one or two cell edges Contamination of the cell material in the edge area of the ingot Typical for polycrystalline solar cells	

Dark cell part	EL-Image:
Description: Area with a lower luminescence around the bus bar Connection problem between the grid finger, the ribbon and bus bar. Could be caused by defective printing or bad ribbon soldering/ connection. Propagation unlikely.	

Flux Corrosion	EL-Image:
Description: Brighter areas around the bus bars with washy transitions. Corroding through solder flux impact likely.	

Printing failure (Back contact)	EL-Image:
Description: Gradation of the luminescence from one cell edge to the cell edge The printing of the cell back is shifted. Failure is generated during the screen-printing process.	

Bus bar connection issue	EL-Image:
Description: Gradation of the luminescence from one cell edge to the cell edge The printing of the cell back is shifted. Failure is generated during the screen-printing process	

Sponge LID	EL-Image:
Description: Sponge-like structure with reduced luminescence. Could be caused by an inhomogeneous crystal-structure on the ingots bottom. Frequently observed with huge power loss.	

Grid finger interruptions (severe)	EL-Image:
Description: No luminescence along the grid finger in a bar-like style. Heavy finger interruptions caused by screen printing failure; the dead finger areas are not connected to the busbar. Power loss of the whole cell likely.