SILICON SOLAR MODULE VISUAL INSPECTION GUIDE

Catalogue of Defects to be used as a Screening Tool

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ABOUT THIS DOCUMENT

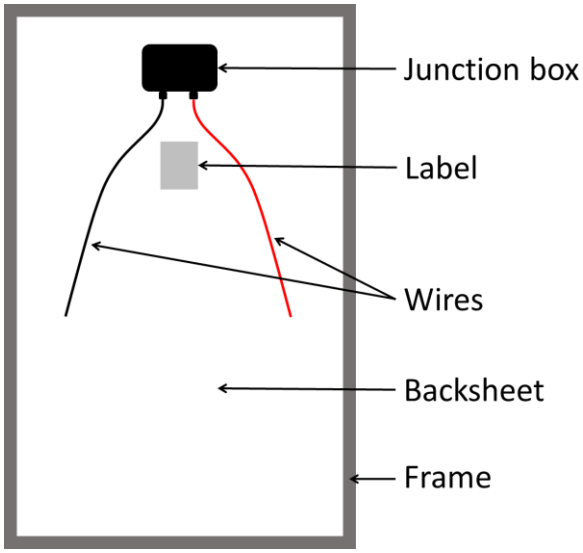
This document is designed to be used as a guide to visually inspect front-contact poly-crystalline and mono-crystalline silicon solar photovoltaic (PV) modules for major defects (less common types of PV modules such as back-contact silicon cells or thin film technologies are not covered here). It is not meant to replace international testing standards (for example IEC 61215 or UL 1703 [1], [2]). It is was developed because of observations of counterfeit and sub-standard quality products on the market in Malawi. Consumers and retailers are typically not aware that defects are present or that there are other options: good quality PV modules should last more than 25 years, whereas the products currently available often degrade quickly and fail in several years or even months. This document is principally focused on defects which are observable at the beginning of product life, although some significant defects that may appear over time are also included for completeness (and to address the second-hand market).

Although visual inspection cannot catch all possible defects, it can be used as an initial screening method. It was designed with the intention of it being a quick tool and not requiring any test equipment. Although helpful, no prior knowledge of solar panels should be required to benefit from this guide.

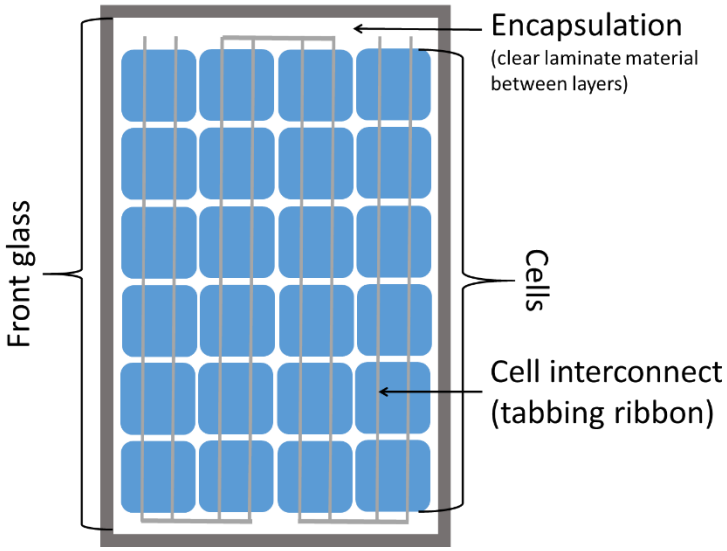
This document is organized into a Terminology section, a Checklist, followed by a table cataloguing and describing the defects to be visually inspected. The schematics in the Terminology section defines where each component is found on a module. A Severity Rating is also defined to give users guidelines on how concerned they should be about a particular defect. In the Checklist and the Catalogue of Defects, defects have been organized by the component of the module on which they appear. The order in which components are inspected goes from the back to the front of the module, following a procedure developed elsewhere [3]. For each component defects within a table are ordered by maximum severity. The Checklist and Terminonlogy pages are designed to be printed together to be used as a quick reference and inspection tool, refering back to the full detail in the Catalogue of Defects as needed.

CLARIFICATION OF TERMINOLOGY

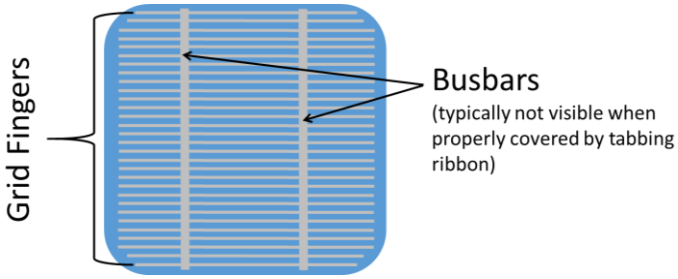
Rear side of silicon module



Front side of silicon module



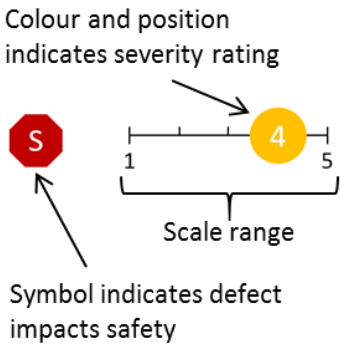
Individual silicon solar cell



CLARIFICATION OF SEVERITY RATING

Efforts were made by the authors to provide a comparative rating of the severity of the defects. This scale is subjective and intended for guidance purposes only. The range of the scale indicates influence to performance and/or reliability, and given is from 1 (low severity) to 5 (high severity). When the severity of a defect varies significantly, for example with defective area, a range is given. An additional icon is given if the defect poses a potential safety risk. The authors assume no liability for actions taken as a result of this document.

1. The defect is an indicator of poor quality with no direct effect on performance or reliability
2. The defect has a minor impact on performance and/or reliability
3. The defect has a moderate impact on performance and/or reliability
4. The defect has a high impact on performance and/or reliability
5. The defect is indicative of critical module failure, or a counterfeit panel



CHECKLIST

COMPONENT	DEFECT		Defect Present? No	Defect Present? Yes
1. Label	1.1	Not present		
	1.2	Not permanent and/or well attached		
	1.3	Does not contain required information		
	1.4	Words are not spelt correctly		
2. Backsheet	2.1	Burn marks		
	2.2	Discolouration		
	2.3	Delamination		
3. Junction Box	3.1	Faulty electrical connection		
	3.2	Housing not waterproof		
	3.3	Sealant failure		
	3.4	Electrical polarity not indicated		
4. Wiring	4.1	No cracks or exposed metal		
	4.2	Not thick or long enough		
	4.3	Wire(s) not present or securely attached		
5. Frame	5.1	Damaged		
	5.2	Adhesive/sealant failure		
6. Front Glass	6.1	Cracking		
	6.2	Scratches		
7. Encapsulation	7.1	Delamination		
	7.2	Discolouration		
8. Cells	8.1	Fake		
	8.2	Dummy pieces disguising missing material		
	8.3	Cracks		
	8.4	"Snail trails"		
	8.5	Shiny locally/inconsistent colour		
	8.6	Scratches		
	8.7	Not fully exposed		
	8.8	Differently sized		
	8.9	Edge chips		
	8.10	All cells very shiny		
9. Cell Metallization	9.1	Fingers not connected to busbar		
	9.2	Not the same pattern on all cells		
	9.3	Fingers off of edge of corner of cells		
10. Cell Interconnection	10.1	Not present / cells are not connected		
	10.2	Cells connected in parallel (counterfeit)		
	10.3	Poorly aligned and/or soldered		
	10.4	Cells connected in parallel (real cells)		

CATALOGUE OF DEFECTS

1. LABEL

Provides product information. Stuck onto module by the module manufacturer.

1.1 Not Present

Description: A label must be present. This may be unlikely if the panel is small (<5W)

Why it's important: Lack of label implies sub-standard manufacture. Label information is needed to properly install and use panel. Lack of this information is a potential safety issue.

Severity:

S 1 5

1.2 Not permanent and/or well attached

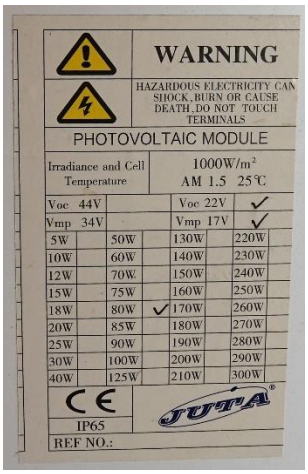
Description: Label should be made of material that resists water or light damage. Label should not be peeling or bubbling.

Why it's important: Label needs to provide panel information for the duration of the panel lifetime. Lack of this information is a potential safety issue.

Severity:

S 1 5

1.3 Does not contains required information



Label on left gives no Current data. Label on right gives no Manufacturer data. Neither gives Model or Serial #, or Fuse current.

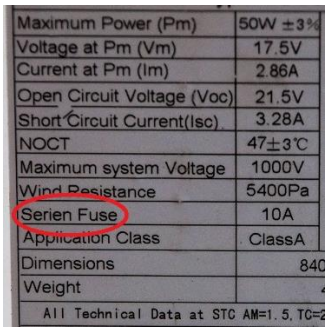
Description: Label should give the following information: Maximum Power, Current and Voltage at Maximum Power, Short-Circuit Current, Open-Circuit Voltage, Maximum system voltage, Fuse rating, Manufacturer name, Model #, Serial # (sometimes on a small label on the front of the module, can be a barcode), and markings of certification (for example high quality products tend to carry UL, IEC or TUV symbols)

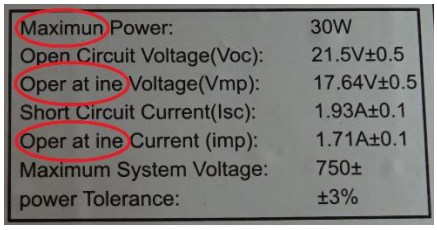
Why it's important: Technical and manufacturer data is needed to properly install and maintain equipment. Lack of this information is a potential safety issue.

Severity:

S 1 — 5

1.4 Words are not spelt correctly





Description: Words should be spelt correctly in whatever language is used

Why it's important: Does not affect performance or safety, but is an indicator of how professional the manufacturer is

Severity:

1 — 5

2. BACKSHEET

Back substrate of module. Protects module interior from the elements.

2.1 Burn marks

Description: Burnt, blackened area. Damage cannot be cleaned off. There may be a hole in the backsheet.

Why it's important: Indicates a catastrophic failure event occurred. Performance, reliability and safety are likely to be severely compromised.

Severity:

S 1 — 5

2.2 Discolouration


[3]

Description: Colour varies across the backsheet, and cannot be cleaned off

Why it's important: Backsheet material is likely degraded. This indicates that the module is suffering from a reliability problem.

Severity:

2.3 Delamination


[3]

Description: Backsheet not well laminated to module. Surface is bubbled or peeling.

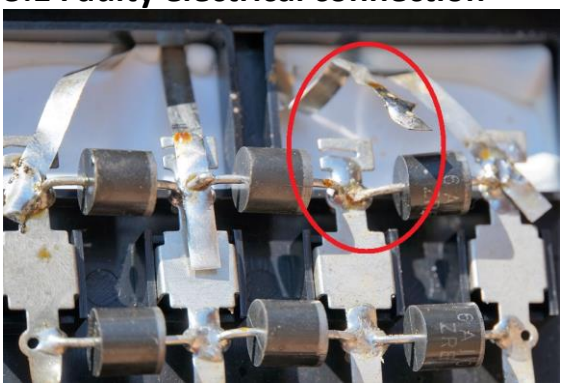
Why it's important: Bubbles are space for moisture to accumulate. Moisture in the module will decrease performance and affect long term reliability.

Severity:

3. JUNCTION BOX

Electrical enclosure on the rear of the module where external wires connect to the internal tabbing ribbon. The junction box also contains the diode(s).

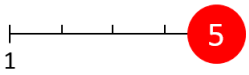
3.1 Faulty electrical connection



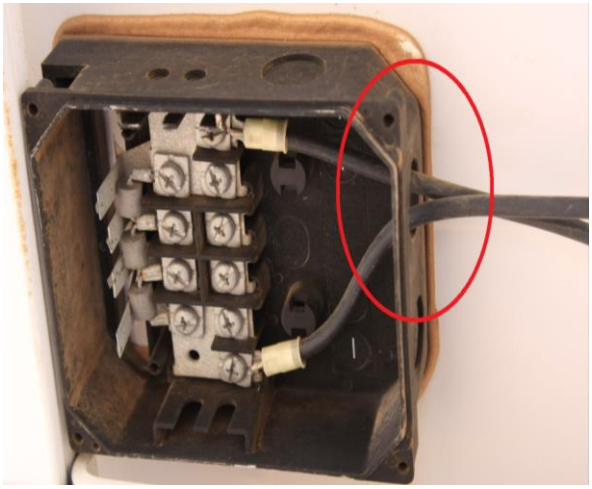
Description: Poor or broken solder joints, broken wire or tabbing ribbon.

Why it's important: Broken electrical contacts can cause module failure. Poor solder joints can decrease performance and affect long term reliability.

Severity:



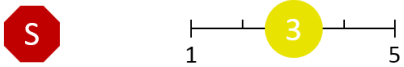
3.2 Housing not waterproof



Description: Cracks in the housing, missing a continuous seal for the lid or around the wires.

Why it's important: Accumulated moisture can cause short circuits or corrosion of the metal contacts, increasing the risk of melting or fire. The junction boxes on high quality modules will be permanently sealed and potted to eliminate this risk.

Severity:

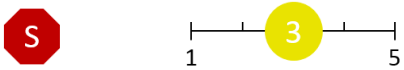


3.3 Sealant failure

Description: Holes in the seal, brittle material (should feel rubbery with fingernail) or adhesion failure.

Why it's important: Accumulated moisture in the junction box can cause short circuits or corrosion of the metal contacts. Corrosion can increase the risk of melting or fire.

Severity:



3.5 Electrical polarity not indicated

Photo not available

Description: Does not include a clear indication of the positive (+ or red) and negative (- or black) terminal of the module. Can be done with colour-coded wires instead of marked on junction box.

Why it's important: Improper wiring of the module could cause a safety risk or lead to equipment failure.

Severity:

4. WIRING

The wires carry electricity from the module to the charge controller or inverter.

4.1 No cracks or exposed metal

Description: The wire insulation is cracked or revealing the metal conductor

Why it's important: Exposed metal in the electrical circuit is a safety risk.

Severity:

S

1 — 4 — 5

4.2 Not thick or long enough

Description: Wires aren't long enough to make a connection to the rest of the system. Thickness requirements depend on module current. Examples of max ratings include: 2.9A for 17AWG (1.04mm^2), 7.4A for 13AWG (2.63mm^2), 15A for 10AWG (5.26mm^2), 30A for 7AWG (10.55mm^2)[4]

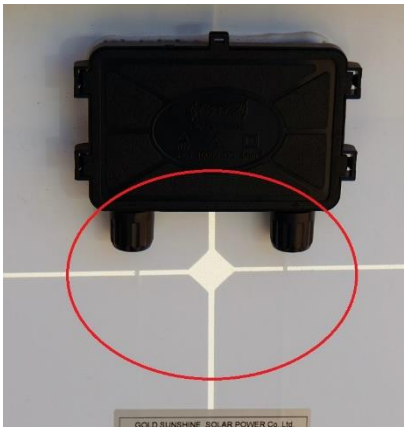
Why it's important: If wires are too thin they could melt or burn. For safety, all electrical connections must take place inside a sealed enclosure, ex. junction box.

Severity:

S

1 — 3 — 5

4.3 Wire(s) not present or securely attached



Description: One or both wires are missing or loosely connected to the module.

Why it's important: Two wires are necessary to make a circuit. All new modules come with wires securely soldered to the tabbing ribbon and diodes inside the junction box. Low severity because it is likely repairable.

Severity:

1 — 5

5. FRAME

The frame provides structure, rigidity, and mounting features. Sometimes non-metal for small modules (for example <10W). Metal is needed for rigidity for large modules. If metal is used, electrical grounding is required.

5.1 Damaged

Photo not available

Description: Bent or cracked frame or the corners are not well aligned.

Why it's important: Not rigid enough to withstand handling during installation and high winds. Could lead to safety issues from cracked glass or poor electrical grounding.

Severity:

S

1 2 3 4 5

5.2 Adhesive/Sealant failure

Description: Discontinuous perimeter seal or loose attachment to module.

Why it's important: The adhesive is also a sealant that prevents water ingress into the module. Water in the module layers will decrease performance and affects long term reliability. Severity depends on atmospheric humidity.

Severity:

1 3 5

6. FRONT GLASS

Provides structure to the module and protects the cells. Allows transmission of light to the cells.

6.1 Cracking

[3]

Description: Front glass is cracked locally or over the full area.

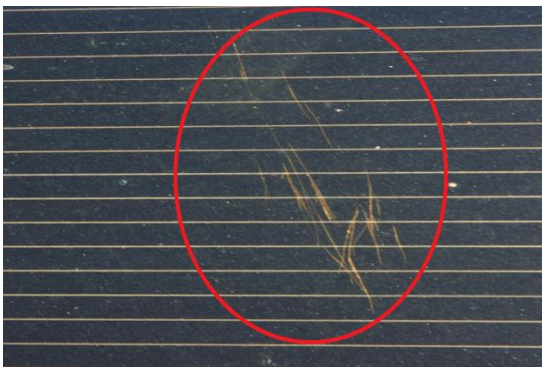
Why it's important: Module structure is compromised. Possible path for water ingress. Mechanical and electrical safety issue.

Severity:

S

1 3 4 5

6.2 Scratches

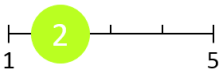


[3]

Description: Permanent scratches in the surface of the front glass. Cannot be removed with cleaning.

Why it's important: Transmission of light to the underlying cells, and therefore module power, is reduced. Severity increases with affected area.

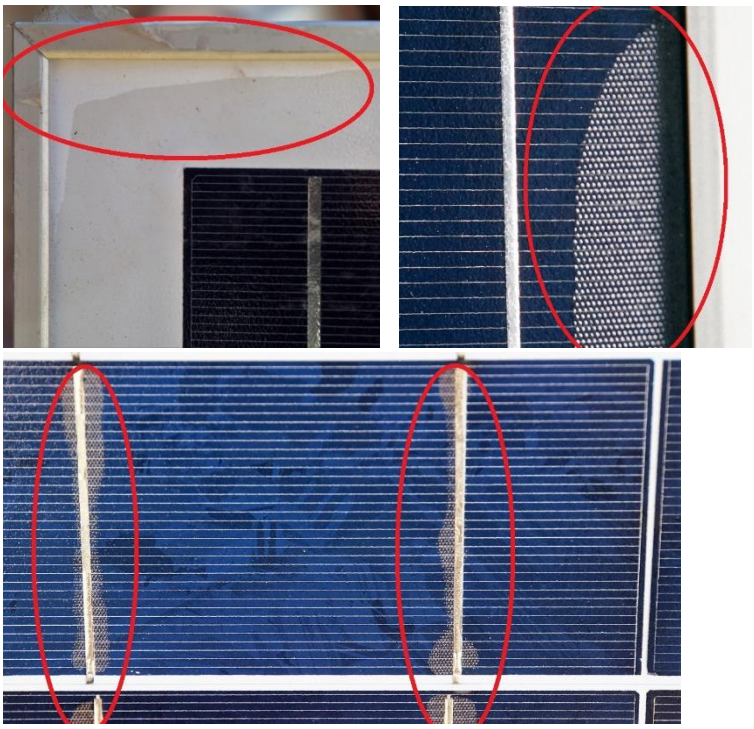
Severity:



7. ENCAPSULATION

Used to laminate module layers together. Transparent to allow light to reach cells.

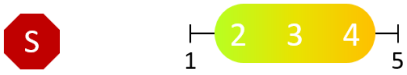
7.1 Delamination



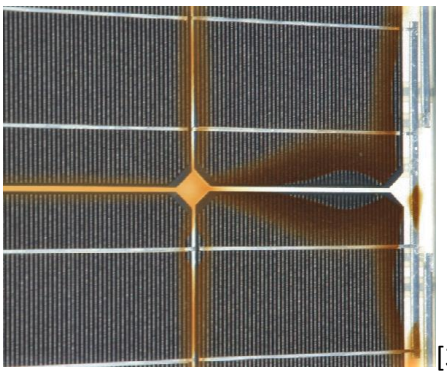
Description: Any local separation of the layers between the front glass and the cells or the front glass and the backsheet. May appear continuous (top left) or spotted (right and bottom, due to texture of glass). Also could be bubbles. Most commonly appears around busbars or at the edge of the panel.

Why it's important: Can reduce structural integrity of the module. Transmission of light to the underlying cells, and therefore module current, is reduced. Severity increases with affected area. Bubbles of delaminations forming a continuous path between any part of the electrical circuit and the edge of the module is considered a major defect [1].

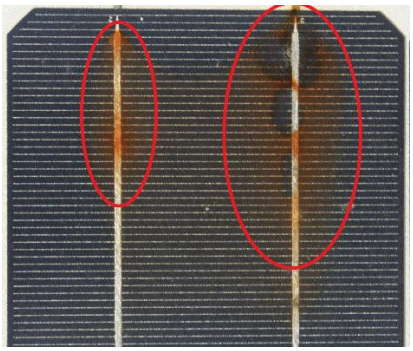
Severity:



7.2 Discolouration



[3]

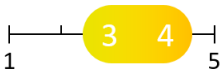


[3]

Description: Colour variation anywhere inside the module. Can be next to or above the cells, along the busbars or cell interconnects. Could be from a catastrophic event or degradation over time.

Why it's important: Indicates encapsulation material is degraded. Transmission of light to the underlying cells, and therefore module current, is reduced. Likely to degrade further over time.

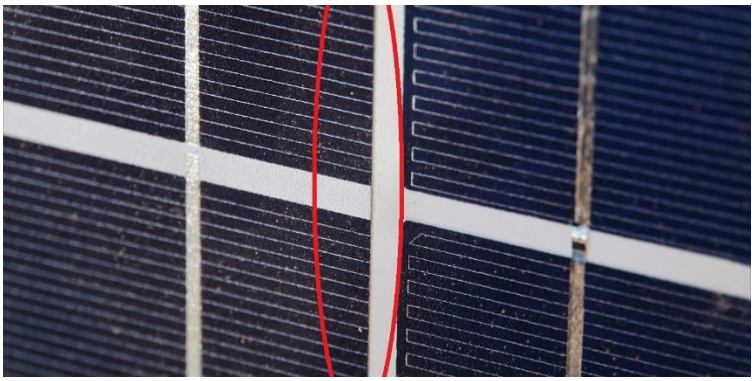
Severity:

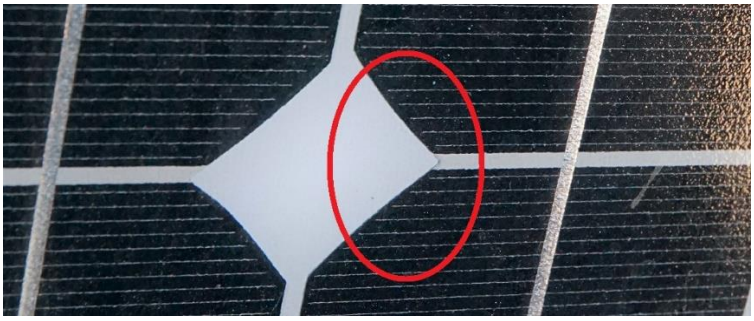


8. CELLS

Active component of the solar module. Electricity producing material converts sunlight to electricity.

8.1 Fake

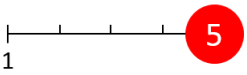




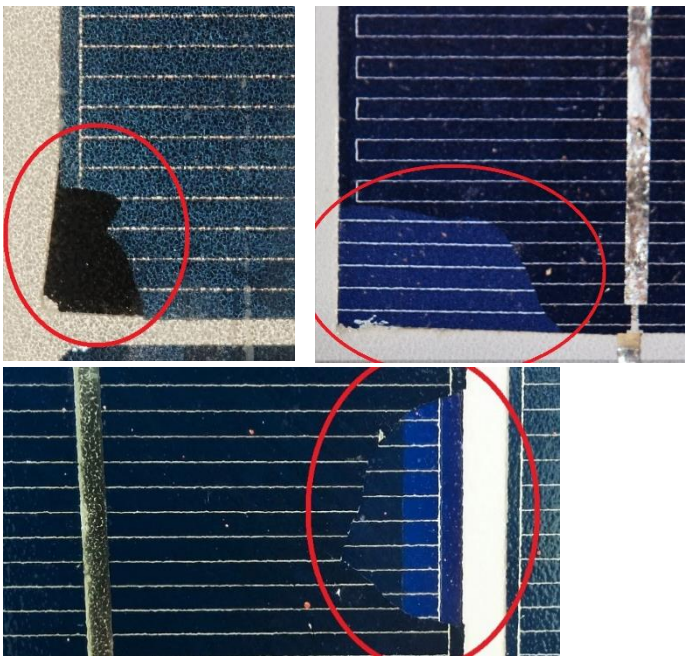
Description: Cells not made of active material, are instead printed paper images. Likely only a portion of the cells in a given module may be fake. May be evident in the white space between fake cells, where the edge of the paper can be seen. Examples of fake poly and mono-crystalline cells in top and bottom images respectively. If counterfeiters instead cut around each paper cell individually it will be harder to spot, and instead might be caught when inspecting the cell interconnection.

Why it's important: Purposely deceitful behaviour of manufacturer. The customer pays for fraudulent material that will not produce power.

Severity:



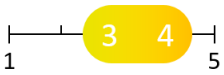
8.2 Dummy pieces disguising missing material



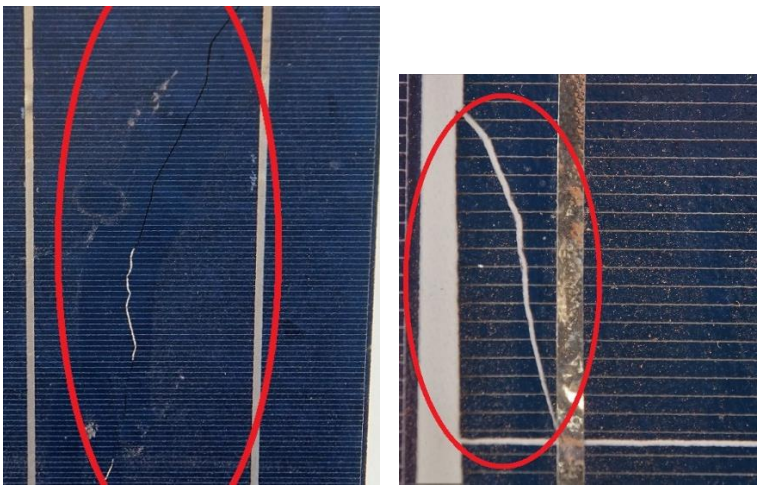
Description: Inactive material (dummy cell fragment or dark paper) has been placed behind an active cell in order to hide the fact that the cell has broken and has a piece missing.

Why it's important: Power output of the module will be limited by the missing cell area. Although power loss will depend on how much area is missing, the severity is high as it demonstrates that the manufacturer is purposely deceitful and is using sub-standard cells and practices.

Severity:



8.3 Cracks

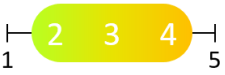


Left: large crack across the cell, but both halves are still connected to busbars. Right: smaller crack is actually more severe: a portion of the cell is no longer electrically connected.

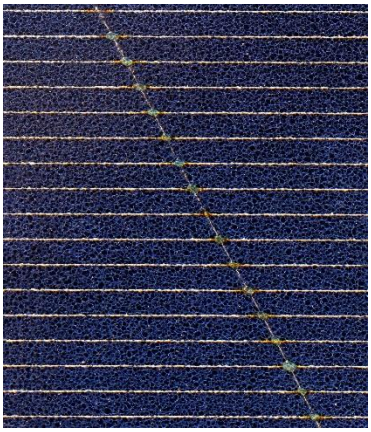
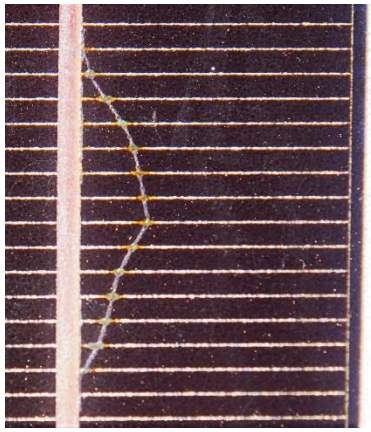
Description: Cell is cracked. Crack may be partially or all the way across a cell. Partial cracks are likely to propagate over time. Depending on size cracks may be hard or impossible to spot.

Why it's important: Severity depends on affected area. A crack is considered a major defect when its propagation could remove more than 10% of that cell's area from the electrical circuit [1]. Visible cracks indicate poor mechanical handling by manufacturer; likely more cracks exist that are not currently visible.

Severity:



8.4 "Snail trails"

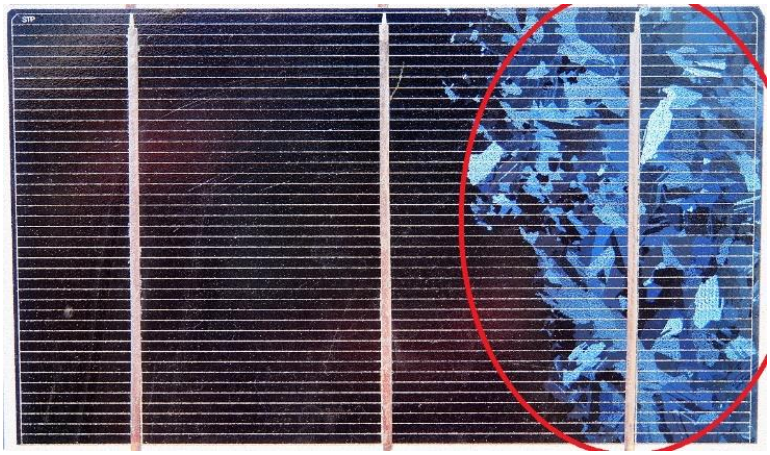



Description: Lines on cell surfaces; might appear silvered as well as yellow or brownish around metal fingers. Appears after several months of sun exposure. Correlates to presence of under-lying micro-crack that may have previously been invisible. May be difficult to distinguish from cracks or scratches.

Why it's important: Same as for cracks (Section 8.3).

Severity:

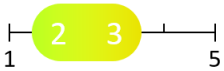
8.5 Shiny locally/significantly varying colour



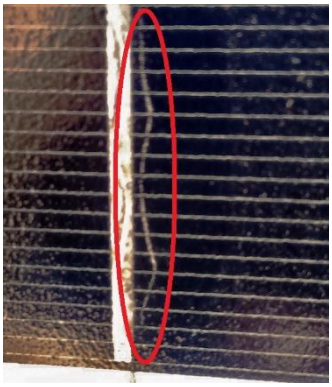
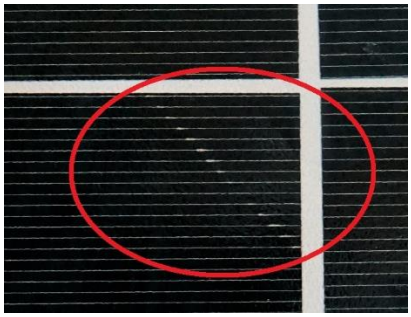
Description: Shiny silicon crystals are visible on a cell locally. Some colour variation from cell to cell can be expected (ex. slightly different shades of blue), but largely varying colour across one cell can be a concern.

Why it's important: A shiny cell is reflecting significant light instead of absorbing it and generating power. Where cells have become shiny or changed colour locally, cells have a poor or degrading anti-reflective coating which is an indicator of poor module performance.

Severity:



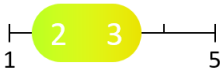
8.6 Scratches

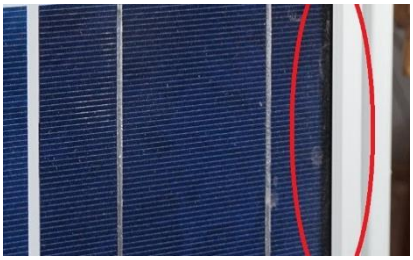
Description: Scratches in the surface of the cell from poor handling during module assembly. Often next to tabbing ribbon and caused by operator scraping the cell during soldering.

Why it's important: Severity hard to evaluate visually; deep scratches risk shorting the cell, but shallow scratches may have minimal impact.

Severity:



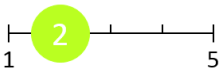
8.7 Not fully exposed



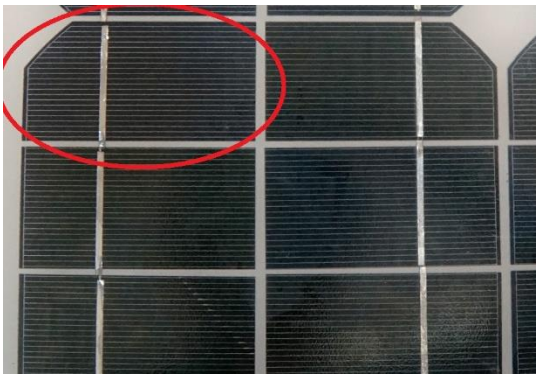
Description: A cell is partially and permanently covered, for example by the frame, a label, or by another cell.

Why it's important: Reduces active cell area. Current will be limited by the smallest cell area. An indicator of sub-standard manufacturer design and fabrication.

Severity:



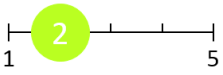
8.8 Differently sized



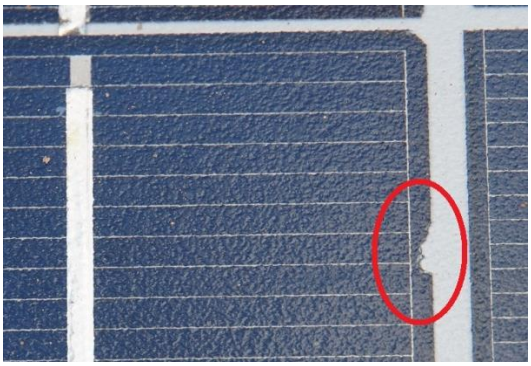
Description: Cell fragments of different sizes connected in series within a module.

Why it's important: Current will be limited by the smallest cell area. Larger cells will operate at a higher temperature as they burn off excess current, potentially decreasing product lifetime. Indication of a poor module design.

Severity:



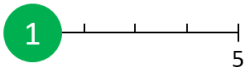
8.9 Edge chips



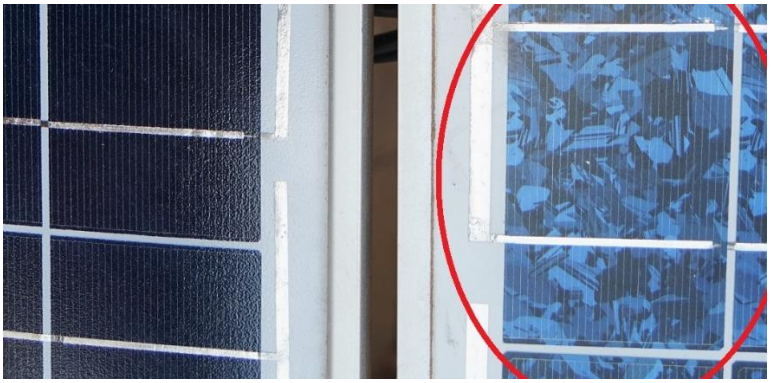
Description: A small region is missing from the edge of the cell. Does not enter metallized region.

Why it's important: Edge region is generally low power producing, so defect has minimal impact. Is a concern if many cells in a module have this defect; it indicates poor mechanical handling.

Severity:



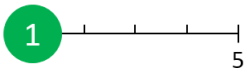
8.10 All cells very shiny



Description: Cells are very shiny, reflecting instead of absorbing light.

Why it's important: May be less efficient than darker cells, which is not inherently a problem if a module is sold based on rated power. Retailers selling such modules at a higher price to uninformed consumers who associate "shiny" with "new" or better is deceitful practice.

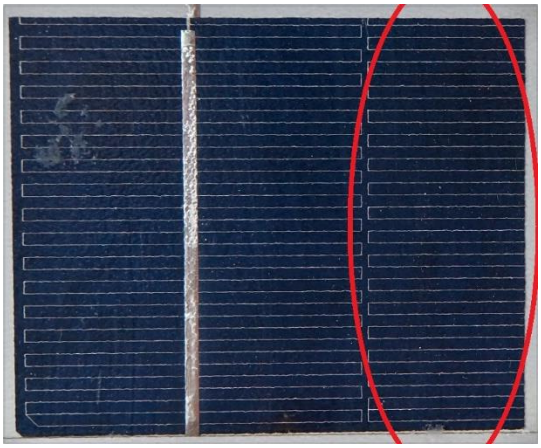
Severity:



9. CELL METALLIZATION

Metal fingers collect and conduct current from the cell to the busbars (covered by tabbing ribbon)

9.1 Fingers not connected to busbar

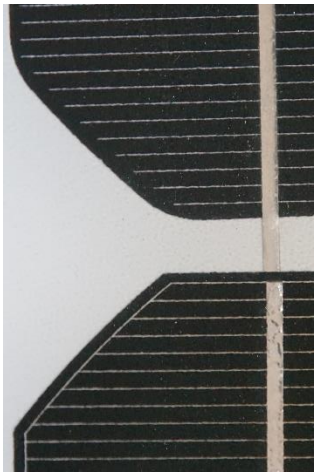


Description: Metal fingers are not connected to the busbars of a cell.

Why it's important: Current of unconnected region cannot be used. Severity depends on effected region. In the example here 1/3 of the cell area is effectively unused. Indicates a poor design and a sub-standard manufacturer.

Severity:

9.2 Not the same pattern on all cells

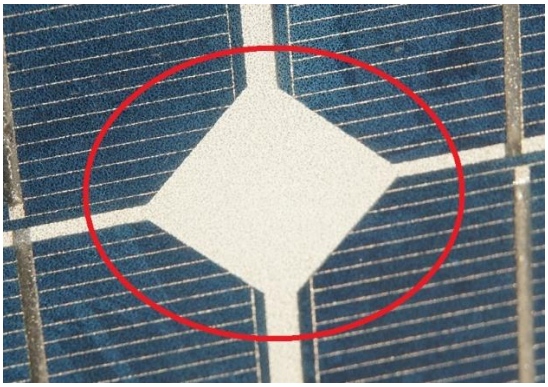


Description: Different metallization patterns apparent on different cells in the same module.

Why it's important: Not inherently an issue if cells have the same performance characteristics. However if mis-matched cells are combined in a module, higher performing cells will be limited by lower performers. Potential indicator of poor manufacturing practices.

Severity:

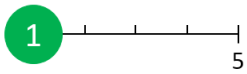
9.3 Fingers off of edge of corner of cells



Description: Metal fingers go right to cell edge in corner of cell.

Why it's important: Indicates deceitful behaviour of manufacturer; lower cost/performance poly-crystalline cells cut to look like high cost/performance mono-crystaline cells.

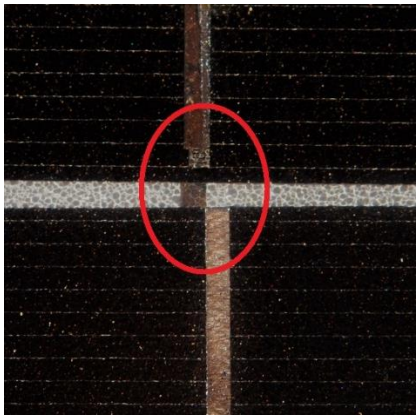
Severity:



10. CELL INTERCONNECTION

Tabbing ribbon that is soldered to busbars. Connects cells together and conducts current to external circuit.

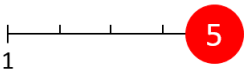
10.1 Not present / cells are not connected



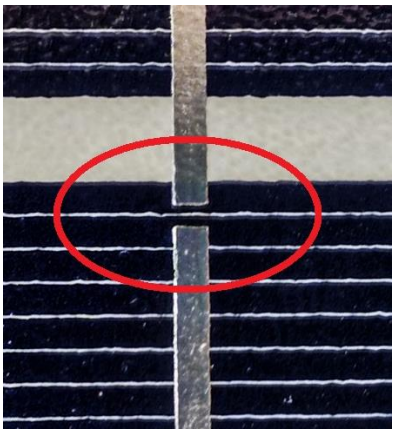
Description: There is no cell interconnection, or tabbing ribbon is present but does not connect cells together (right image gives an example where tabbing ribbon is discontinuous).

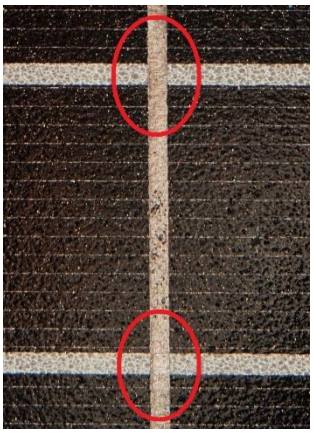
Why it's important: Power of unconnected cells does not contribute to module power. Indicator of a partially or completely counterfeit/fake product.

Severity:



10.2 Cells connected in parallel (counterfeit)

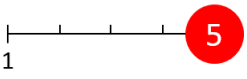




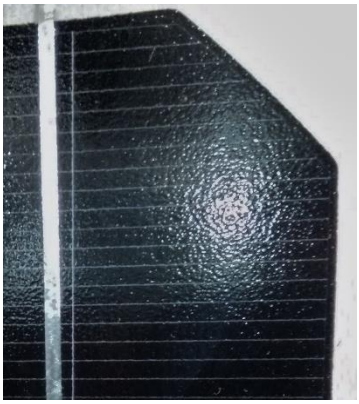
Description: Tabbing ribbon appears two dimensional in the area between cells. Rather than connecting the bottom of one cell to the top of the next (standard series connection), the top of one cell is connected to the top of the next (parallel connection).

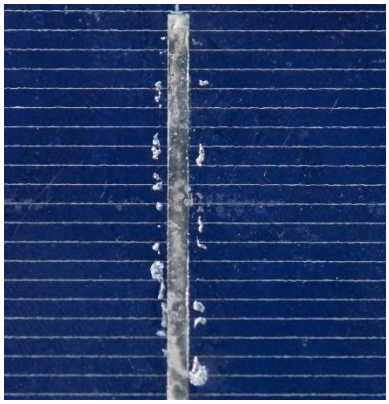
Why it's important: Often indicates a counterfeit product with fake printed paper instead of soldered tabbing ribbon.

Severity:



10.3 Poorly aligned and/or soldered

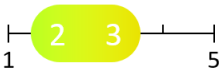




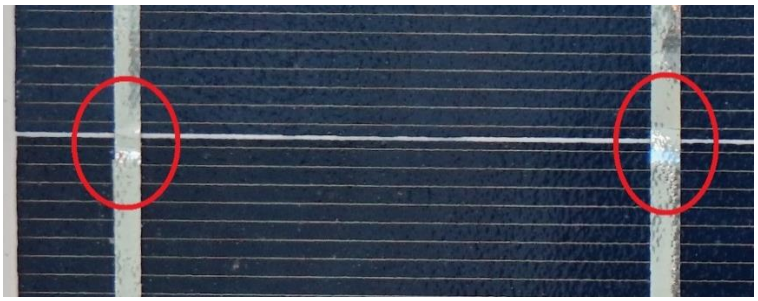
Description: Poorly soldered tabbing ribbon. For example misaligned to busbars or excess solder dripped on cell.

Why it's important: Tabbing ribbon mis-aligned to busbars increases resistances and decreases module power. Excess solder shades cells locally, decreasing current. Overall indicators of low quality control standards of the manufacturer.

Severity:



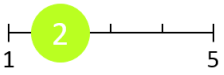
10.4 Cells connected in parallel (real cells)



Description: Real cells tabbed together in a parallel connection to combine small cut cell fragments with full-sized cells in one module

Why it's important: Poor manufacturing practice. Typically correlates with a manual process and broken cells.

Severity:



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