Fielded PV Module Condition

27th EU PVSEC and IEA PVPS Task 13 Subtask 3.2 Meeting

Corinne E. Packard

Colorado School of Mines/National Renewable Energy Laboratory

John H. Wohlgemuth, Sarah R. Kurtz, Ulrike Jahn,
Karl Berger, Thomas Friesen, Marc Koentges

NREL/PR-5200-56781

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Cataloging Module Condition by Visual Inspection

The Need-

Understanding PV module aging in different climate zones is crucial for predicting lifetime, but **no accepted tool for the collection of large-scale, consistent data on module degradation exists**

NREL/PIX 11060, NREL/PIX 14729

The Charge-

IEA PVPS Task 13: Performance and Reliability of PV Systems, Subtask 3.2: Collecting Failures and Adapting Testing Methods to Failure Mechanism for PV Modules (Lead: Marc Koentges)

NREL's Role- Create an inspection tool for documentation of visually observable defects in PV modules

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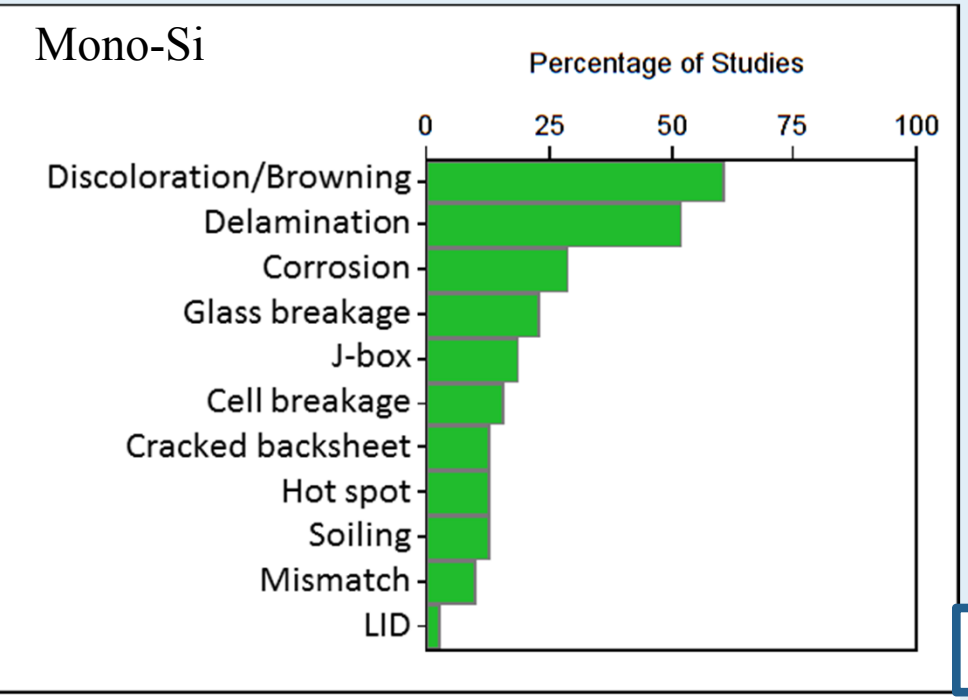
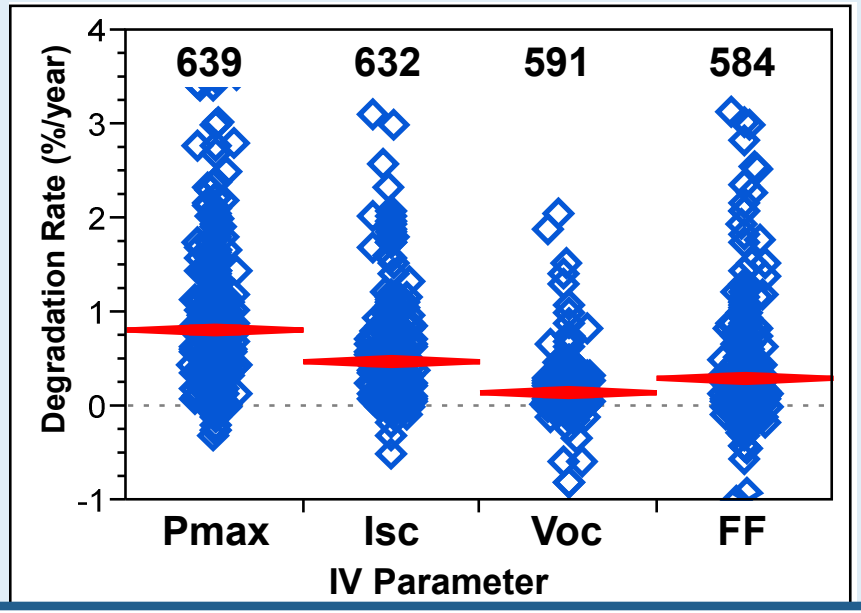
Connecting visually observed defects to power loss

- Important for prediction of lifetime and setting of warranty





Dirk Jordan, Thursday 15:15, 4DO.5.1

Visual Observations ⟷ Electrical Measurements

Establish Causality

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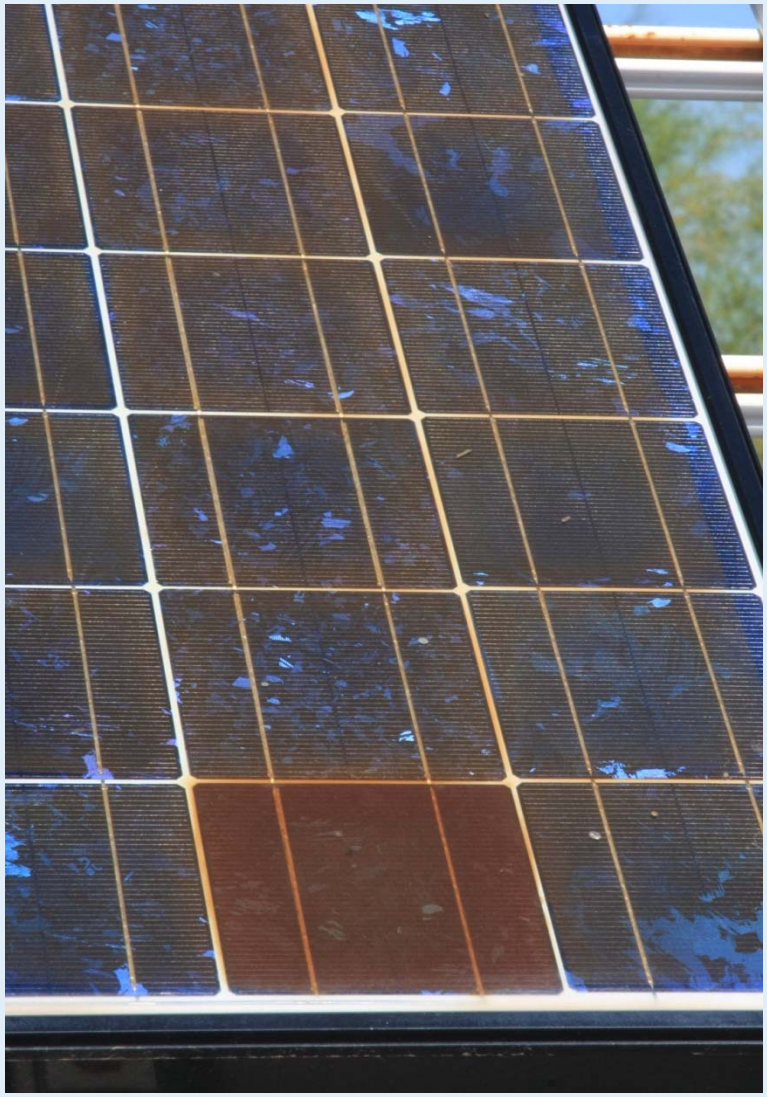
Quantification and standardization are necessary

Describe the problems with this module

- *Brown with one spot worse than others*
- *One cell is orange*
- *Minor and major discoloration*
- *Overheating over the junction box*
- *Severe encapsulant yellowing*
- *…etc.*

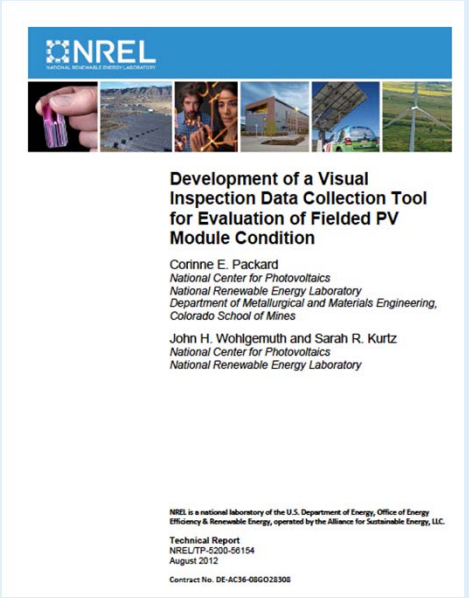


Overview of Visual Inspection Data Collection Tool

- Uses IEC/UL standard terminology
- Attempts to balance collection of sufficient detail for failure mode evaluation against minimizing recording time per module
- Consists of 14 sections- based on module component
  - Long form & short form evaluations

Additional detail can be found in the full NREL report TP-5200-56154

Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition
C.E. Packard, J.H. Wohlgemuth, S.R. Kurtz


NREL

Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition

Corinne E. Packard
National Center for Photovoltaics
National Renewable Energy Laboratory
Department of Metallurgical and Materials Engineering, Colorado School of Mines

John H. Wohlgemuth and Sarah R. Kurtz
National Center for Photovoltaics
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-5200-56154
August 2012

Contract No. DE-AC36-08GO28308

Development of the Inspection Tools

- Developed by members of NREL's PV Reliability Group (led by Sarah Kurtz) with input from IEA Collaborators
  - Ulrike Jahn (TÜV Rheinland Immissionsschutz und Energiesysteme GmbH, Germany), Karl Berger (Austrian Institute of Technology), Thomas Friesen (Scuola Universitaria Professionale della Svizzera Italiana), Marc Koentges (Institut fuer Solarenergieforschung GmbH Hameln/Emmerthal)
- Evaluated with a total of >60 modules from 3 different sites.
  - Broad range of technologies, vintages, and field exposure times
- Based on ***SYMPTOMS, not DIAGNOSES***
  - Unexpected degradation can't be captured if you don't know what you're looking for

1. System Data

Documentation of module condition

Date _____ Name of data recorder _____

Location _____

Latitude _____ Longitude _____ Altitude _____

1. System Data

System design: ☐ single module ☐ multiple modules ☐ unknown

Multiple module system: ☐ not applicable

Module location/number in a series string (from negative) _____

# of modules in series (string) _____ # of strings in parallel (array) _____

# of bypass diodes _____ # of modules per bypass diode _____

System Bias: ☐ open circuit ☐ resistive load ☐ max. power tracked ☐ short circuit ☐ unknown

System Grounding: ☐ negative ☐ positive ☐ center tap on one ☐ unknown

BEGIN INSPECTION AT BACK SIDE OF MODULE

2. Module Data

Technology: ☐ mono Si ☐ multi Si ☐ a--Si ☐ CdTe ☐ CIGS/CIS
☐ other: _____

Certified: ☐ unknown ☐ UL 1703 ☐ IEC 61215 ☐ IEC 61646 ☐ IEC 61730
☐ other: _____

As indicated on nameplate

Estimated deployment date _____

Photo taken of nameplate: ☑ yes ☐ no

Manufacturer _____
Model # _____
Serial # _____
Installation Site/Facility Serial # _____
Width _____cm Length _____cm

Nameplate: ☐ nameplate missing

P_{max} _____ V_{oc} _____ J_{sc} _____
Sys Volt_____ V_{max} _____ I_{max} _____
Bypass diode, I_f _____
Series fuse _____

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3. Rear-side Glass

3. Rear-side Glass: ☐ not applicable ☐ applicable

Damage: ☐ no damage ☐ small, localized ☐ extensive

Damage Type (mark all that apply):

☐ crazing or other non--crack damage

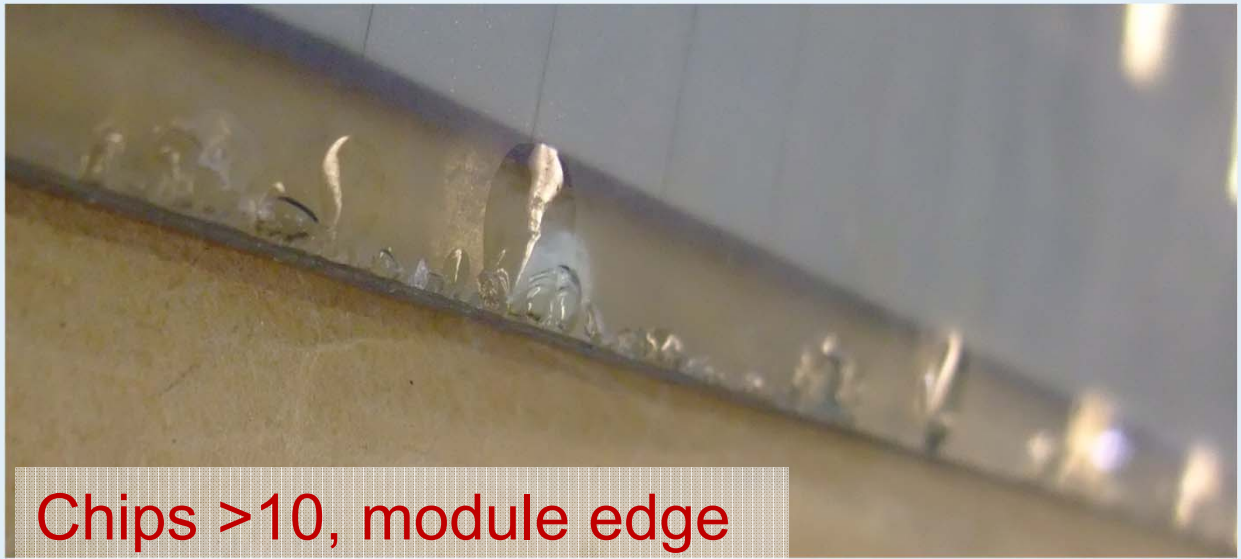
☐ shattered (tempered) ☐ shattered (non-tempered) ☐ Cracked (a.) ☐ Chipped (b.)

(a.) Cracks (#):☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Crack(s) start from: ☐ module corner ☐ module edge ☐ cell ☐ junction box

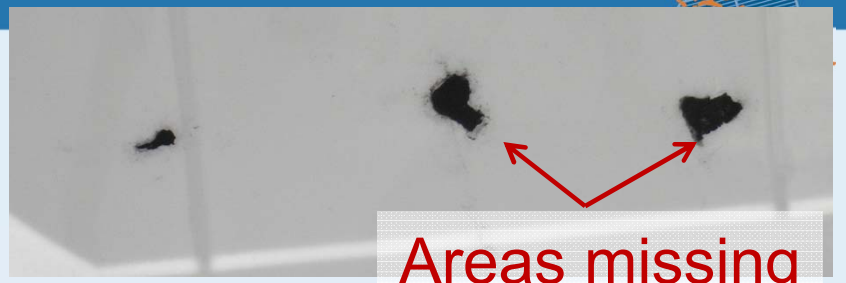
(b.) Chips (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Chipping location: ☐ module corner ☐ module edge



Chips >10, module edge

4. Backsheet

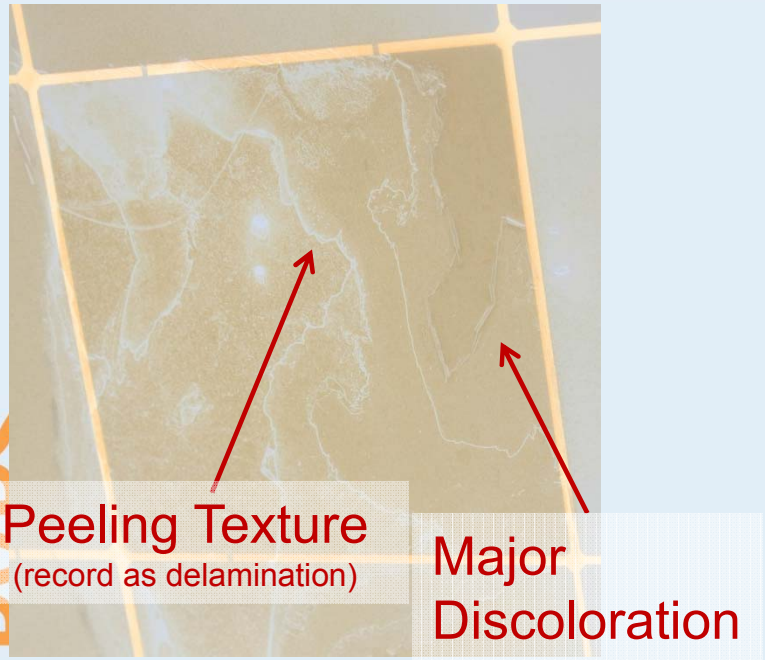


4. Backsheet: ☐ not applicable ☐ applicable

Appearance: ☐ like new ☐ minor discoloration ☐ major discoloration
Texture: ☐ like new ☐ wavy (not delaminated) ☐ wavy (delaminated) ☐ dented
Material quality --chalking: ☐ none ☐ slight ☐ substantial
Damage: ☐ no damage ☐ small, localized ☐ extensive

Damage Type (mark all that apply):

☐ burn marks (a.) ☐ bubbles (b.) ☐ delamination (c.) ☐ cracks/scratches (d.)



4. Backsheet- Detail on Damage Type


Burn Marks

Damage Type (mark all that apply):

☑ burn marks (a.) ☐ bubbles (b.) ☐ delamination (c.) ☐ cracks/scratches (d.)

(a.)Burn marks (#):☐ 1 ☑ 2 ☐ 3 ☐ 4--10 ☐ >10

Fraction of area burned:

☑ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(b.) Bubbles(#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Average bubble dimension: ☐ <5mm ☐ 5--30mm ☐ >30mm

Fraction of area with bubbles > 5 mm:

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(c.) Fraction of area delaminated:

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

Fraction of delamination that exposes circuit or cell(s)

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(d.) Cracks/scratches (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Cracks/scratches location: ☐ random/no pattern ☐ over cells ☐ between cells

Fraction of area affected by cracks/scratches (approx.):

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

Fraction of cracks/scratches that expose circuit (approx.):

☐ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%

5. Wires/ Connectors

5. Wires/Connectors:

Wires: ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled
(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt
☐ corroded ☐ animal bites/marks

Connectors: ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled

Type: ☐ unsure ☐ MC3 or MC4 ☐ Tyco Solarlok ☐ other
(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt ☐ corroded

Animal bites/marks

http://www.gutachten.streib.de/bilder/index.html

Cracked/disintegrated insulation

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5. Wires/ Connectors

Connectors: ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled
Type: ☐ unsure ☐ MC3 or MC4 ☐ Tyco Solarlok ☐ other
(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt ☐ corroded

MC3

MC4

Multi-Contact Staubli Group

Tyco Solarlok

Tyco Electronics

6. Junction Box

6. Junction Box:

Junction box itself: ☐ not applicable/observable ☐ applicable

Physical state: ☐ intact ☐ unsound structure

(mark all that apply): ☐ weathered ☐ cracked ☐ burnt ☐ warped

Lid: ☐ intact/potted ☐ loose ☐ fell off ☐ cracked

Junction box adhesive: ☐ not applicable/observable ☐ applicable

Attachment: ☐ well attached ☐ loose/brittle ☐ fell off

Pliability: ☐ like new ☐ pliable, but degraded ☐ embrittled

Junction box wire attachments: ☐ not applicable/observable ☐ applicable

Attachment: ☐ well attached ☐ loose ☐ fell off

Seal: ☐ good seal ☐ seal will leak

other: ☐ arced/started a fire

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7. Frame Grounding

7. Frame Grounding:

Original state: ☐ Wired ground ☐ Resistive ground ☐ No ground ☐ unknown
Appearance: ☐ N/A ☐ Like new ☐ Some corrosion ☐ Major corrosion
Function: ☐ Well grounded ☐ No connection

Photos taken of ☐ back, label, and junction box

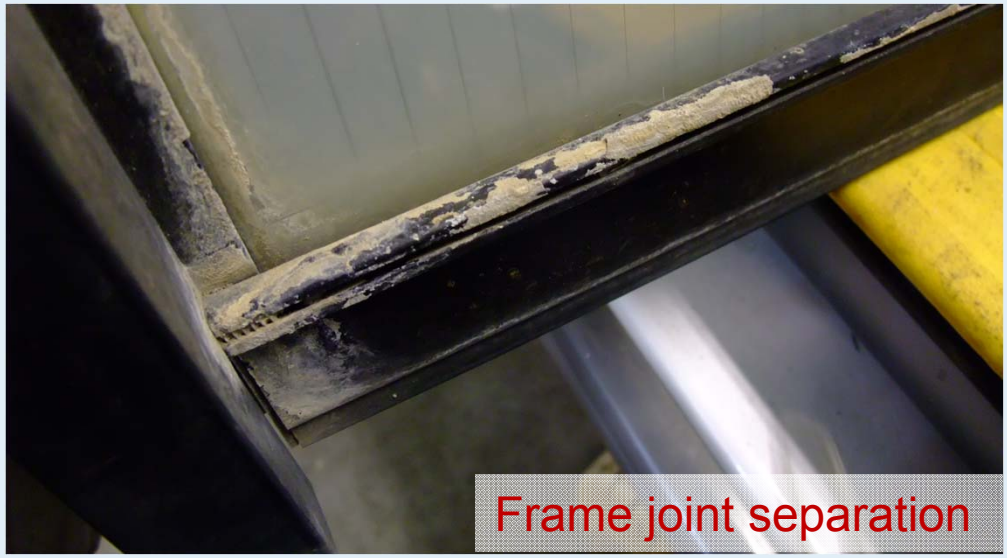
CONTINUE INSPECTION ON FRONT SIDE OF MODULE

8. Frame

8. Frame: ☐ not applicable ☐ applicable

Appearance: ☐ like new ☐ bent ☐ discolored ☐ missing
(mark all that apply): ☐ minor corrosion ☐ major corrosion ☐ frame joint separation
☐ frame cracking

Frame Adhesive: ☐ like new/not visible ☐ degraded
(mark all that apply): ☐ adhesive oozed out ☐ adhesive missing in areas



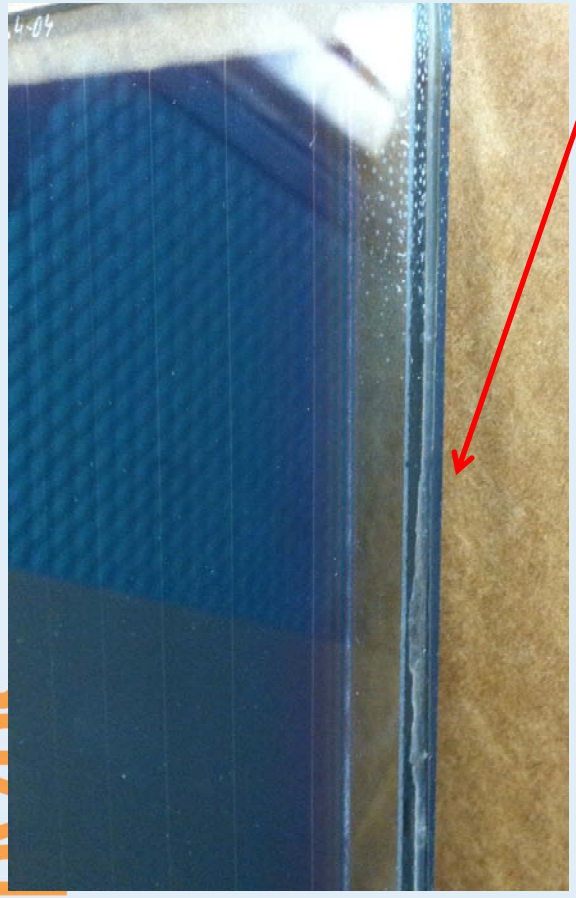
Frame joint separation

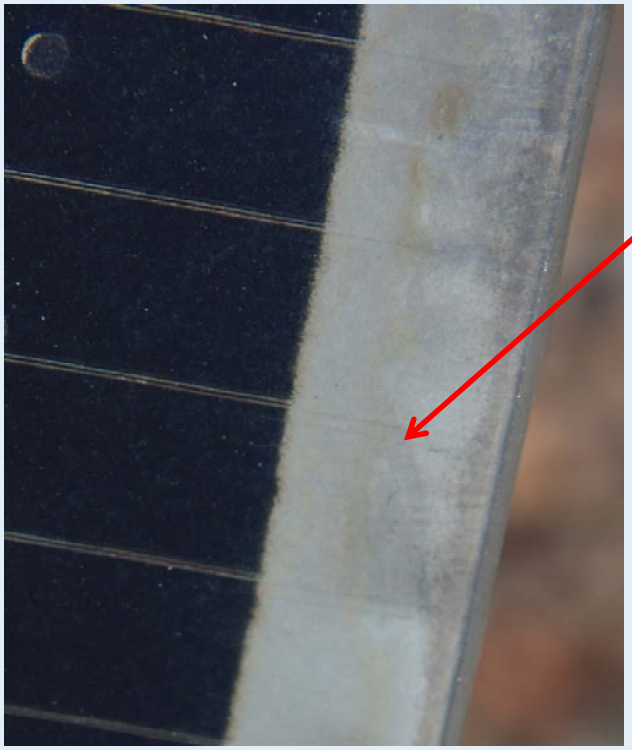
9. Frameless Edge Seal

9. Frameless Edge Seal: ☐ not applicable ☐ applicable

Bead of Silicone Around Module Edges

Not an Edge Seal- NOT Applicable





White or Gray Polymeric Sealant Around Module

Edge Seal- Applicable

9. Frameless Edge Seal

9. Frameless Edge Seal: ☐ not applicable ☐ applicable

Appearance: ☐ like new ☐ discoloration (a.) ☐ visibly degraded

(a.) Fraction affected by discoloration:

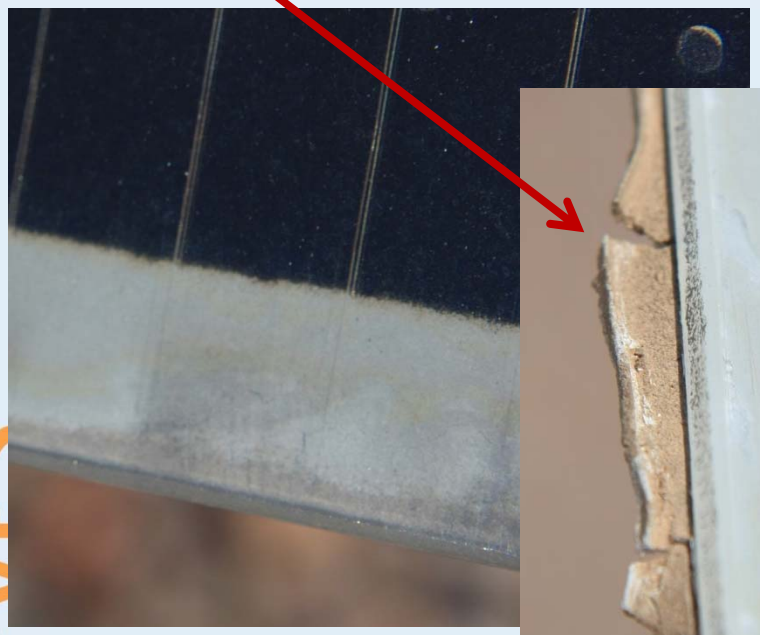
☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

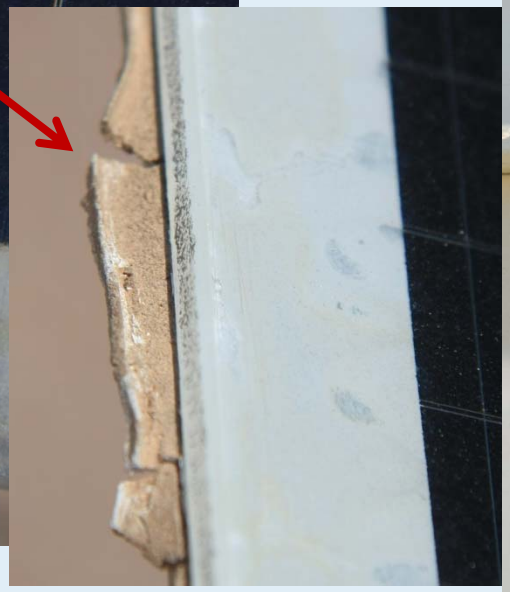
Material problems:

☐ squeezed/pinched out ☐ shows signs of moisture penetration

Delamination: ☐ local only ☐ widespread

Fraction Delaminated: ☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)





10. Glass/Polymer (front)

10. Glass/Polymer (front):

Material: ☑ glass ☐ polymer ☐ glass/polymer composite ☐ unknown
Features: ☑ smooth ☐ slightly textured ☐ pyramid/wave texture
☐ antireflection coating
Appearance: ☐ clean ☑ lightly soiled ☐ heavily soiled
Location of soiling:
☐ locally soiled near frame:
☐ left ☐ right ☐ top ☐ bottom ☐ all sides
☐ locally soiled on glass /bird droppings
Damage: ☐ no damage ☑ small, localized ☐ extensive
Damage Type (mark all that apply):
☑ crazing or other non--crack damage
☐ shattered (tempered) ☐ shattered (non--tempered) ☐ Cracked (a.)
☐ Chipped (b.) ☐ milky discoloration (c.)
(a.) Cracks (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10
Crack(s) start from: ☐ module corner ☐ module edge ☐ cell ☐ junction box
(b.) Chips (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10
Chipping location: ☐ module corner ☐ module edge
(c.) Fraction of area:
☐ <5% ☐ 5-25% ☐ 50% ☐ 75% -- 100% (consistent overall)

Localized scratches (non-crack damage)

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10. Glass/Polymer (front)

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Material: ☑ glass ☐ polymer ☐ glass/polymer composite ☐ unknown
Features: ☑ smooth ☐ slightly textured ☐ pyramid/wave texture
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☐ locally soiled on glass /bird droppings
Damage: ☐ no damage ☐ small, localized ☐ extensive
Damage Type (mark all that apply):
☐ crazing or other non--crack damage
☐ shattered (tempered) ☐ shattered (non--tempered) ☐ Cracked (a.)
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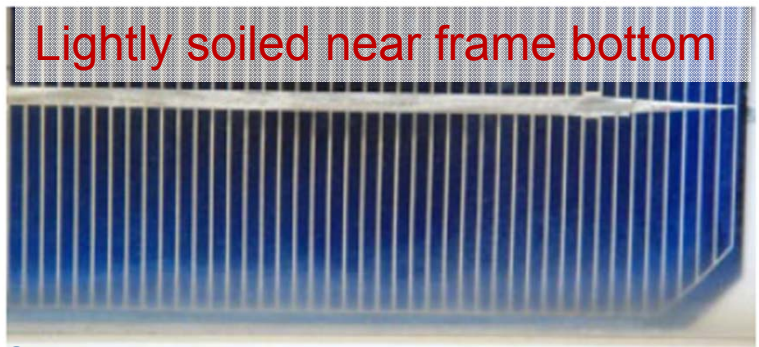
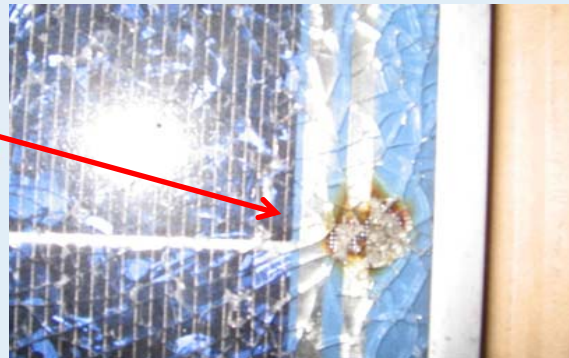


Sanchez-Friera et al. Prog. Photovolt: Res. Appl. 2011



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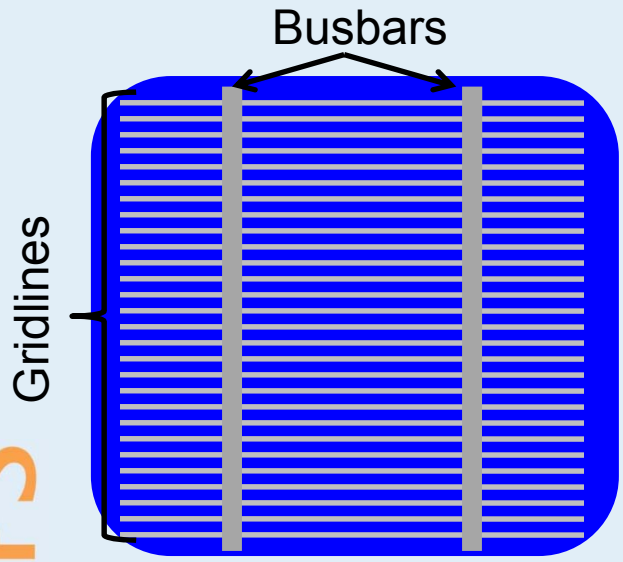
11. Metallization- Clarification of Terminology

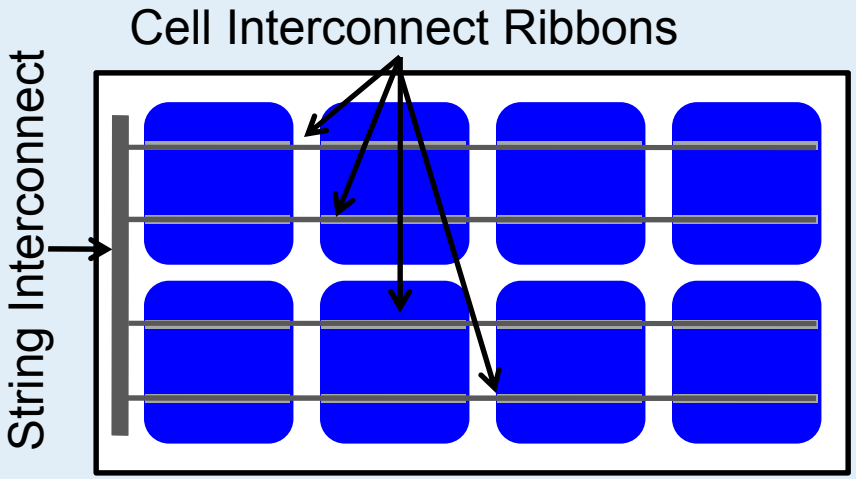
Up to 4 levels of metallization and interconnects considered:

1. **Gridlines/Fingers**- finest level of metallization, <1mm thick
2. **Busbars**- connect gridlines/fingers within a single cell; often obscured by cell interconnect ribbon
3. **Cell Interconnect Ribbon**- connects multiple cells into a string
4. **String Interconnect**- connects multiple strings of cells

On an individual silicon cell



On a silicon module



Note: The condition of the busbars is often unobservable due to the overlap of the cell interconnect ribbon

For thin film modules-
Consider function of metallization; generally will not use all 4 levels

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11. Metallization

11. Metallization:

Gridlines/Fingers: ☐ not applicable/barely observable ☑ applicable

Appearance: ☐ like new ☑ light discoloration(a.) ☐ dark discoloration(a.)

(a.) Fraction of discoloration:

☑ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

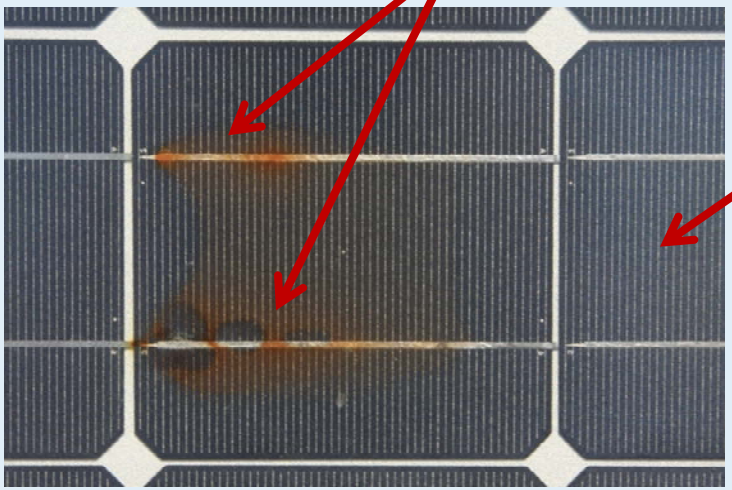
Busbars: ☐ not applicable/not observable ☑ applicable

Appearance: ☐ like new ☐ light discoloration(a.) ☑ dark discoloration(a.)

(a.) Fraction of discoloration:

☑ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☑ diffuse burn mark(s) ☐ misaligned



11. Metallization

Cell Interconnect Ribbon: ☐ not applicable/not observable ☑ applicable

Appearance: ☑ like new ☐ light discoloration(a.) ☐ dark discoloration(a.)

(a.) Fraction of discoloration:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☐ burn marks ☐ breaks

String Interconnect: ☐ not applicable/not observable ☑ applicable

Appearance: ☐ like new ☐ light discoloration(a.) ☑ dark discoloration(a.)

(a.) Fraction of discoloration:

☑ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☑ burn marks ☐ breaks

☐ arc tracks (thin, small burns)

Dark Discoloration on String Interconnect

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12. Silicon Module: Cells

12. Silicon (mono or multi) module: ☐ not applicable ☐ applicable

Number of:

Cells in module _____

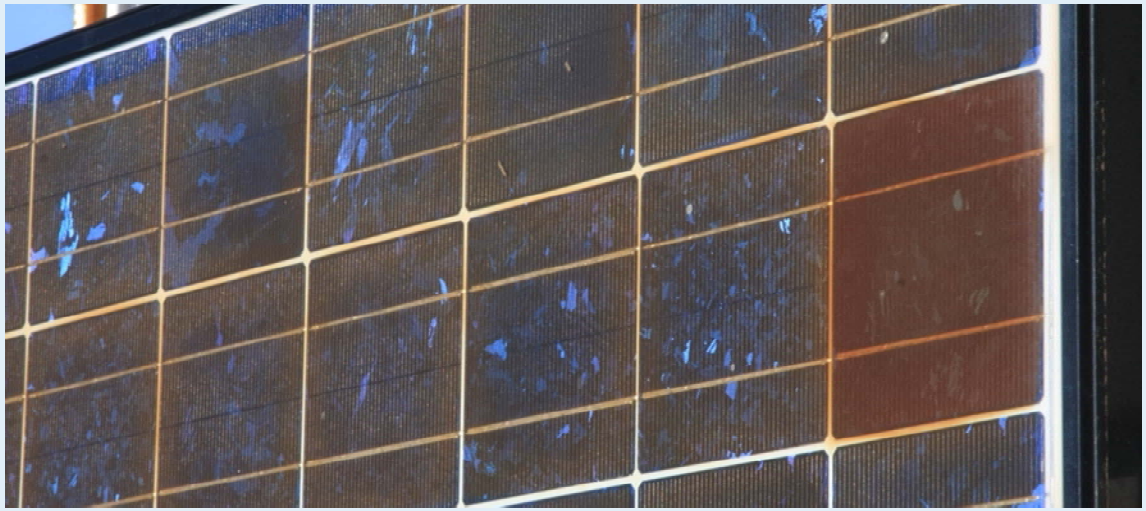
Cells in series/string _____

Strings in parallel _____

Cell size: Width _____ cm Length _____ cm

Distance between frame and cell: ☐ >10 mm ☐ <10 mm

Distance between cells in a string: ☐ >1 mm ☐ <1 mm



12. Silicon Module: Discoloration

Discoloration: ☐ none/like new ☐ light discoloration ☐ dark discoloration

Number of cells with any discoloration: _____

of those, average % discolored area:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% ☐ 100% (consistent overall)

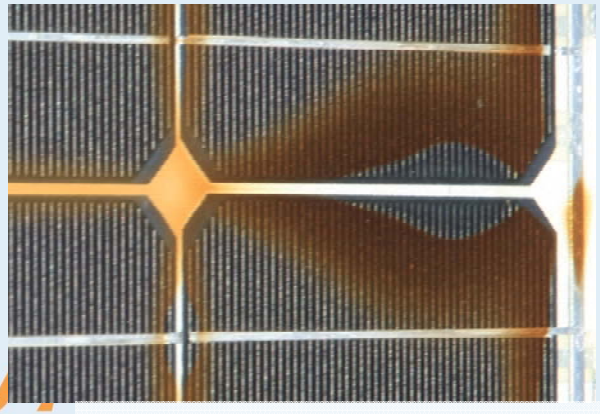
Discoloration location(s) (mark all that apply):

☐ module center ☐ module edges ☐ cell centers ☐ cell edges

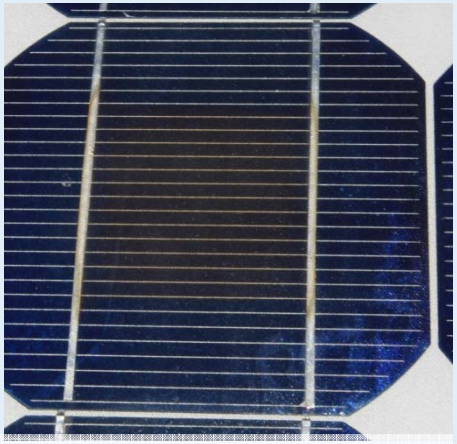
☐ over gridlines ☐ over busbars ☐ over tabbing ☐ between cells

☐ individual cell(s)darker than others ☐ partial cell discoloration

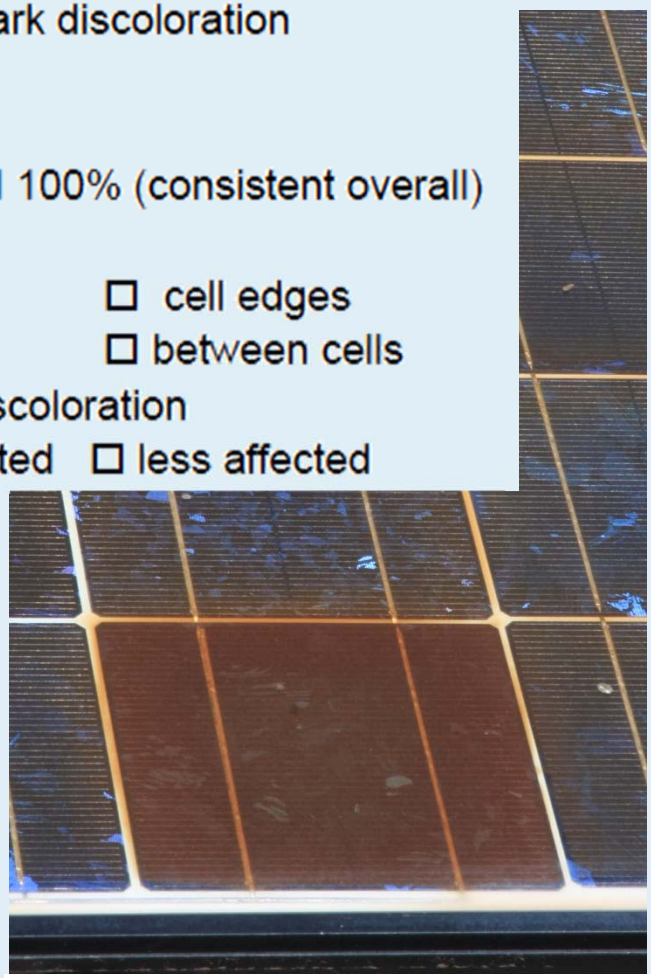
Junction box area: ☐ same as elsewhere ☐ more affected ☐ less affected



Dark discoloration at cell edges, between cells, and over gridlines and busbars



Light discoloration at cell center



Light and dark discoloration with one individual cell darker than others

12. Silicon Module: Discoloration

Discoloration: ☐ none/like new ☐ light discoloration ☐ dark discoloration

Number of cells with any discoloration: _____

of those, average % discolored area:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% ☐ 100% (consistent overall)

Discoloration location(s) (mark all that apply):

☐ module center ☐ module edges ☐ cell centers ☐ cell edges

☐ over gridlines ☐ over busbars ☐ over tabbing ☐ between cells

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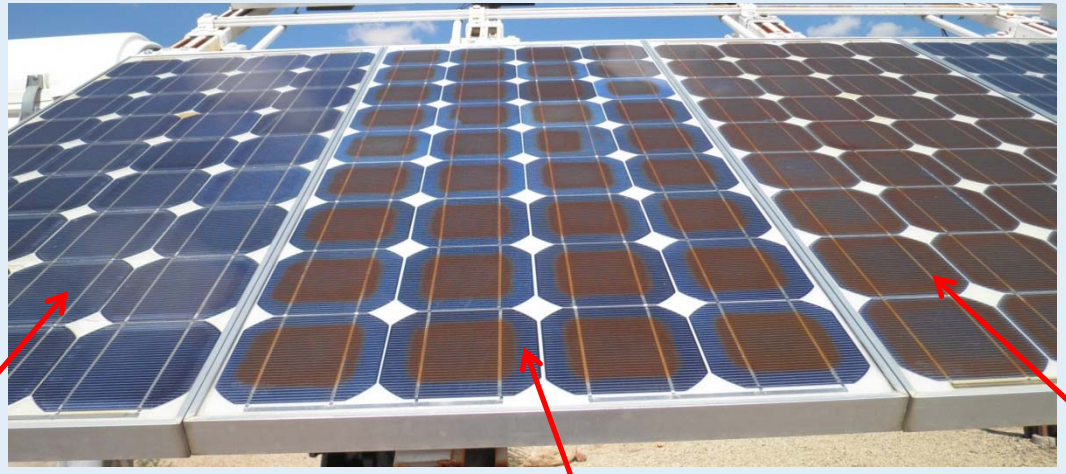


No discoloration

Discoloration over Center Of Cells

Discoloration over whole cell

12. Silicon Module: Damage

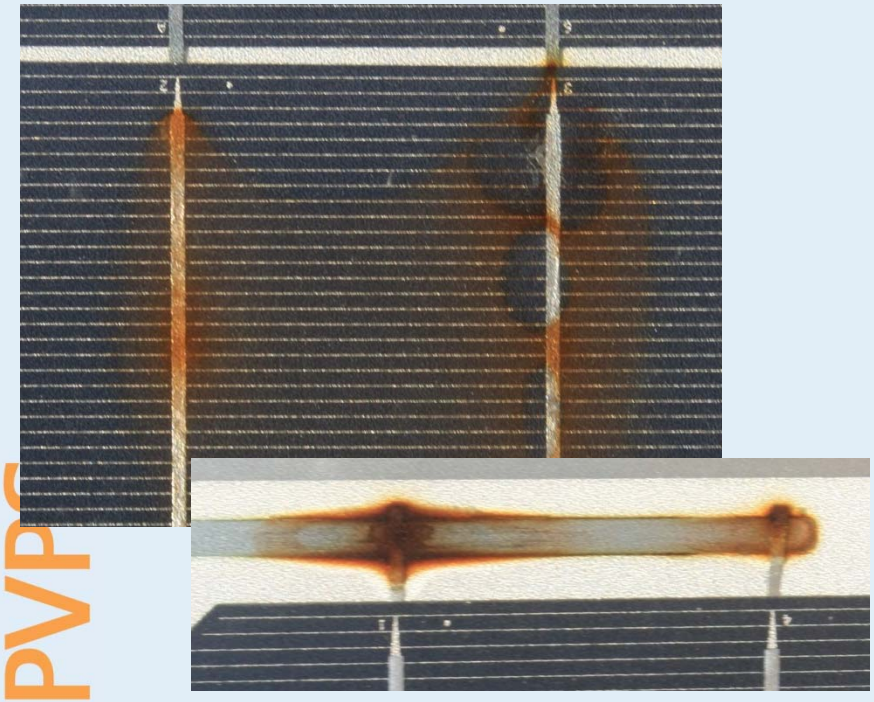
Damage: ☐ none

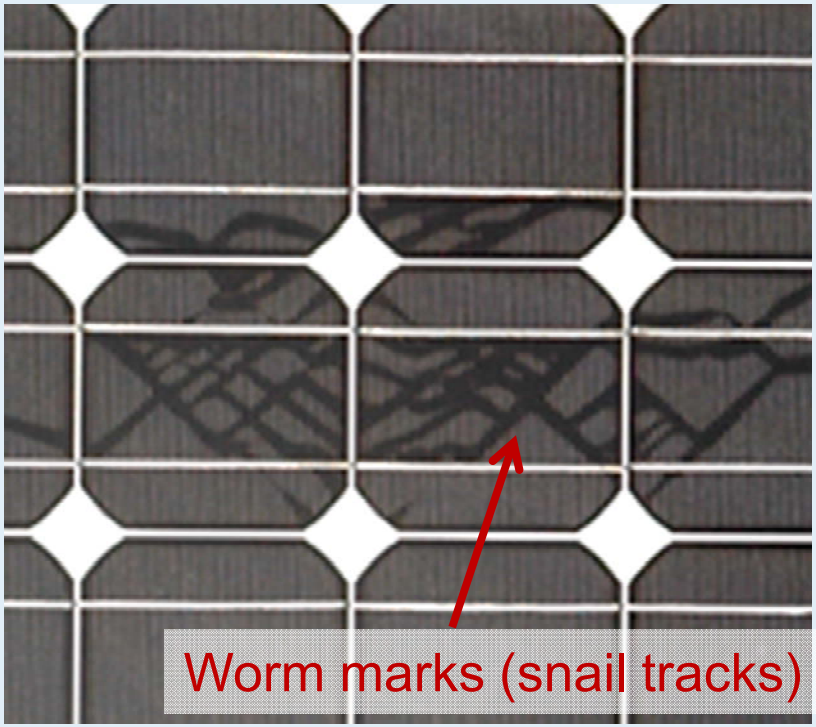
(mark all that apply): ☐ burn mark (a.) ☐ cracking (b.) ☐ moisture
☐ worm marks/snail tracks (c.) ☐ foreign particle embedded

(a.) Burns (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4-10 ☐ >10

(b.) Number of cells cracked: _____

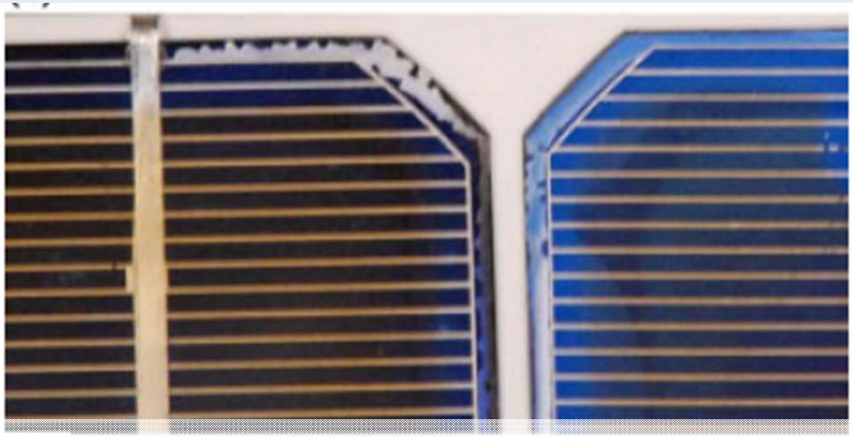
(c.) Number of cells with worm marks/snail tracks: _____





12. Silicon Module: Delamination

Delamination: ☐ none ☐ from edges ☐ uniform ☐ corner(s) ☐ near junction box
☐ between cells (a.) ☐ over cells (b.) ☐ near cell or string interconnect
(a.) Fraction delamination between cells:
☐ <5% ☐ 5-25% ☐ 50% ☐ 75-100% (consistent overall)
(b.) Fraction delamination over cells:
☐ <5% ☐ 5-25% ☐ 50% ☐ 75-100% (consistent overall)
Likely interface (choose 2):
☐ glass ☐ semiconductor ☐ encapsulant ☐ back sheet ☐ busbar

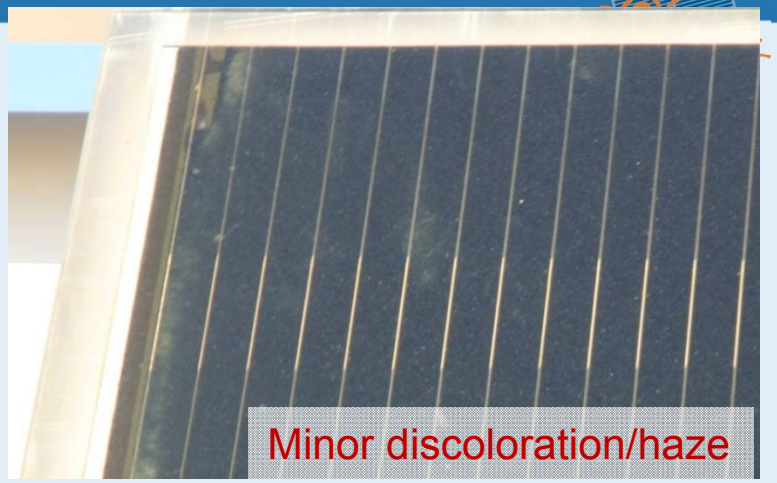


Semiconductor/Encapsulant delamination near edges

Semiconductor/Encapsulant delamination near busbar

Sanchez-Friera et al. Prog. Photovolt: Res. Appl. 2011

13. Thin Film Module



13. Thin film module: ☐ not applicable ☐ applicable

Number of cells:

Number of cells in module _____

Number of cells in series/string _____

Number of strings in parallel _____

Cell size: Width _____ cm Length _____ cm

Distance between frame and cell: ☐ >10 mm ☐ <10 mm

Appearance: ☐ like new ☐ minor/light discoloration ☐ major/dark discoloration

Discoloration type (mark all that apply):

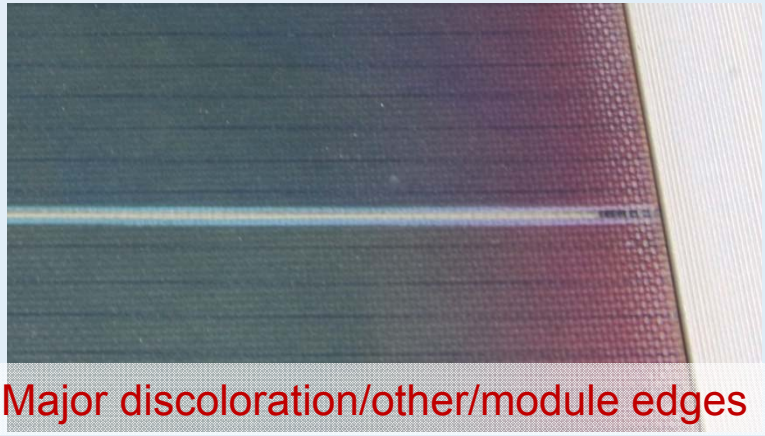
☐ spotted degradation ☐ haze (encapsulant browning) ☐ other

Discoloration location (mark all that apply):

☐ overall/no location pattern ☐ module center ☐ module edge(s)

☐ cell center ☐ cell edges ☐ near crack(s)


Major discoloration/spotted degradation/no pattern


Major discoloration/other/module edges

13. Thin Film Module

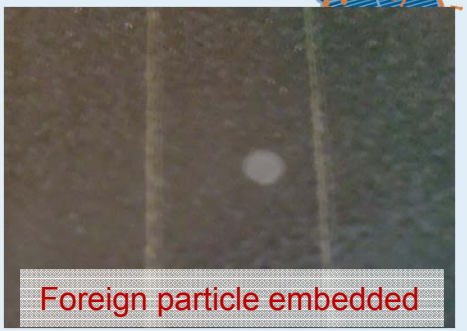
Damage: ☐ no damage ☐ small, localized ☐ extensive

Damage Type (mark all that apply): ☐ burn mark(s) ☐ cracking ☐ possible moisture ☐ foreign particle embedded

Delamination: ☐ no delamination ☐ small, localized ☐ extensive

Location: ☐ from edges ☐ uniform ☐ corner(s) ☐ near junction box ☐ near busbar ☐ along scribe lines

Delamination Type: ☐ absorber delamination ☐ AR coating delamination ☐ other



Foreign particle embedded

Absorber delamination

Small, localized damage/
Possible moisture/cracking

PVPS

14. Electronic Records

Photos taken of ☐ front and defects

14. Electronic Records ☐ applicable ☐ not applicable
Photographs and I--V curves recorded electronically--list file names in blanks
Photo files _____
I--V curve _____
Connector function: ☐ functions ☐ no longer mates ☐ exposed
Irradiance _____ Sensor _____
Temperature _____ Sensor _____
EL picture _____
IR picture _____
Bypass Diode Test: ☐ applicable ☐ not applicable
Number of diodes:
In total _____, shorted _____, open _____

OTHER

Preliminary Data

Site 1: Tempe, Arizona, USA
49 modules
83% Silicon (mono + multi)
18% Thin film

Site 2: New Delhi, India
14 modules
17% Silicon (mono + multi)
83% Thin film

Observation	% of Modules	Observation	% of Modules
Glass (front): Lightly soiled	55%	Glass (front): Small, localized damage	50%
Glass (front): Bird droppings	24%	Wires: Pliable but degraded	43%
Connectors: Pliable but degraded	22%	Glass (front): Lightly soiled	43%
Encapsulant: Major discoloration	20%	Junction box: seal will leak	36%
Backsheet: Small, localized damage	20%	Thin film module: Distance between frame and cells <10mm	36%

Summary & Conclusion

- Data collection tool has been created and is available for use

Additional detail can be found in the full NREL report TP-5200-56154

Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition
C.E. Packard, J.H. Wohlgemuth, S.R. Kurtz

- Long form and short form data collection tools available, along with report detailing intended data collection procedures
- Collection of uniform, detailed data from multiple climate zones is one part of understanding module degradation and failure