ESREF 2010
Tutorial on
“RELIABILITY ISSUE OF PHOTOVOLTAIC DEVICES AND SYSTEMS”
Part I - PV Devices

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Enea Portici Research Centre

October 2010  11th - 15th
Monte Cassino Abbey and Gaeta- Italy
PART I: Reliability of Photovoltaic devices

- PV Technology
- PV Solar cells & Module manufacturing:
  - Wafer based Silicon Technology
  - Thin film (Thin Silicon, CIGS, CdTe)
  - PV Concentration
  - Organic and hybrid Solar cells
- Reliability and Qualification Tests
- Overview of Solar cells and PV Modules Failure Mechanisms
PART II: Reliability of Photovoltaic Systems

- Photovoltaic Power Management Systems
- DC-AC Converter Architectures
- DC-DC Converter Topologies
- Reliability Theory
- Reliability Model
- DC-DC Converter Reliability Evaluation
Part I: references

- NREL-DOE Photovoltaic Module Reliability Workshop February 18-19, 2010  Denver, Colorado (USA)  
  http://www1.eere.energy.gov/solar/pv_module_reliability_workshop_2010.html
- G. TamizhMani et.. Al. Failure Analysis of design qualification testing 2007 vs 2005 33nd PVSC Conference San Diego, 2008
Part I: references

- Reliability of PV-modules Natural, accelerated and simulated degradation Projects PV-Zuverlässigkeit and Performance SP5 Michael Köhl Fraunhofer ISE,D SPIE Conference 7048-4

IEC Technical norms

- IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules – design qualification and type approval
- IEC 61646: ‘Thin-film terrestrial photovoltaic (PV) modules – design qualification and type approval’,
- IEC 62108: Concentrator photovoltaic (CPV) modules and assemblies – design qualification and type approval
This conference:

Oct, 12-2010 16.20
Reliability of III-V Concentrator Solar Cells. - Carlos Algora (Solar Energy Institute, Polytechnic University of Madrid, Spain)

Oct, 13-2010 15.00 G.A.2
Humidity Study of a-Si PV Cell. - C.M. Tan,², BK.E..Chen², K.P. Toh¹ (¹Nanyang Technological University, ²SIMTech)

Oct, 13-2010 16.00 G.A.4
Novel accelerated testing method for III-V concentrator solar cells N.Núñez¹,²,.- M.Vazquez¹,², J.González¹, C.Algora¹, P.Espinet¹ (¹IES-Universidad Politécnica de Madrid, ²EUITT-Universidad Politécnica de Madrid)

Oct, 13-2010 17:00-18:30 G.P.5
Induced degradation on c-Si solar cells for concentration terrestrial applications L.Lancelotti¹, R.Fucci¹, A.Romano¹, A.Sarno¹, S.Daliento² (¹ENEA, ²University of Naples Federico II)

Oct, 13-2010 17:00-18:30 G.P.5
G.p.6 Development and reliability of antireflective coatings specific for PV Concentration Applications F.Roca¹, E.Bobeico, G.Gradit¹, L.La Notte, A.Merola, F.Russo (ENEA)
PV Market & Perspective
Generation cost for PV
(EPIA: Toward an Effective Industrial Policy for PV (RWE Shott Solar))
Evolution of the turn-key System prices
The table below summarises the key targets contained in the SRA. The figures are rounded and indicative.

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>Today</th>
<th>2015</th>
<th>2030</th>
<th>Long term potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical turn-key system price</td>
<td>&gt;30</td>
<td>5</td>
<td>2.5</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>(2006 €/Wp, excl. VAT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical electricity generation</td>
<td>&gt;2</td>
<td>0.30</td>
<td>0.15</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>costs southern Europe (2006 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/kWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical commercial flat-plate</td>
<td>up to 8%</td>
<td>up to 15%</td>
<td>up to 20%</td>
<td>up to 25%</td>
<td>up to 40%</td>
</tr>
<tr>
<td>module efficiencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical commercial concentrator</td>
<td>(&lt;10%)</td>
<td>up to 25%</td>
<td>up to 30%</td>
<td>up to 40%</td>
<td>up to 60%</td>
</tr>
<tr>
<td>module efficiencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical system energy pay-back</td>
<td>&gt;10</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>time southern Europe (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“Flat plate” refers to standard modules for use under natural sunlight, “concentrator” refers to systems that concentrate sunlight (and, by necessity, track the sun across the sky).
Module price trends:

Opportunities and Threats

Source: DisplayBank

Source: Maycock, Strategies Unlimited
PV market forecast:

Source: DisplayBank
PV cells and Modules production:

China main producer

http://re.jrc.ec.europa.eu/refsys/
PV market Share forecast (by application):

PV Installation:
Annual PV Production capacities of Thin-Film and Crystalline Silicon based solar modules.

PV market forecast short term:

3rd PV Generation and Advanced concepts:

Advanced concepts for high efficiency
Photovoltaic technology prospects

Existing 1st and 2nd PV generation

3rd PV Generation and advanced concepts

I – Crystalline silicon technologies: single crystalline, multi-crystalline, ribbon

II – Thin-film technologies: cadmium-telluride, copper-indium/gallium-/diselenide/disulphide and related II-VI compounds, thin-film silicon

III – Emerging technologies and novel concepts

IV – Concentrating photovoltaics

Quantum wells, up-down converters, intermediate band gaps, plasmonics, thermo-photovoltaics, etc

Source: IEA PVPS.
PV market forecast mid- long-term:
PV market summary:

- **Short Mid-term**
  - Continuation to expand solar grade silicon production capacities in line with solar cell manufacturing capacities;
  - Accelerated reduction of material consumption per silicon solar cell and Wp, e.g. higher efficiencies, thinner wafers, less wafering losses, etc.;
  - Accelerated ramp-up of thin-film solar cell manufacturing;

- **Mid-long term**
  - Accelerated CPV and very high efficiency SC introduction into the market, as well as capacity growth rates above the normal trend
  - Advanced concepts for low cost-high reliability
PV Solar Cells and modules
Technology & reliability
PV Systems

Off Grid PV system

PV Module

POWER CONDITIONING UNIT

Storage

INVERTER

~ AC

Load
PV Modules
Importance of Reliability

Sarah Kurtz, NREL Workshop on Accelerated Stress Testing & Reliability
"Renewable Reliability" October 7-9, 2009 Jersey City, NJ, USA
Check Reliability

Prototype

Observe failure
Identify mechanism
Develop test
Mitigate problem
Identify next failure

Mature product

Failure analysis
Identify mechanism
Develop (ALT) test
Measure acceleration
Predict performance

NREL-DOE Photovoltaic Module Reliability Workshop February 18-19, 2010 Denver, Colorado (USA)
PV Modules: Typical tests

- Corrosion of materials, especially metals
- Water-vapor intrusion
- Delamination of encapsulant materials, especially polymers
- Physical damage from wind, hail, and installation
- Thermal excursions, including coefficient of thermal expansion mismatches
- Ultraviolet (UV) radiation
- Deterioration of or damage to external components such as junction boxes
In the late 1970s, JPL conducted a series of Block Buys of PV modules. For each Buy, they required that the module design pass a set of tests. The modules were deployed and the resulting failures analyzed to revise the set of tests. A Block VI Buy was planned, but not implemented.

<table>
<thead>
<tr>
<th>Test</th>
<th>Block I</th>
<th>Block II</th>
<th>Block III</th>
<th>Block IV</th>
<th>Block V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Cycle (°C)</td>
<td>100 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>200 cycles -40 to +90</td>
</tr>
<tr>
<td>Humidity or humidity/freeze (RH is relative humidity)</td>
<td>70 C, 90%RH, 68 hr</td>
<td>5 cycles 40 C, 90%RH to 23 C</td>
<td>5 cycles 40 C, 90%RH to 23 C</td>
<td>5 cycles 54 C, 90%RH to 23 C</td>
<td>10 cycles 85 C, 85%RH to -40 C</td>
</tr>
<tr>
<td>Hot spots</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3 cells, 100 hrs</td>
</tr>
<tr>
<td>Mechanical load</td>
<td>-</td>
<td>100 cycles ± 2400 Pa</td>
<td>100 cycles ± 2400 Pa</td>
<td>10000 cyc. ± 2400 P</td>
<td>10000 cyc. ± 2400 Pa</td>
</tr>
<tr>
<td>Hail</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9 impacts 3/4&quot; - 45 mph</td>
<td>10 impacts 1&quot; - 52 mph</td>
</tr>
<tr>
<td>High pot</td>
<td>-</td>
<td>&lt; 15 µA 1500 V</td>
<td>&lt; 50 µA 1500 V</td>
<td>&lt; 50 µA 1500 V</td>
<td>&lt; 50 µA 2*Vts+1000</td>
</tr>
</tbody>
</table>
Reliability of cSi PV Modules

*(Whipple 1993) Pre-Block V: 45% module failure rate
Post-Block V: <0.1% module failure rate

Joint Research Center of the European Commission, Ispra, Italy also developed qualification tests. Their early testing (CEC 201) included hail, UV, wind, temperature cycling, “smog,” humidity cycling, and thermal degradation including shocks from cold-water spray. The CEC 201 test later evolved into CEC 501 and 502

IEC technical committee 82: Solar photovoltaic energy systems.

Commission Electrotechnique Internationale
International Electrotechnical Commission
http://www.iec.ch/

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für elektrotechnische Normung
http://www.cenelec.eu/

National Committees

Comitato Elettrotecnico Italiano
http://www.ceiuni.it/

<table>
<thead>
<tr>
<th>Test</th>
<th>Block I</th>
<th>Block II</th>
<th>Block III</th>
<th>Block IV</th>
<th>Block V</th>
<th>IEC 61215</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Cycle (°C)</td>
<td>100 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>50 cycles -40 to +90</td>
<td>200 cycles -40 to +90</td>
<td>200 cycles -40 to +85 w current flow</td>
</tr>
<tr>
<td>Humidity or humidity/freeze (RH is relative humidity)</td>
<td>70 C, 90%RH, 68 hr</td>
<td>5 cycles 40 C, 90%RH to 23 C</td>
<td>5 cycles 40 C, 90%RH to 23 C</td>
<td>5 cycles 54 C, 90%RH to 23 C</td>
<td>10 cycles 85 C, 85%RH to -40 C</td>
<td>10 cycles 85 C, 85%RH to -40 C; 1000 hr 85 C, 85%RH</td>
</tr>
<tr>
<td>Hot spots</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3 cells, 100 hrs</td>
<td>5 hr, worst case</td>
</tr>
<tr>
<td>Mechanical load</td>
<td>-</td>
<td>100 cycles ± 2400 Pa</td>
<td>100 cycles ± 2400 Pa</td>
<td>10000 cyc. ± 2400 Pa</td>
<td>10000 cyc. ± 2400 Pa</td>
<td>3 cyc. 2400 Pa</td>
</tr>
<tr>
<td>Hail</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9 impacts 3/4” - 45 mph</td>
<td>10 impacts 1” - 52 mph</td>
<td>11 impacts 25 mm - 23 m/s</td>
</tr>
<tr>
<td>High pot</td>
<td>-</td>
<td>&lt; 15 μA 1500 V</td>
<td>&lt; 50 μA 1500 V</td>
<td>&lt; 50 μA 1500 V</td>
<td>&lt; 50 μA 2*Vs+1000</td>
<td>1 min at 2*Vs+1000, then measure @ 500 V: R X A &gt; 40 MΩ•m²</td>
</tr>
</tbody>
</table>
Crystalline Si PV modules

cSi PV Module (front)

Multi Si PV Module (front)

Multi Si PV Module (back)
xSi module cross section

Common encapsulation materials
EVA Ethylene vinyl acetate - vinyl acetate
PET - polyethylene terephthalate
PVF - poly vinyl fluoride

EVA
Tempered Glass
Back Sheet
Cell
Junction box
Tab (electrical connection)
Fastening Holes
Anodized Aluminium framework
Sealant

Low Iron Glass
Quality assurance (reduction of impurities in Si processing give light-induced degradation, quality of metallization, etc) can assure for cSi PV modules long-term, quantitative predictions.

Typical degradation rates are 0-1%/yr (difficult to measure); field failure rates are often < 0.1%/yr.

Currently, most reports imply that c-Si module failures dominated by improper installation, lightning strikes, critters, etc.
Typical damages

Ag gridline corrosion visible

Connector damage

EVA Yellowing
Thin Film Solar cells
(2\textsuperscript{nd} Generation PV)
Thin Film Solar cells (ThinSi, CIGS, CdTe)
Effect of Damp Heat with System Bias

a-si
• 600 V
• 12 Months in the field
• Electrochemical corrosion from Sodium ion with water at the TCO/glass interface cause delamination of the TCO

Key drivers are
• Negative celle polarity vs ground
• Moisture ingestion
• Temperature
• Low Na content in glass
Testing sequences
Typical testing sequence for PV modules

8 modules

Initial Preconditioning
5 kWh/m²

Initial Performance and Electrical Insolation Tests

1 module
Control Module

1 module
Characterization Tests

2 modules
UV Preconditioning
15 kWh/m²

2 modules
200 Thermal Cycles w/ Bias
-40°C to +85°C

2 modules
1000 h Damp Heat
+85°C/85% RH

1 module
Outdoor Exposure
60 kWh/m²

50 Thermal Cycles
-40°C to +85°C

1 module
Bypass Diode Thermal Test

10 Humidity Freeze Cycles
+85°C/85% RH to -40°C

2 modules
Robustness of Terminations

Final Performance and Electrical Insolation Tests

Adapted from IEC 61215/IEC61646
1st and 2nd Generation PV Reliability

- IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules – design qualification and type approval
- IEC 61646: 'Thin-film terrestrial photovoltaic (PV) modules – design qualification and type approval',

A module design shall be judged to have passed the qualification tests, and therefore to be IEC type approved, if each sample meets the following criteria:

- The degradation of the maximum power output at standard test conditions (STC) does not exceed 5% after each test nor 8% after each test sequence;
- The requirements of tests 10.3 (and 10.20) are met;
- No major visible damage (breakage or cracks in cells or glass, detachment of the embedding mass, etc.);
- No sample has exhibited any open circuit or ground fault during the tests;
- For IEC 61646 only: the measured maximum output power after final light-soaking shall not be less than 90% of the minimum value specified by the manufacturer

Metastability
## Overview of IEC 61215 / IEC 61646 tests

<table>
<thead>
<tr>
<th>Code</th>
<th>Qualification Test</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1</td>
<td>Visual Inspection</td>
<td>according defined inspection list</td>
</tr>
</tbody>
</table>
| 10.2  | Performance at STC               | cell temperature = 25 °C
irradiance = 1000 W/m²
spectral irradiance distribution according to IEC 60904-3 |
| 10.3  | Insulation Test                  | 1000 VDC + twice the open circuit voltage of the system at STC for 1 min, leakage current < 50 µA, isolation resistance > 50 MΩ at 500 VDC |
| 10.4  | Measurement of Temperature Coefficients | Determination of the temperature coefficients of short circuit current and open circuit voltage in a 40°C interval |
| 10.5  | Measurement of NOCT              | total solar irradiance = 800 W/m²
spectral irradiance distribution according to IEC 60904-3
wind speed = 1 m/s |
| 10.6  | Performance at NOCT              | cell temperature = NOCT
irradiance = 800 W/m²
spectral irradiance distribution according to IEC 60904-3 |
# Overview of IEC61215/IEC 61646

<table>
<thead>
<tr>
<th>Section</th>
<th>Test Name</th>
<th>Description</th>
</tr>
</thead>
</table>
| 10.7    | Performance at low Irradiance          | cell temperature = 25°C
irradiance = 200 W/m²
spectral irradiance distribution according to IEC 60904-3 |
| 10.8    | Outdoor Exposure Test                  | 60 kWh/m² solar irradiation                                                 |
| 10.9    | Hot-Spot Endurance Test                | 5 one hour exposures to 1000 W/m² irradiance in worst-case hot-spot condition |
| 10.10   | UV-Exposure according IEC 61345        | 7.5 kWh/m² UV-radiation (280 - 320 nm and ≥15 kWh/m² UV-radiation (280 - 400 nm) at 60°C module temperature |
| 10.11   | Thermal Cycling                        | 50 and 200 cycles -40°C to +85°C                                            |
| 10.12   | Humidity Freeze Test                   | 10 cycles -40°C to +85°C, 85% RH                                             |
| 10.13   | Damp Heat                              | 1000 h at +85°C, 85% RH                                                     |
| 10.14   | Robustness of Terminations             | As in IEC 60068-2-21                                                        |
| 10.15   | Twist Test                             | Deformation angle 1.2° over the module diagonal                             |
| 10.16   | Mechanical Load Test                   | Two cycles of 2400 Pa uniform load, applied for 1 h to front and back surfaces in turn |
Overview of IEC61215/IEC 61646

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.17</td>
<td>Hail Test</td>
<td>25 mm diameter ice ball at 23 m/s, directed at 11 impact locations</td>
</tr>
<tr>
<td>10.18*</td>
<td>Light soaking</td>
<td>Light exposure of 800 W/m² to 1000 W/m², until Pmax is stable within 2 %</td>
</tr>
<tr>
<td>10.19*</td>
<td>Annealing</td>
<td>Heat soak at 85 °C until Pmax is stable within 2 %</td>
</tr>
<tr>
<td>10.20*</td>
<td>Wet leakage current test</td>
<td>Water spray of terminals and edge immersion with 500 V d.c. applied to determine leakage current</td>
</tr>
</tbody>
</table>

* Tests only relevant for IEC 61646 qualification
Past success does not guarantee future success

Qualification Testing of 3169 c-Si Modules at TUV Rheinland PTL (1997-2009)

TamizhMani et al. Experience with Qualification and Safety Testing of Photovoltaic NREL Reliability Workshop February 18, 2010
Qualification Testing

Qualification Testing of 467 Thin-Film Modules at TUV Rheinland PTL (1997-2009)

- Failure Rate
- Initial dry hipot
- Initial wet resistance
- Thermal cycling (200 cycles)
- UV test
- Thermal cycling (50 cycles)
- Humidity freeze (10 cycles)
- Damp heat
- Outdoor exposure
- Termination
- Hall impact
- Static load
- Diode
- Hotspot
- Light soaking

Thin Silicon

Qualification Testing of c-Si PV Modules at ASU-PTL

TamizhMani et al. Experience with Qualification and Safety Testing of Photovoltaic NREL Reliability Workshop February 18, 2010
Outdoor testing

- Outdoor monitoring of climatic loads:
  - Radiation (UV, solar)
  - Humidity
  - Temperature (ambient and sample)
  - Wind and mechanical loads

- Outdoor testing of innovative PV-modules and new materials:
  - Impact of extreme, but natural loads
  - Identification of weak points
  - Validation of accelerated indoor tests
PV Concentration (PV-C)

It could be profitable a secondary lens/optics (SOE):

- To enhance concentration ratio
- Filtering concentrator optics spectrum
- modifying light intensity distribution
- changing light direction
- relax tracker accuracy
- protection against the missing of the focal point
PV-C Concentrators: refractive optics

Schematic of linear-focus Fresnel lens PV concentrator

Schematic of point-focus Fresnel lens PV concentrator
PV-C Concentrators: reflective optics

- Parabolic dish prototype
- Parabolic mirror
- Off-axis light reflection from parabolic mirror
- Parabolic trough subsystem
  - Point-focus dish PV concentrator
  - Linear-focus trough PV concentrator
Schematic of a heliostat CPV
RXI: Refractive & Reflexive & Internal Reflection

* Prototype of the HERCULES project (EU contract JOR3-CT97-0123)
Terms used for CPVs

<table>
<thead>
<tr>
<th>Primary optics</th>
<th>CPV Module</th>
<th>CPV Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary optics</td>
<td>prefabricated and the focus point is not field adjustable, similar to most Fresnel lens systems.</td>
<td>needs some field installation and the focus point is field adjustable, similar to most reflective systems.</td>
</tr>
<tr>
<td>CPV cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric energy transfer means</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal energy transfer means</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interconnection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
IEC 62108: Concentrator photovoltaic (CPV) modules and assemblies – design qualification and type approval
IEC 62108: Concentrator photovoltaic (CPV) modules and assemblies – design qualification and type approval.
Analysis techniques from microelectronics for:

- Electrical defects (EMMI, voltage contrast)
- X-ray and X-ray tomography
- LBIC - Light beam induced current
- OBIRCH - Optical Beam Induced Resistance Change
- Electroluminescence imaging
- Photoluminescence imaging
- Thermal imaging
- Scanning Acoustic Microscopy
PV-C Receiver Failures

Die Attach Voids

Ejected material

Thermal, mechanical stress
PV-C Housing Failures
Pathways for Degradation of OPV

- Delamination
- Interdiffusion of Electrode Material
- Morphology Changes
- Interfacial Degradation
- Photo-oxidation of Organic Layers
- Oxidation of Electrodes
- Moisture induced degradation
- Moisture ingress failure of package
OPV Modules
Results with Various Flexible Barrier Films

65°C dry oven (open circuit, dark)

65°C /85%RH (open circuit, dark)

NREL Reliability Workshop February 18 & 19, 2010 Konarka Technologies Inc
OPV Modules
Results with Various Flexible Barrier Films

Light Stability @ 1 sun, 65C

Thermal Cycling IEC 61646 10.11

NREL Reliability Workshop February 18 & 19, 2010 Konarka Technologies Inc
Overview of failure mechanisms
Overview on cSi PV Module failure

Reliability Concerns Associated with PV Technologies

By Nick Bosco, NREL

- Cracked cells (bonding processes, strain, etc.)
- Solder joint or gridline interface failure (increased series resistance)
- Reduced adhesion leading to corrosion and/or delamination
- Slow degradation of ISC
- Fatigue of ribbon interconnect
- Junction box failure (poor solder joints, arcing, etc.)
- Busbar adhesion degradation, electrical contact, etc.
- Glass edge damage of frameless modules (though installation, handling, etc.)
- Light-induced cell degradation
- Effect of glass on encapsulant performance
- Front surface soiling
- Mechanical failure of glass-glass laminates
Overview on Thin Film Module failure

**Thin Film Silicon**
- Electrochemical corrosion of SnO2:F
- Initial light degradation (a-Si)
- Annealing instabilities (a-Si)

**CdTe**
- Layer integrity- back contact stability [25]
- Cell layer integrity- interlayer adhesion and delamination;
- Electrochemical corrosion of SnO2:F Fill-factor loss (increased series resistance and/or recombination)
- Busbar adhesion degradation, electrical contact, etc.
- Shunt hot spots at scribe lines before and after stress
- Weak diodes, hot spots, nonuniformities before and after stress

*Reliability Concerns Associated with PV Technologies*
*By Nick Bosco, NREL*
CIGS

- Cell layer integrity – contact stability
- Cell layer integrity – interlayer adhesion
- Fill-factor loss (increased series resistance and/or recombination)
- Busbar failure – mechanical (adhesion) and electrical
- Notable sensitivity of TCO to moisture
- Moisture ingress failure of package
- Cell-to-cell interconnect (discrete cells)
- Notable sensitivity of TCO to moisture; need to pass damp heat test (non-shingle specific)
- Shunt hot spots at scribe lines before and after stress [30]
- Weak diodes, hot spots, nonuniformities before and after stress
- Edge shunting
OPV

- Delamination of layers
- Photolytic Instability
- Moisture induced degradation
- Moisture ingress failure of package
- O2 induced degradation
- Thermal instability of donors and acceptor

Reliability Concerns Associated with PV Technologies
By Nick Bosco, NREL
Overview on C-PV Module failure

CP-V

- Depolymerization, bubble formation, and yellowing of silicone encapsulants under high flux and high temperature with thermal cycling for long periods of time
- Soiling and delamination of anti reflective coatings on internal optical components
- Cell damage from thermal runaway (may be caused by solder voids?)
- Loss of efficiency of optics
- Poor solder joints between string ribbons and wires inside junction boxes - arcing
- Potential issues with highly non-uniform illumination
- Defect migration, ...(especially for lattice mismatched)
- Corrosion and diffusion of silver gridlines/contacts

Reliability Concerns Associated with PV Technologies
By Nick Bosco, NREL
Overview on C-PV Module failure

**CP-V**

- Electromigration due to high current under high concentration (tunnel junction)
- Inverter reliability (ability to withstand rapid changes in current)
- Module thermal fatigue (including high frequency and amplitude), materials, interconnects, cell attachment, adhesive failure
- Operational integrity of the mechanical parts of the trackers (for high concentration systems)
- High Al content AlInP can be sensitive to oxidation

*Reliability Concerns Associated with PV Technologies*
*By Nick Bosco, NREL*
all Technologies

- Corrosion leading to loss of grounding
- Quick connector reliability
- Improper insulation leading to loss of grounding
- Delamination
- Glass fracture
- Bypass diode failure
- Inverter reliability
- Moisture ingress
National Labs & Academia
- Build & communicate knowledge
- New test development especially for emerging technologies

T&E/R on R&D products, Field tests

Industry Partners
- Improved product performance and reliability
- Commercialization

Test Technology Transfer

Codes & Standards Development
- Commercial product and Qual testing

Commercial Test Houses, Test Labs
- Commercial testing
- New test capabilities for commercial products
1st PV generation PV Module (wafer based modules) are very stable components

2nd generation PV module are improving long term reliability

Emerging tecnologies need a new approaches on reliability
Thanks for your attention