QA TG5: UV, temperature and humidity

http://pvqataskforceqarating.pbworks.com/ ⇒ goto 5. UV, temperature, and humidity

2013 Thin Film PV Reliability Workshop
Golden, Colorado
Thursday, February 28, 9:40-10:00

Task-Force coordinated by:

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Presented by David Miller, NREL, David.Miller@nrel.gov
Needs and Approaches (Motivating Questions)

- Service life assessment needs to take UV-degradation seriously into account (up to 3000 kWh/m² in the desert for 25 years)

- Different suitable artificial UV radiation sources are available for ALT with varying spectral distribution of the irradiation

- Different spectral sensitivities of the tested materials have to be expected

- Are comparable tests in different labs possible?

- Can we accelerate tests by increasing UV intensity?

- Can we accelerate tests by increasing the sample temperature?
Goal and Activities for QA TG5 (UV, T, RH)

- IEC qualification tests (61215, 61646, 61730-2) presently prescribe up to 137 days equivalent (IEC 60904-3 AM 1.5) UV-B dose
- Goal develop UV & temperature facilitated test protocol(s) that may be used to assess materials, components, and modules relative to a 25 year field deployment.

Core Activities:
1: (weathering and climates... location dependent information)
   e.g., known benchmark locations... Miami, FL; Phoenix, AZ
2: (standards from other fields of work)
   summary exists from Kurt Scott et. al.
3: (test conditions)
4-1 (collect information about observed failure mechanism)
   e.g., the literature, site inspections
4-2 (find appropriate models for ALT procedures)
5: (suitable UV sources)
   summary exists from David Burns et. al.
6: (proposal for accelerated service testing)
7: (laboratory verification of acceleration of proposed test standard/failure mechanism)
   Japan mini-module study, Sophia round-robin, $E_a$ interlaboratory study
Overview of the QA TG5-Japan Activities

Objectives:

(1) Develop the procedure for a suitable UV weathering test using mini modules. Factors during the test: irradiation intensity, temperature, humidity. Experiment will help determine: test duration + characteristics to measure.

(2) A combination test or a sequential test series (if appropriate).
   UV weathering + Dynamic Mechanical load test
   UV weathering + DH Test

Provisional schedule:

• 4 cell mini-module test  2000 cumulative hours: 2013 June
• Examination of UV weather resistant test of 1 cell module: 2013 October
• Examination of a compound or sequential test: 2013 October
• International proposal for a new comparative UV weathering test system and certification including the test of a full-size module, a mini module, and materials: 2014 May.
UV weathering test of 4-cells small size module

Irradiance ・・・ 90 W / m² (UV 300-400nm)
Nearly 2x UV (ASTM G173 Xenon Lamp)

Chamber temp. ・・・ 65 ℃
Chamber humidity. ・・・ No Control
  (typical 1–10%RH)

Test Modules ・・・ 4-cells, polycrystalline Si
Termination ・・・ Open circuit
Backsheet ・・・ Multilayer laminated PET

Encapsulant ・・・ EVA (fast cure)
  EVA A ・・・ Within the shelf life
  EVA B ・・・ Over the shelf life

Sample ID and Test sequence

<table>
<thead>
<tr>
<th>ID</th>
<th>EVA</th>
<th>UV330h 1stRUN</th>
<th>UV660h 2ndRUN</th>
<th>UV990h 3rdRUN</th>
<th>UV1320h 4thRUN</th>
</tr>
</thead>
<tbody>
<tr>
<td>120410-01</td>
<td>A</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
<td>Back side</td>
</tr>
<tr>
<td>120410-02</td>
<td>A</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
<td>Back side</td>
</tr>
<tr>
<td>120410-03</td>
<td>A</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
<td>Back side</td>
</tr>
<tr>
<td>120410-04</td>
<td>A</td>
<td>Back side</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
</tr>
<tr>
<td>120710-01</td>
<td>A</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
<td>Back side</td>
</tr>
<tr>
<td>120710-02</td>
<td>A</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
<td>Back side</td>
</tr>
<tr>
<td>120710-03</td>
<td>A</td>
<td>Back side</td>
<td>Front side</td>
<td>→</td>
<td>→</td>
</tr>
</tbody>
</table>

* The front or back side is irradiated

Module layout in the UV chamber

X: Thermocouple gage
☐ : Junction BOX
Irradiation on Front : 990h + on Back : 324h

$P_{\text{max}}$ decreased
1.5 to 2% approximately

$I_{\text{sc}}$ decreased
1.5 to 2% approximately

No major performance loss.
$I_{\text{sc}} \downarrow$ with $P_{\text{max}} \downarrow$ is consistent with encapsulation discoloration.
Slight yellowing of BS was observed. Yellowing of BS differs on a cell vs. off of a cell.

When UV light irradiation was carried out on the front side, after irradiation on back side, yellowing of the backsheet increased significantly.

→ Result: higher temperature on cell?

Test sequence I:
Front side 990h → + Back side 324h

Test sequence II:
Back side 330h → + Front side 984h
UV – Round Robin Light and Back-Sheets

**Aim:**
Comparison of the effect of different UV- sources on glass/encapsulant/backsheet laminates with different materials

- Spectral distribution of different UV-light sources leads to different degradation on different materials

- Stronger UV testing needs better definition of the test conditions

Spectra of radiation sources used in PV testing
UV – Round Robin Samples

- Samples:
  - manufacturers provide different back-sheet types
  - ISE produces laminates (usual glass and EVA, 13x20 cm) and 300 sample holders (till end of February)

3 long-pass filters

Unfiltered area

2 neutral density filters (grids)
UV – Round Robin Procedure

- Time frame: September 2013
- Samples:
  - manufacturers provide different backsheets
  - ISE produces laminates (usual glass and EVA, 13x20 cm)
  - direct radiation on the back side and on the front glazing
- Testing procedure:
  - 2 temperature levels: 60° C, 80° C (e.g.) (Assessment of sample temperatures)
  - Irradiation: integral UV dose: min. 120 kWh/m²
  - Light sources and (spectral distribution) characterised radiometrically (Fluorescence, Metal-halide, Xenon)
  - 3 longpass and 2 neutral density filters provided by ISE
Characterisation procedures after 0, 30, 60, 120 kWh (when available):

- Spectral hemispherical reflectance (UV-VIS-NIR)
  Calculation of Yellowness Index or adequate degradation indicator
- Raman / Micro-Raman spectroscopy
- FTIR-ATR measurements for BS
  Calculation of carbonyl-index
- Optical microscopy/AFM investigation for microcracks in BS
- Fluorescence for encapsulants

And .....?
UV – Round Robin Schedule

Preparation and Testing

- Purchasing of components (filters, etc) is finished
- Back-sheet materials are collected
- Production of Mini-modules and filter-holders in March 2013
- Distribution of samples to test labs beginning of April 2013
- Testing till August 2013 (at least 120 kW/m²)
  - Intermediate telecons or meetings at NRELMRW, TC82 WG2 meeting)

- Final characterisation of the samples and evaluation of data by Fraunhofer ISE August - September 2013

- Final discussion of the results during PVSEC2013 or fall meeting of TC82 WG2
As in Kempe, “Group 3: Understanding the Temperature and Humidity Environment Inside a PV Module”, knowing $E_a$ is critical to prescribing and interpreting a <UV and temperature> mediated test.

Unfortunately, $E_a$ is not known for the common UV PV degradation modes.

**Critical unknowns**

(Goals for the interlaboratory experiment):

1. Quantify $E_a$, so that applied test conditions can be interpreted.
2. Provide a sense of the range of $E_a$ that may be present by examining “known bad”, “known good”, and “intermediate” material formulations.
3. Determine if there is significant coupling between relevant aging factors, *i.e.*, UV, temperature, and humidity.
4. Investigate the spectral requirements for light sources by comparing $E_a$ for different sources, *i.e.*, Xe-arc, UVA 340.

*What factors does TG5 need to consider?*

*Is visible light required in addition to UV light?*
Details of the $E_a$ Test Specimens

- (4) custom EVA formulations, (1) TPU product proposed for study.
- EVA to be extruded at NREL; specimens to be laminated at NREL.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Comment</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elvax PV1400</td>
<td>Dupont EVA resin, 33 wt% VAc</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Dow Corning Z6030</td>
<td>Silane primer, gama-methacroyloxy propyl trimethoxysilane</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Tinuvin 770</td>
<td>Hindered amine light stabilizer (HALS)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>N/A</td>
</tr>
<tr>
<td>Tinuvin 123</td>
<td>Non-basic aminoether-hindered amine light stabilizer (NOR-HALS)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.13</td>
</tr>
<tr>
<td>TBEC</td>
<td>Curing agent, OO-Tertbutyl-O-(2-ethyl-hexyl)-peroxycarbonate, 0.133kPa at 20°C.</td>
<td>N/A</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Lupersol 101</td>
<td>Curing agent, 2,5-Bis(tert-butylperoxy)-2,5-dimethylhexane</td>
<td>1.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Naugard P</td>
<td>Phosphite anti-oxidant (AO)</td>
<td>0.25</td>
<td>0.25</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tinuvin 328</td>
<td>Benotriazole UV absorber (UVA)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.3</td>
</tr>
<tr>
<td>Cyasorb 531</td>
<td>Benzophenone UV absorber</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>N/A</td>
</tr>
</tbody>
</table>

| Comments                | "Known bad", "Intermediate", "fast cure", "Known good"                  |

- 50x50mm$^2$ quartz/encapsulation/quartz geometry for transmittance.

- Details of adhesion experiment to be determined.
The $E_a$ Interlaboratory Experiment Enables a Wider Range of Study

- Discoloration & adhesion will be studied in detail at different institutions using the same make & model of instrument (i.e., Ci5000, QUV).
- This overcomes the difficulty of limitedly-available aging equipment.
- A standard condition (70°C in chamber) allows a broad variety of other instruments to also be compared.

<table>
<thead>
<tr>
<th>LIGHT SOURCE, FILTER</th>
<th>Xe Arc (right-light/cira filter)</th>
<th>UVA 340 fluorescent (no filter)</th>
<th>UVA 340 fluorescent (no filter)</th>
<th>No light</th>
<th>field deployment (outdoors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV LIGHT INTENSITY</td>
<td>NOMINAL (92 W*m$^{-2}$ for 300≤λ≤400)</td>
<td>NOMINAL (0.92 W*m$^{-2}$ at 340 nm)</td>
<td>NOMINAL (245.5 W*m$^{-2}$ for 300≤λ≤400)</td>
<td>0 W*m$^{-2}$</td>
<td></td>
</tr>
<tr>
<td>CHAMBER RELATIVE HUMIDITY (%)</td>
<td>20 (“low”)</td>
<td>50 (“high”)</td>
<td>~7% (“very low”)</td>
<td>50 (“high”)</td>
<td>25 ambient</td>
</tr>
<tr>
<td>CHAMBER TEMPERATURE (°C)</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>PARTICIPANT (INSTRUMENT MODEL)</td>
<td>3M (Ci5000)</td>
<td>3M (Ci5000)</td>
<td>3M (Ci5000)</td>
<td>ATLAS (Ci5000)</td>
<td>Mitsu(SX120)</td>
</tr>
<tr>
<td></td>
<td>OLAB (QSUN XE3)</td>
<td>QLAB (QSUN XE3)</td>
<td>NREL (XR260)</td>
<td>NREL (UV suitcase)</td>
<td>Fraunhofer (custom)</td>
</tr>
<tr>
<td></td>
<td>ATLAS (SunTest XXL)</td>
<td>Suga (SX75)</td>
<td>Suga (FDP)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary of participating laboratories and test conditions

- Rate of degradation will be compared against field data to allow site specific acceleration factors to be computed.
- Outdoor data should help verify validity of the test.
- Separate experiment at NIST (same EVA’s) will determine action spectrum
Degradation Mechanisms for Crystalline Si PV

Failure/degradation mechanisms from the literature†:

- Corrosion of AR coating on glass (Group 3/Group 5)
- Corrosion of cells (Group 3/Group 5)
- Corrosion of electrical interconnects (Group 3/Group 5)
- Crazing of glass. Crazing/roughening of front surface (Group 3/Group 5)
- Delamination of encapsulation (Group 3/Group 5)
- Diode failure during “hot spots” (Group 4)
- Discoloration of encapsulation (Group 5)
- Embrittlement of back sheet (Group 5)
- Embrittlement of encapsulation (Group 5)
- Embrittlement of junction box material and wire insulation (Group 5)
- Fatigue of solder bonds (Group 2)
- Fatigue of interconnects [open circuits/arcing] (Group 2)
- Fracture of cells (Group 2)
- Fracture of glass/superstrate (Group 2)
- Ground faults (Group 3/Group 5)
- Junction box and module connection failures (Group 2)
- Soiling of glass/superstrate (TBD)
- Structural failures (TBD)

Si flat-panel PV modules are complex devices, containing many components. TF modules may not have as many layer/components. This simplicity may aid reliability. 😊

The QA TG’s to date have really only considered Si flat-panel PV (consider this slide).
Key Differences Between Monocrystalline Silicon & TF PV

- Device layer may be deposited on superstrate (CdTe, a-Si) or substrate (CIGS).
  - UV may be filtered by superstrate devices-
- An edge seal may be present.
- Interconnection accomplished scribing TCO or metal layer (vs. gridlines, ribbons, solder joints, etc. in crystalline Si).
- Alternatives to EVA encapsulation.
- Often no backsheet. Maybe glass instead. Maybe different form factor (e.g., shingles).
- Substrate/superstrate may consist of a thin flexible ceramic/polymeric layer (laminate or other).
- Different diode protection schemes, with smaller j-box.
- May use adhesive facilitated rails for mounting.
Failure/degradation mechanisms from the literature†:

- Delamination of edge-seal (Group 3/Group 5/Group 8)
  - Kempe et al. have shown coupled (UV, T, & RH) effects
- Electro-chemical corrosion of TCO – Group 5
- Inadequate Edge Deletion – Group 8
- Light Induced Degradation of a-Si (performance issue only?)
- Shunts at laser scribes – Group 8
- Shunts at impurities in films – Group 8
- Other?

TF in General:
• Are there other key components that were not identified?
• Are there other relevant features/considerations for TF?

Your UV experience:
• What UV facilitated degradation modes have you observed?
• How significant is UV damage to you?
• What UV facilitated degradation modes are the most urgent?

Feedback for QA TG5:
• Are the objectives, activities, & experiments relevant to you?
• Can you help/contribute in the existing QA TG5 groups?
  (all of three groups have regular meetings - refer also to Europe, Japan, and US points of contact)
• Where and how significant is UV degradation for TF? (How does UV change TG8)?
Summary of QA TG5 (UV, T, RH)

• Goal develop UV & temperature facilitated test protocol(s) that may be used to assess materials, components, and modules relative to a 25 year field deployment.

Round-robin (under Sophia project)
  • Emphasis on backsheet materials
  • Examination of source (spectral) dependence

Mini-module round-robin (QA Task-5 Japan)
  • Examining backsheet and encapsulation
  • Apply a combination or series of aging plus dynamic mechanical or DH tests?

$E_a$ interlaboratory study
  • Examining discoloration and delamination of encapsulation
  • Quantify coupled and (irradiation) source dependent effects

Application to TF PV:
  • Significant differences in components/materials between c-Si and TF PV
  • What are your experiences? How much is UV relevant?
  • Can you contribute to QA TG5 (UV, T, and RH)?
  • What is unique to QA TG8 (TF PV)?