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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NREL/PR-5200-59336

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 mimi-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

QA Task-5 Japan

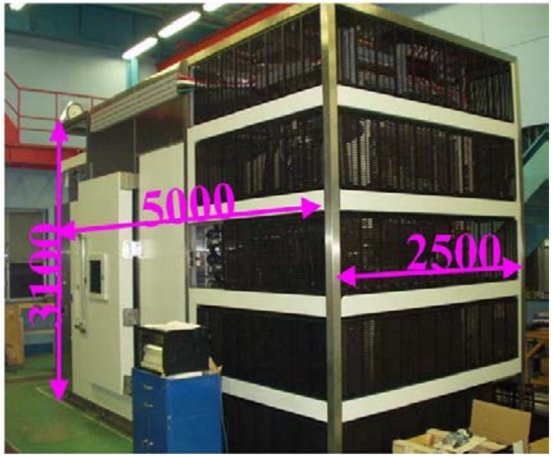
Irradiance ･･･ 90 W / m² （UV 300-400nm）
Nearly 2x UV （ASTM G173 Xenon Lamp)

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

Test Modules ･･･ 4-cells, polycrystalline Si
Termination ･･･ Open circuit

Backsheet ･･･ Multilayer laminated PET

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

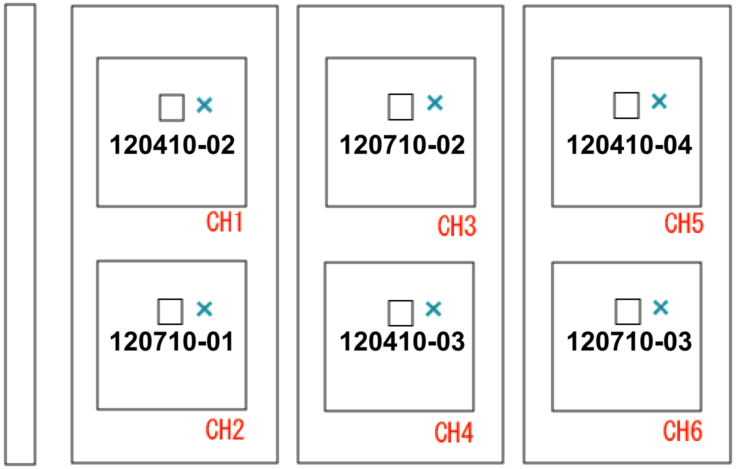


Sample ID and Test sequence

ID	EVA	UV330h 1st RUN	UV660h 2nd RUN	UV990 h 3rd RUN	UV1320 h 4th RUN
120410-01	A	Control module			
120410-02 (CH1)	A	Front side	→	→	Back side
120410-03 (CH4)	A	Front side	→	→	Back side
120410-04 (CH5)	A	Back side	Front side	→	→
120710-01 (CH2)	B	Front side	→	→	Back side
120710-02 (CH3)	B	Front side	→	→	Back side
120710-03 (CH6)	B	Back side	Front side	→	→

＊ The front or back side is irradiated

Module layout in the UV chamber

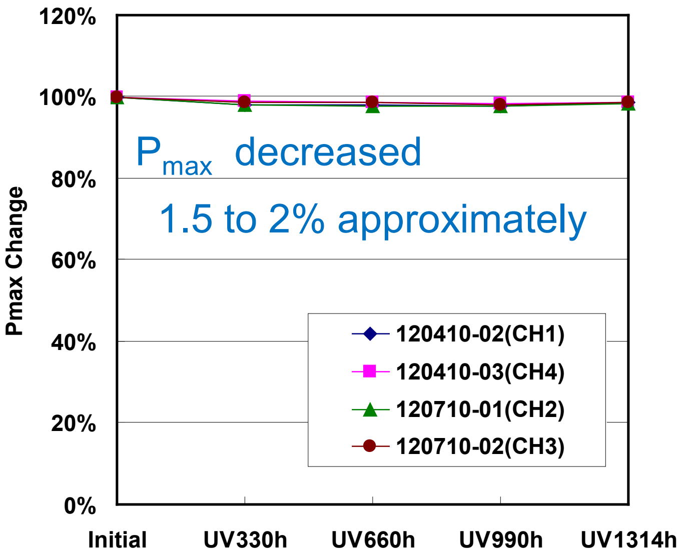


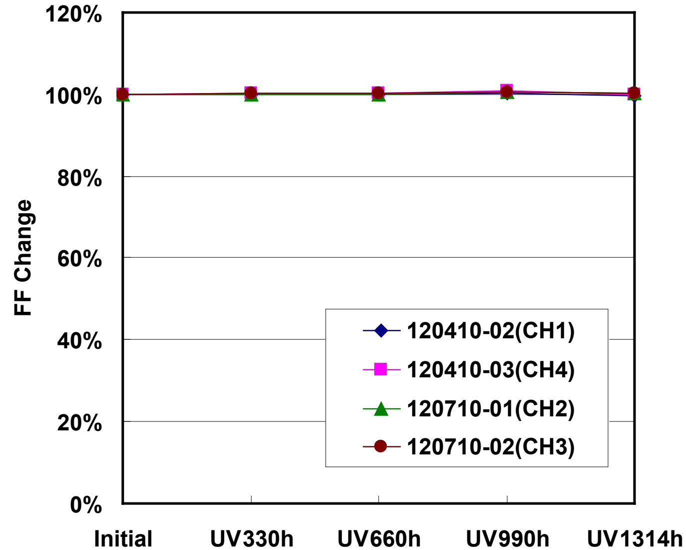
X: Thermocouple gage
□ : Junction BOX

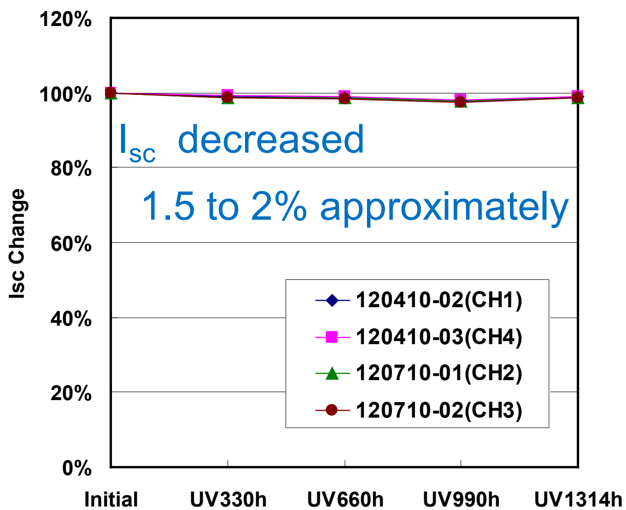
Output power performance

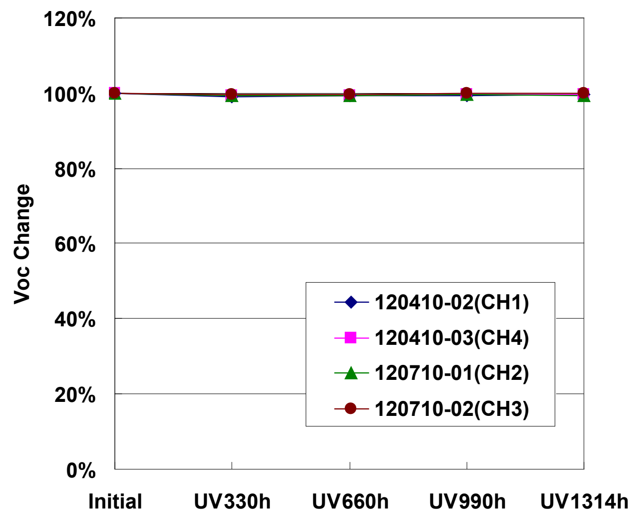
QA Task-5 Japan

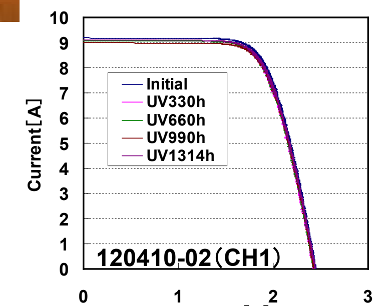
Irradiation on Front :990h + on Back :324h

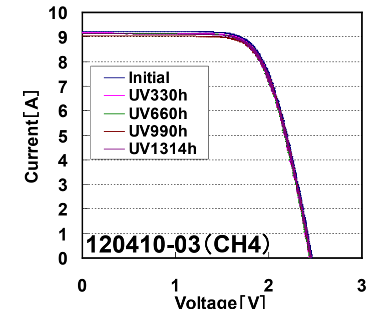


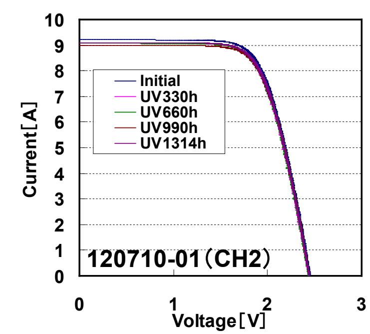


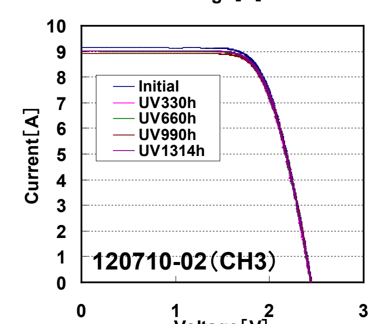










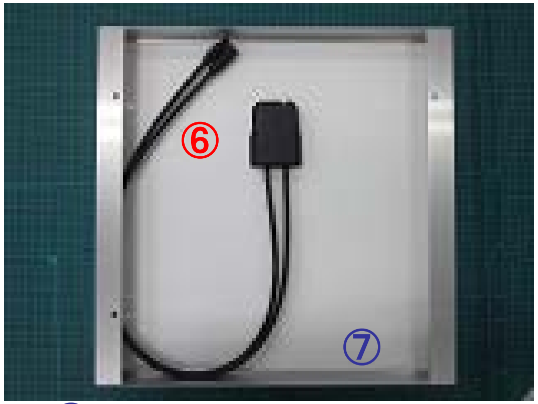


No major performance loss.

I_{sc}↓ with P_{max} ↓ is consistent with encapsulation discoloration.

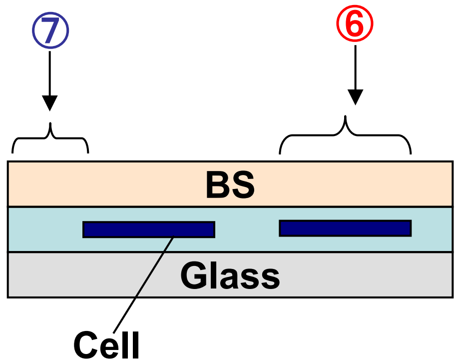
Discoloration of the Backsheet

Measurement position



＊⑦ measured at 990hrs,1314 hrs only

Measurement position (Cross sectional view)



Slight yellowing of BS was observed.

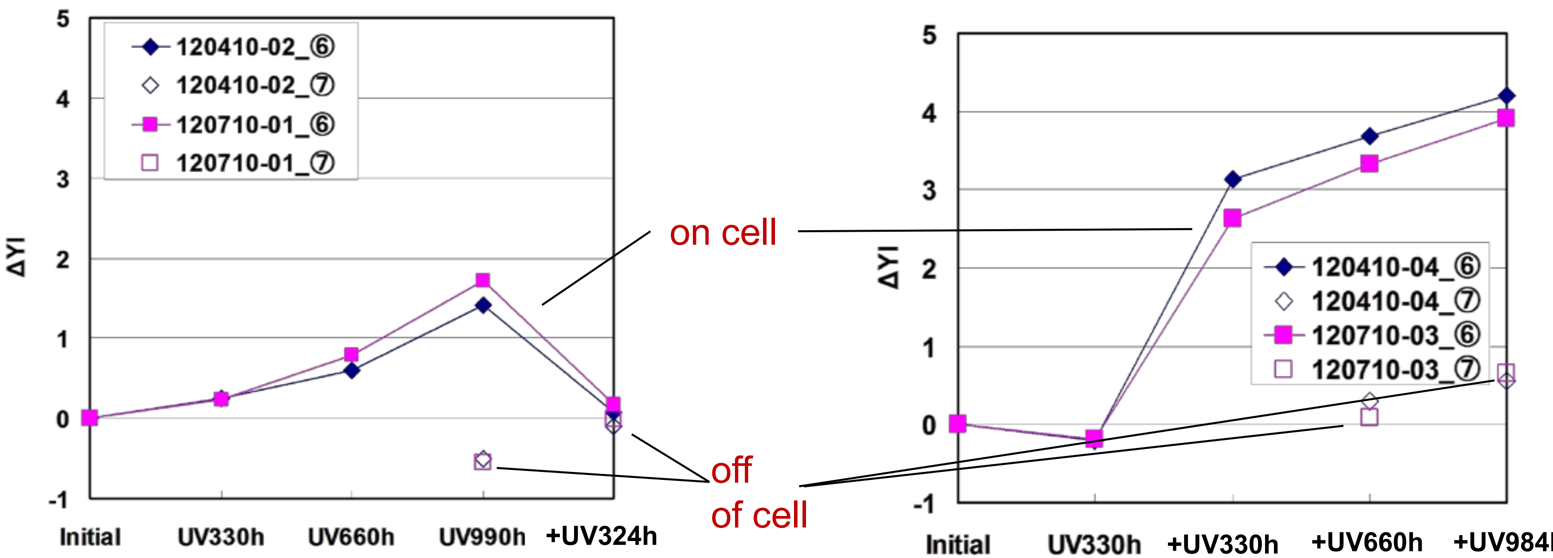
Yellowing of BS differs on a cell vs. off of a cell.

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



SOPHIA European Research Infrastructure

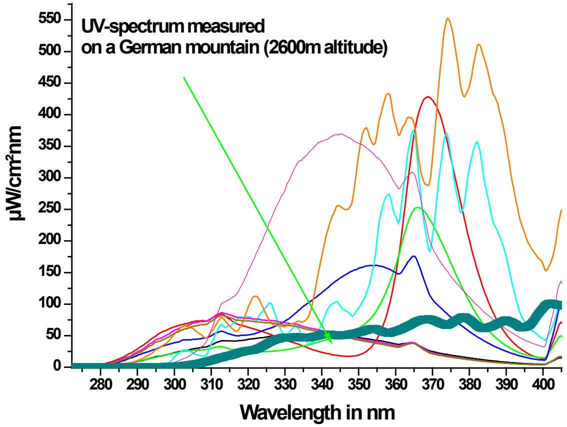
UV – Round Robin Light and Back-Sheets

- 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

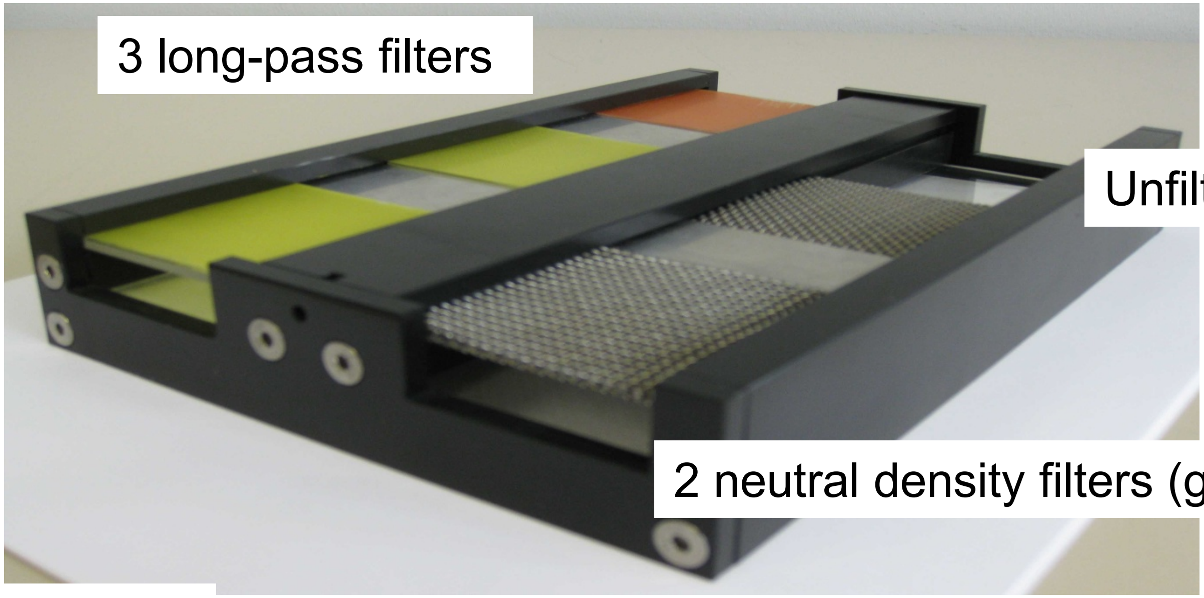


Spectra of radiation sources used in PV testing

Fraunhofer ISE

SOPHIA 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)



SOPHIA UV – Round Robin Procedure

- Time frame: September 2013
- Samples:
  - manufacturers provide different backsheet types
  - 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

SOPHIA European Research Infrastructure

UV – Round Robin Procedure

- 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)

  intermediadte 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

Motivation for the E_a Interlaboratory Experiment

•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.

$$k = A\left[\frac{T}{T_0}\right]^n e^{\left[\frac{-E_a}{RT}\right]}$$

The modified Arrhenius equation

Critical unknowns
<u>(Goals for the interlaboratory experiment)</u>:

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.
What factors does TG5 need to consider?

4. Investigate the spectral requirements for light sources by comparing E_a for different sources, *i.e.*, Xe-arc, UVA 340.
Is visible light required in addition to UV light?

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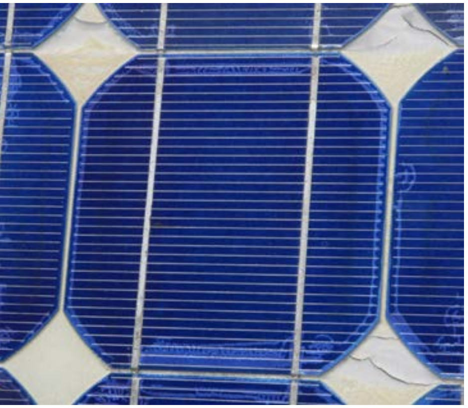
Details of the E_a Test Specimens

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

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

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



quartz/EVA/quartz specimen
Kempe et. al., Proc. PVSC 2009, 1826-1831.

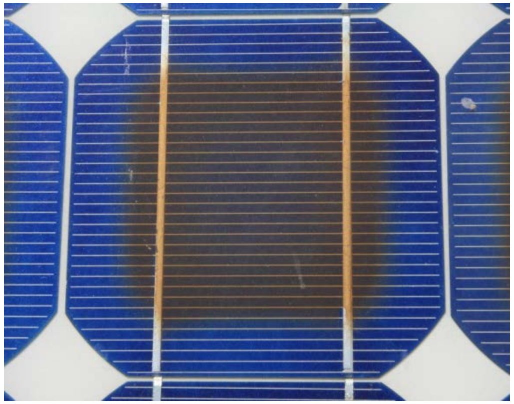


Photo of aged PV module
Miller, from APS-STAR site

- 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.

LIGHT SOURCE, FILTER	Xe Arc (right-light/cira filter)						UVA 340 fluorescent (no filter)			UVA 340 fluorescent (no filter)			No light	field deployment (outdoors)
UV LIGHT INTENSITY	NOMINAL (92 W•m^{-2} for 300≤λ≤400)						NOMINAL (0.92 W•m^{-2}@ 340 nm)			NOMINAL (245.5 W•m^{-2} for 300≤λ≤400			0 W•m^{-2}	
CHAMBER RELATIVE HUMIDITY {%}	20 ("low")			50 ("high")		match for "very low" (~7%)	~7% ("very low")			50 ("high")			25	ambient
CHAMBER TEMEPRATURE {°C}	50	70	90	50	70	70	50	60	70	50	70	90	70	ambient
PARTICIPANT (INSTRUMENT MODEL)	3M (Ci5000)	3M (Ci5000)	3M (Ci5000)	ATLAS (Ci5000)	Mitsui(SX120)	NREL (Ci5000)	CWRU (QUV)	ATLAS (UVTEST)	QLAB (QUV)	Fraunhofer (custom)	Fraunhofer (custom)	Fraunhofer (custom)	NREL	ATLAS (EMMA in Phoenix)
		QLAB (QSUN XE3)			QLAB (QSUN XE3)	NREL (XR260)			NREL (UV suitcase)					CWRU (5x in Cleveland)
		ATLAS (SunTest XXL)							Fraunhofer (custom)					ATLAS (rack in Phoenix)
		Suga (SX75)							Suga (FDP)					ATLAS (rack in Miami
														NREL (rack in Golden)

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.

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- Separate experiment at NIST (same EVA's) will determine action spectrum

Degradation Mechanisms for Crystalline Si PV

Failure/degradation mechanisms from the literature†:

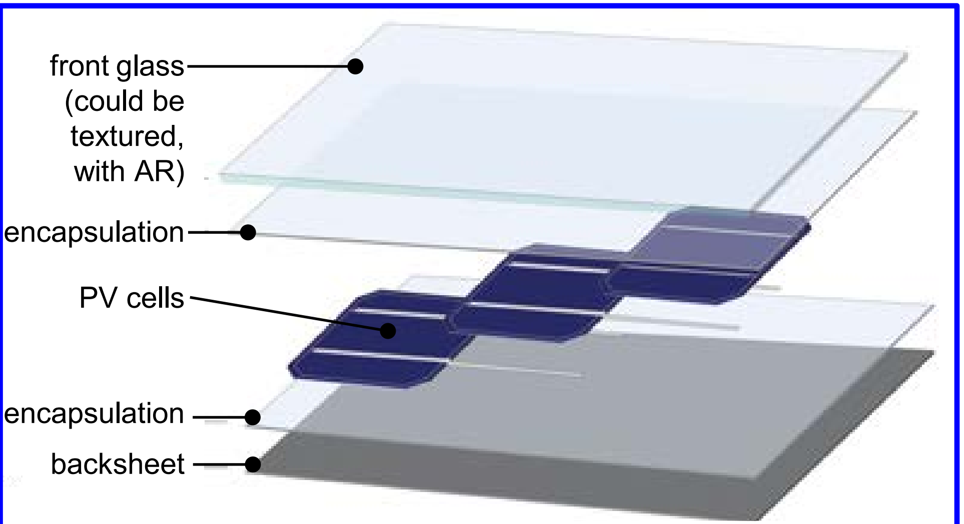
- Corrosion of AR coating on glass (Group3/Group 5)
- Corrosion of cells (Group 3/Group 5)
- Corrosion of electrical interconnects (Group 3/Group 5)
- Crazing of glass. Crazing/roughening of front surface (Group3/Group 5)
- Delamination of encapsulation (Group3/Group 5)
- Diode failure during "hot spots" (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 (Group3/Group 5)
- Junction box and module connection failures (Group 2)
- Soiling of glass/superstrate (TBD)
- Structural failures (TBD)

Literature*, site inspections, and industry feedback suggest these are most common

† based on Wohlgemuth, "PV Modules: Validating Reliability, Safety and Service Life", Intersolar 2012 Conf.

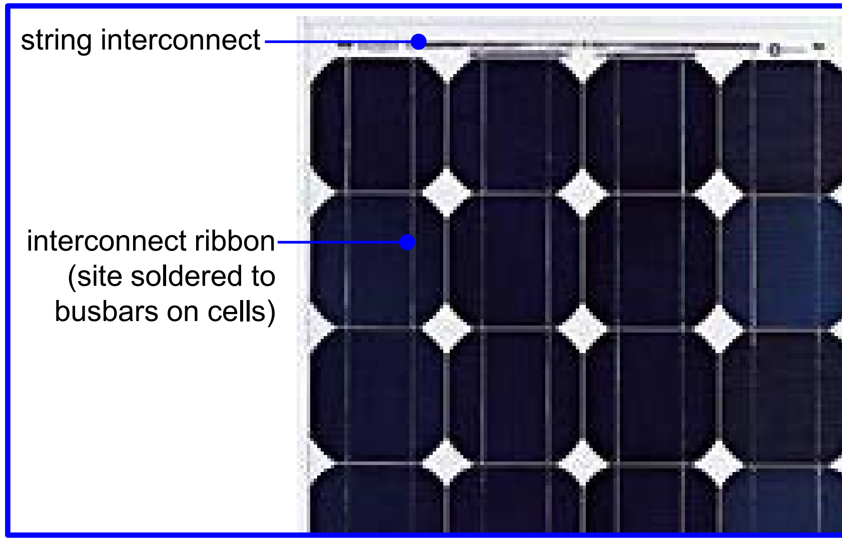
*e.g., D. C. Jordan and S. R. Kurtz, "Photovoltaic Degradation Rates—an Analytical Review", PIP, 21 (1), 2013, pp. 12-29.

The Components of a Monocrystalline Silicon Module

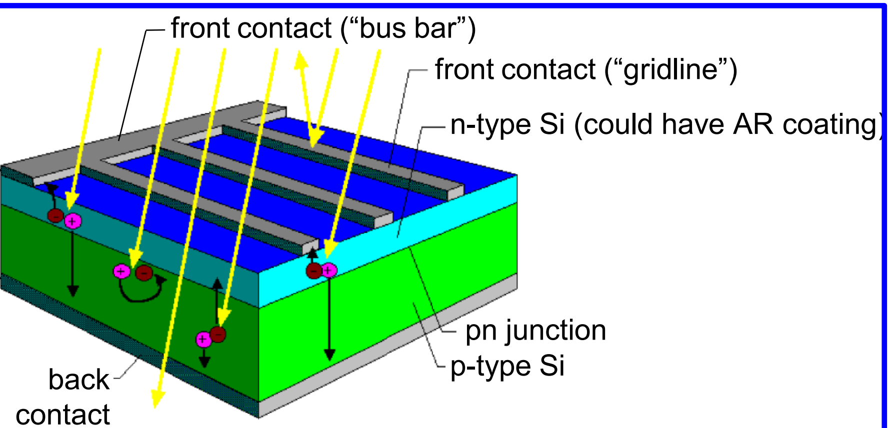


also: junction box & diodes; cables & connectors; frame & grounding

The Si PV module laminate (cross-section)



Si PV module (front view)



The Si PV cell (cross-section)

- 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*).

http://www.viridiansolar.co.uk/Assets/Images/Technical/laminate_small.jpg
http://www.staffordarea.saveyourenergy.org.uk/what/solar/monoPVarray.jpg
Wohlgemuth, "Reliability PV Cells, Modules and Systems", Tutorial, IEEE PVSC, 2011.

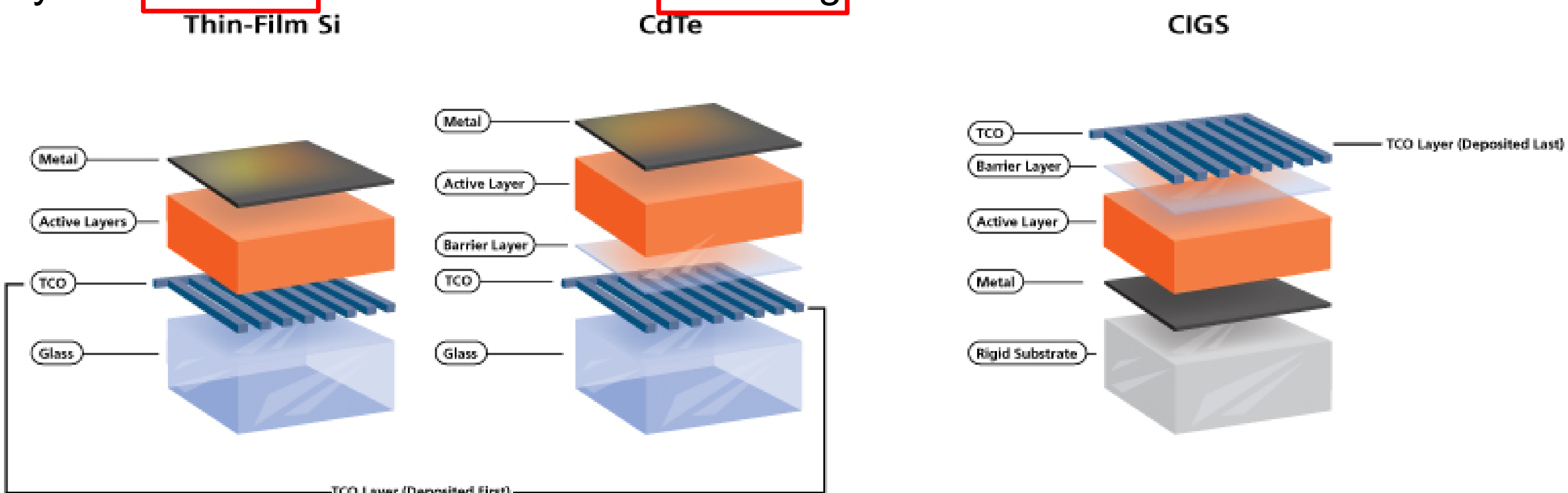
Key Differences Between Monocrystalline Silicon & TF PV

- 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.

polymeric materials, subject to UV degradation



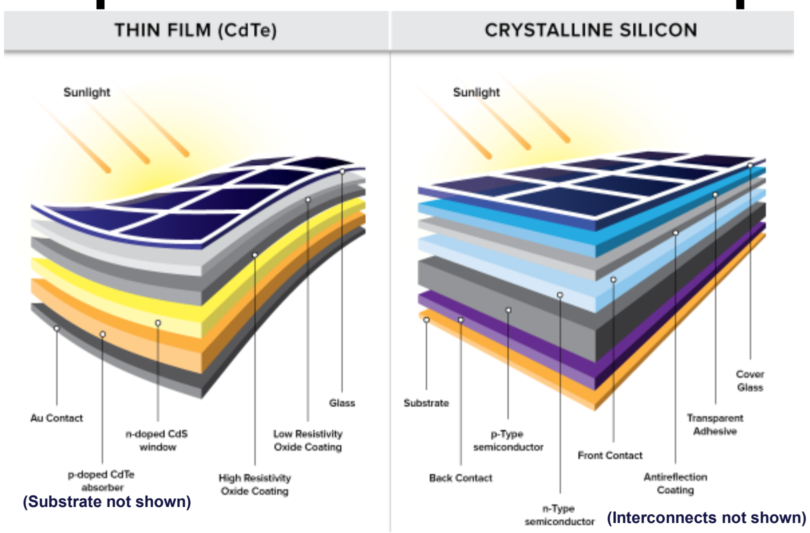
Some differences between Si, CdTe, and CIGS TF device implementations

http://www.advanced-energy.com/upload/Image/Newsletters/2008Q4PVSunTimes/TCO_Order_800x252.jpg

Additional Degradation Mechanisms for Thin Film PV

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?**



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e.g., D. C. Jordan and S. R. Kurtz, "Photovoltaic Degradation Rates—an Analytical Review", PIP, 21 (1), 2013, pp. 12-29.

QA TG5: Discussion for Thin Film PV

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)?