

Common Failure Modes for Thin-Film Modules and Considerations Toward Hardening CIGS Cells to Moisture

A “Suggested” Topic

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Outline

- **Warnings, disclaimers and objective assessment**
 - **Scope**
 - **Field experience (limited hard data, but anecdotal information abounds)**
 - Mechanical
 - Thermal
 - Electrical
 - **Qualification testing – building a transfer function**
 - **Where do the majority of thin-film modules encounter trouble in the qualification testing sequences?**
 - Mechanical
 - Thermal
 - Stress testing
 - **Damp Heat –**
 - Does it mean anything?
 - Dark vs. damp – is it distinguishable?
 - Is moisture hardening achievable?
-

Warning!!

QUESTION

- Do I have a bias?
- How objective can I really be?
- How current is my information?
- Am I aiming at a particular manufacturer?
- Am I interested in casting a dark shadow on the thin-film industry?

RISK/EVIDENCE

- **High/Obvious**
 - **Medium/**Have participated in all sides on this issue.
 - **Fairly Low Risk/**Attempt to stay on top of voluminous data on the subject.
 - **Low.** No manufacturer has zero failure modes. The outcome is dictated 100% by their response to a finding.
 - **NO!!!** There are highly reliable thin-film products in the market today.
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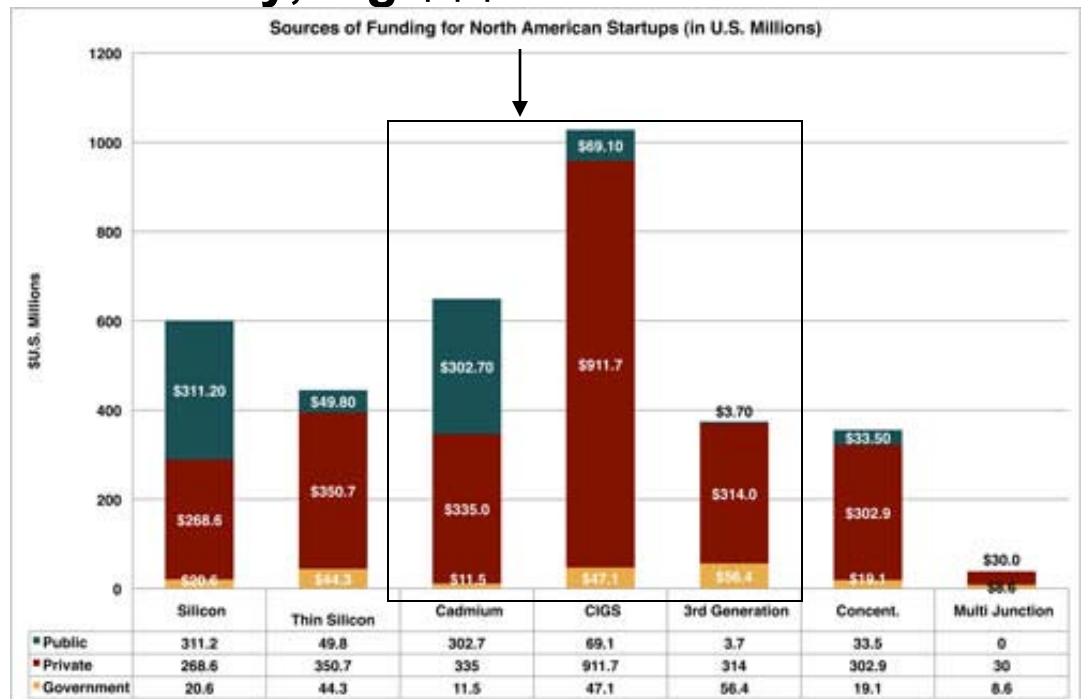
Field Experience – Thin-Film PV

- Not a sterling history.
- Some high-profile issues (not dissimilar from crystalline Si's terrestrial start).
- Many manufacturers have come and gone.
- Through 2008 and even true today, big \$\$\$ investment

Changes since 2008?

Triumvirate of despair:

1. Financial conservatism
2. Softened demand
3. Oversupply of x-stal Si



Source GreenTech Media

		Thin-Film (Glass Substrate)	Crystalline Technologies	Approx. Sys. Cost Impact to Thin-Film
1	Module Power (to Edge)	4 to 7.5 W/Ft ²	10 to 15 W/Ft ²	\$0.30/W - \$1.25/W
2	Mechanical Strength	Annealed/ Heat Strengthened	Tempered (5 to 10X stronger)	\$0.06/W - \$0.30/W
3	Lamination QA/QC	Poor	Good	Included in #2
4	Module O.C. Voltage	45V to 100V typ.	20V to 50V typ.	\$0.03/W - \$0.33/W
5	Typical 'String' Power	200W to 750W	1500W to 3000W	Included in #4
6	Stability	Poor	Good (Not Great)	\$0.30/W - \$0.60/W
7	Voltage Isolation	Intermittent	Excellent	Included in #6
8	Module Design Flex.	Poor	Excellent	Not quantified
9	Blocking Diode Req'd	Yes	No	\$0.02/W - \$0.05/W
10	Opaque to UV?	No	Yes	\$0.00/W - \$0.10/W
11	End of Life Recycle?	Some	No	<u>\$0.00/W - \$0.20/W</u>
Avg cost impact:		\$1.77/W	TOTAL:	\$0.71/W - \$2.83/W

http://www.nrel.gov/pv/thin_film/docs/powerlight.pdf

The Past:

One somewhat controversial presentation made at NREL by a large system integrator indicated that thin-film had a LONG way to go to improve reliability.

Some have proven lessons learned from this experience.

F.E. Mechanical

- **Mainly packaging-related**
- **Inadequate glass strength, impact toughness.**
 - **Installation breakage**
 - Do not underestimate poor practices by installers.
 - **Cleaning damage and sometimes breakage**
 - Power washers
 - Mechanical brush damage (dragging grit along superstrate)
 - **Environmentally-related breakage**
 - Wind blown debris (tempered glass)
 - Hail
 - Module-to-array differential expansion



PI Photovoltaik-Institut Berlin AG

Now that's Texas hail! →



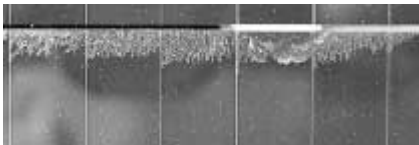
- **Main concerns – performance degradation**
 - **Leakage current rates (performance degradation and potential safety concern)**
 - High voltage stress → electro-chemical corrosion of contacts
 - Both thick and thin-film PV have it, but thin tends to be more pronounced (10x).
 - Can lead to other issues.

□ Leakage Currents:

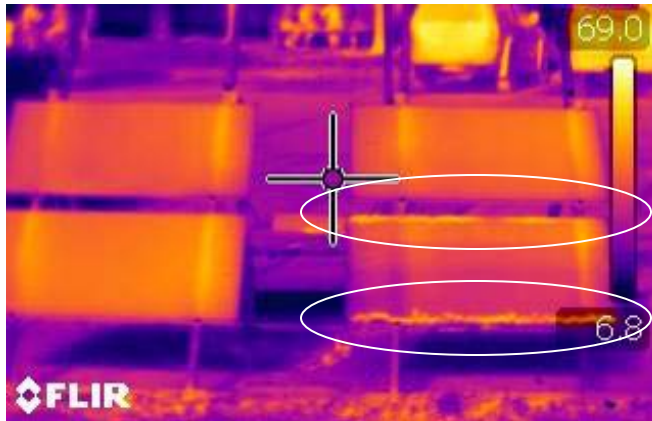
- Measured and characterized
- Appear thermally activated
- May point to potential corrosion problems in hot environments, where average daytime air temperatures are at, or exceed 25-30 °C for 200 days or more per year, after 10 years.

J.A. del Cueto, B.R. Sekulic NREL, 2006

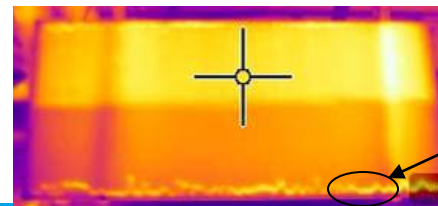
ye ol' bar-graph
delamination failure



McMahon, 2004



But don't forget shade induced hot spot!!!



Trise~60°C

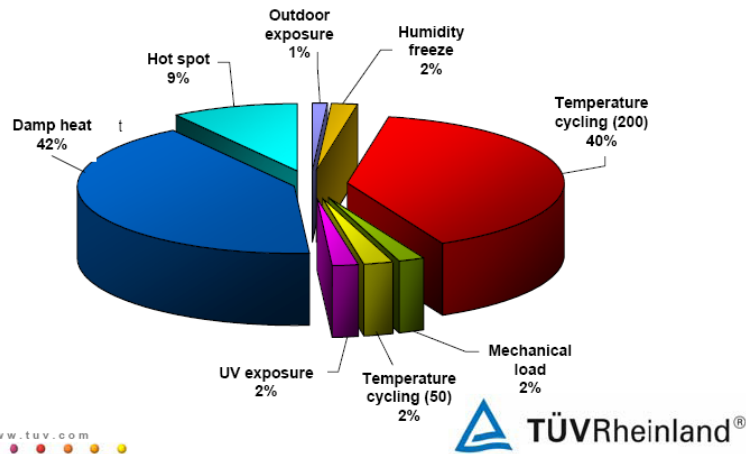
Qualification Testing

- **UL 1703, IEC 61646, IEC 61730**
 - **Don't be fooled...these are really standards built around crystalline PV failure modes with a dash of thin-film specific conditioning tests thrown in.**
 - **Nevertheless are remarkably good stress tests for identifying weaknesses with thin-film PV.**
 - *Should be thought of as hitting the product with different impact hammers and listening to the resonant response.*
 - Cannot alone provide useful failure probability information, but can clearly identify weaknesses requiring further investigation.
 - Are not Accelerated Lifetime Tests – but – thermal cycling and damp heat are particularly useful tests in a test-to-failure program for thin-film PV.
-

Where Do The Majority of Failures Occur?

3. IEC qualification testing and failure mechanisms

Qualification testing in accordance with IEC 61215 Ed. 1/Ed. 2
Failure analyses of qualification tests at TÜV Rheinland since 1998



Crystalline Si - Courtesy of Werner Herrmann

#1 for X-stal Si or thin-film – Damp Heat
#2 ...Thermal cycling

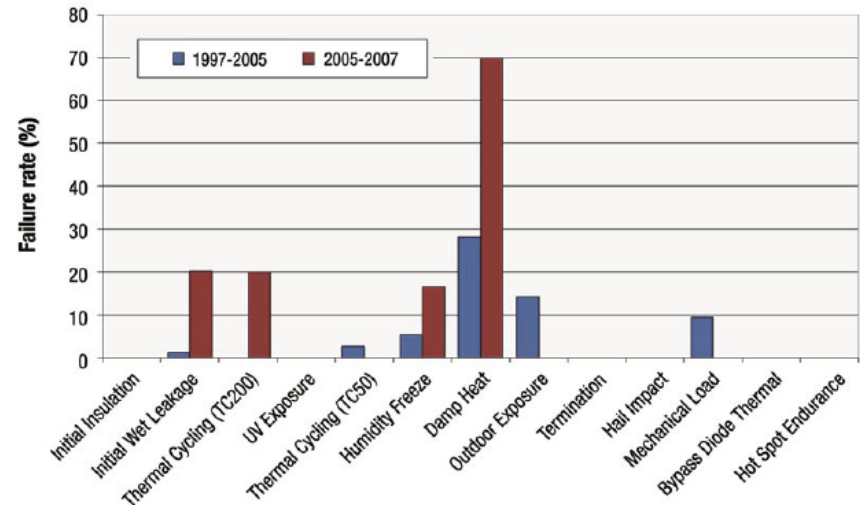


Figure 3. Failure rate comparison of thin-film modules for the 1997-2005 and 2005-2007 periods.

Failure analysis of design qualification testing: 2007 vs. 2005

G. Tamizhmani, B. Li, T. Arends, J. Kuitche, B. Raghuraman, W. Shisler, K. Farnsworth, J. Gonzales, & A. Voropayev, Arizona State University Photovoltaic Testing Laboratory (ASU-PTL), Mesa, Arizona, USA

This article first appeared in *Photovoltaics International* journal's first edition in August 2008.

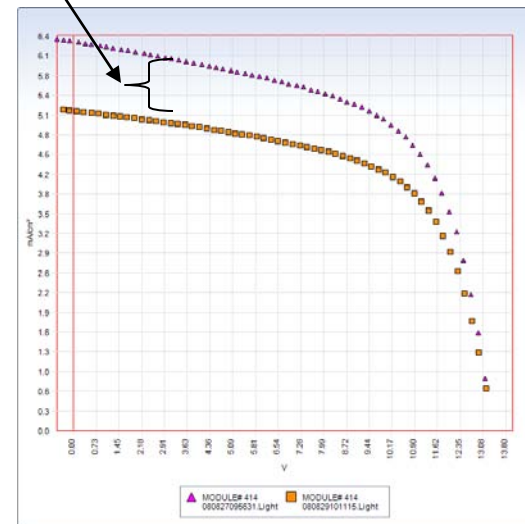
Disturbing recent trends for thin-film:
Initially non-compliant wet leakage current values?

- **Mechanical**

- **Hail Impact Test (IEC 61646 clause 10.17)**
- **Static Load Test (IEC 61646 clause 10.16)**
 - Must use specified mounting system to be valid.
 - Optional 5400Pa positive load to cover extreme snow conditions for low ($<20^\circ$) tilt angles.
- **TC200 - Adhesive/cohesive stack damage (IEC 61646 clause 10.11)**
- **TC200 w/current – interconnect/bus bar fatigue or run away series resistance change.**

N.R. Sorenson, M.A. Quintana, et. al.

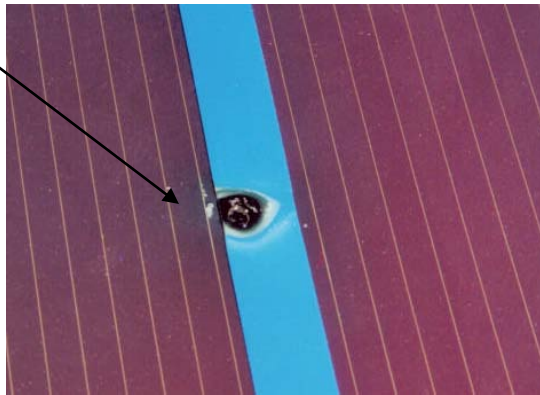
“Accelerated testing of metal foil tape joints and their effect of photovoltaic module reliability” Proc. SPIE, Vol. 7412, 74120R (2009); doi:10.1117/12.826876



Non Pareto'ed – But Historical Issues

- **Electrical**

- **Outdoor Exposure (IEC 61646 clause 10.8)**– usually just a ratings adjustment issue.
- **Reverse Current Overload (IEC 61730-2, MST 26)**
 - Caution – many integrators love to parallel modules. Not all know to de-rate the fuse accordingly!
- **Hot Spot Endurance (IEC 61646 clause 10.9)**
 - Caution – Should use IR and should consider effects of multiple modules.



PI Photovoltaik-Institut Berlin AG, 2008

Reverse Current Failure

So about 1000 HR Damp Heat...

- **Does it mean anything?**
 - **Does not mean**
 - 20 years life regardless of location
 - A predictor of long-term electrical performance
 - Edge seal is hermetic
 - Chemical compatibility for module material set
 - No electrochemical corrosion issues will form (if conducting voltage biased testing)
 - **Does mean**
 - A significant milestone and check mark towards a certifiable product.
 - Tends to be a particularly grueling single-stress test for some thin-film modules.
 - **Will point to problem areas in construction, process or material choices**
 - **Can mean much more if part of a MULTI-STRESS TTF program and combined with many other diagnostics.**
 - Electroluminescence
 - Polymer characterization tools (DSC, TMA, Mocon, etc., etc.)
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What to Look for

- Moisture ingress has a classic electrical degradation pattern:

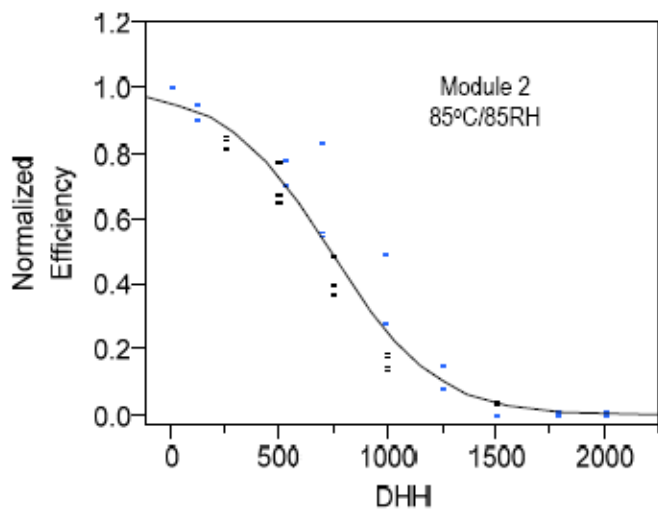
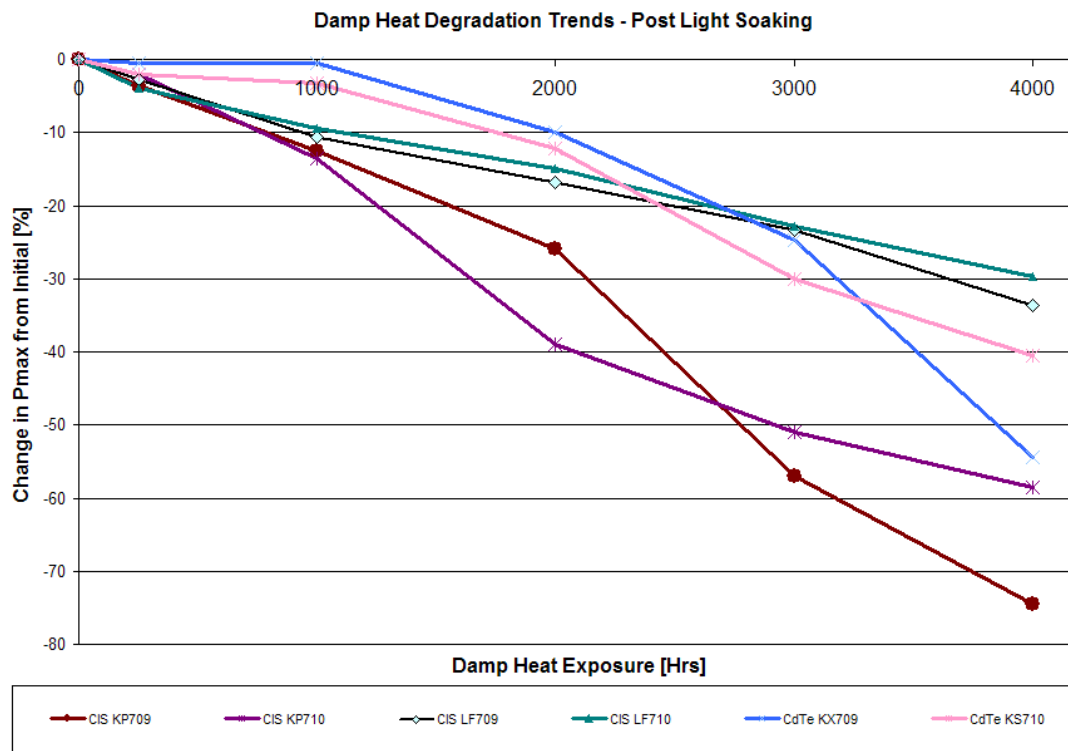


Fig. 9. Performance evolution in Module 2 at fixed EC 85°C, 85%RH.

V.A. Kuznetsova, R.S. Gaston, et. al. 2009

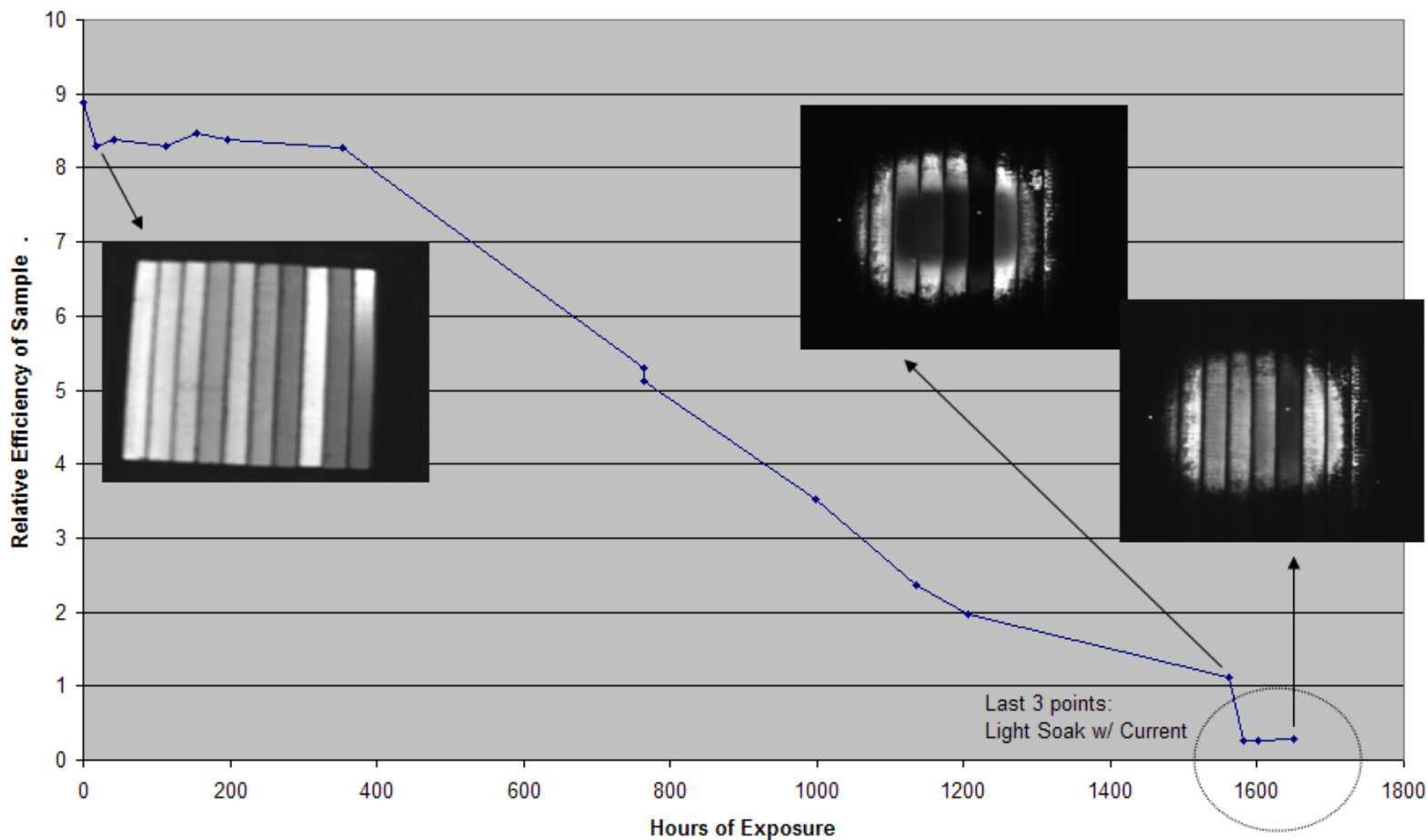


T. Sample, A. Skoczek, et. al. 2009

Bound the Problem

Damp Heat - Boundary Condition for Moisture Ingress
11-cell sample with 1000:1 WVTR encapsulant and no edge seal

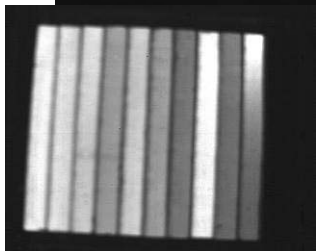
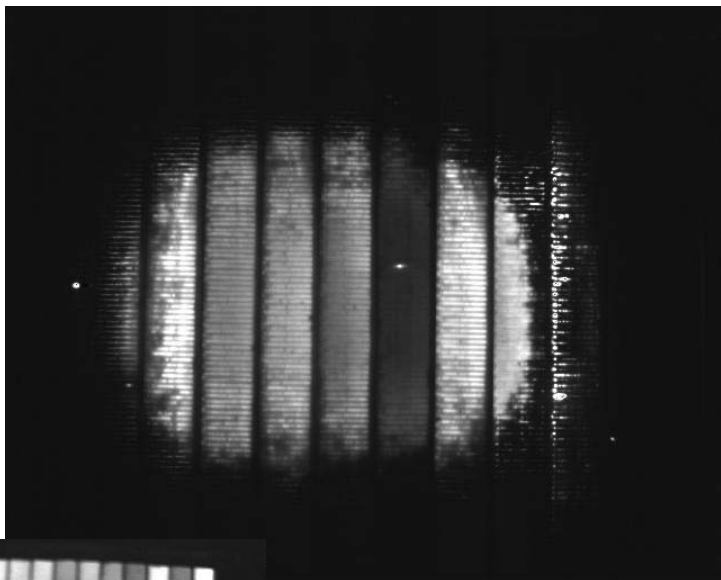
Ingress BC



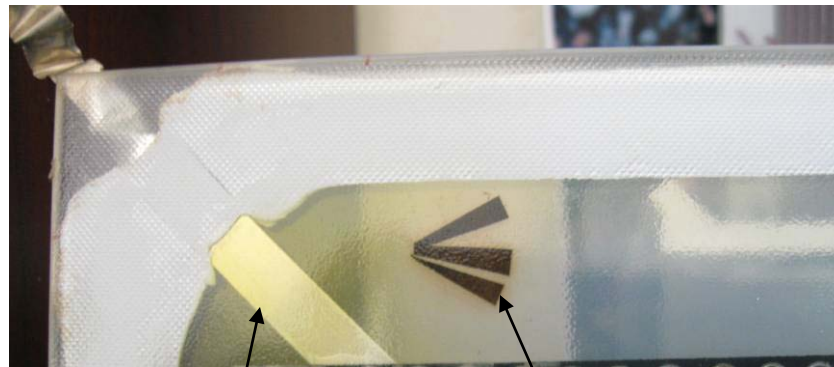
The other BC? "Dry", dark heat.

What to look for

- Moisture ingress almost always leaves very perceptible signs

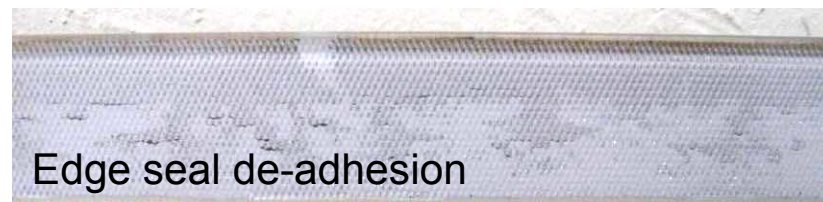


EL Image



Metallic corrosion
(in this case yellowing)

Color change
indicator



Edge seal de-adhesion

Dark Heat

- Exponential behavior that “reaches” an asymptote and may also be reversible to some extent with light soak under load.

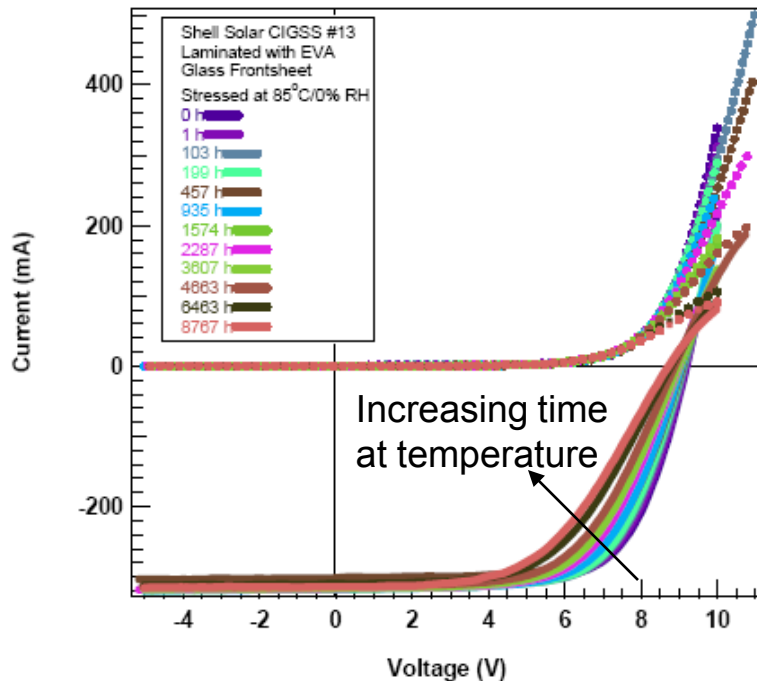


Fig. 5. Typical IV traces for a EVA/Glass encapsulated mini-module exposed to 85°C and 0% RH.

M. Kempe, K Terwilliger, D Tarrant 2008

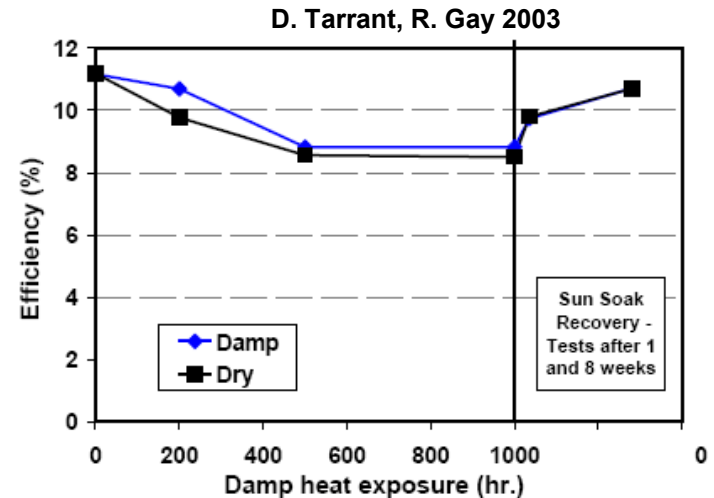
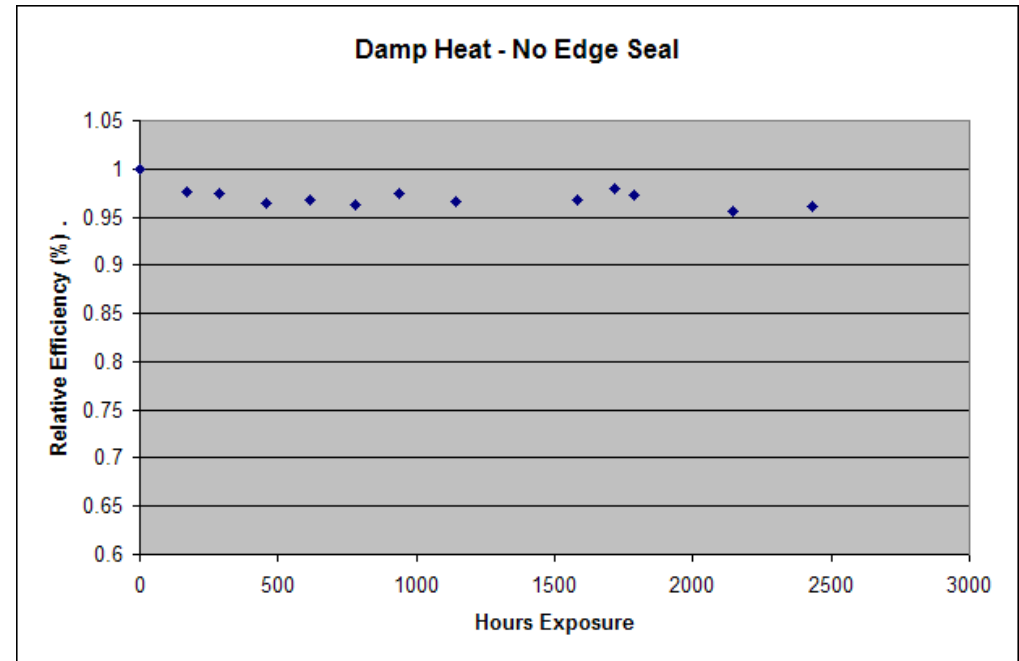
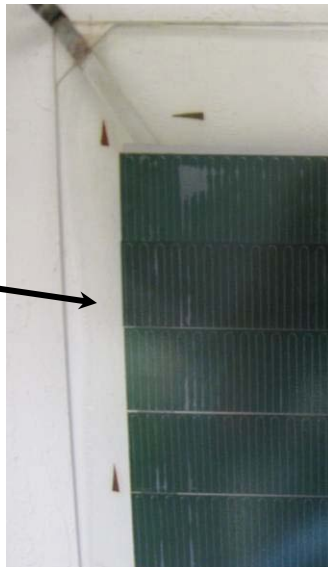
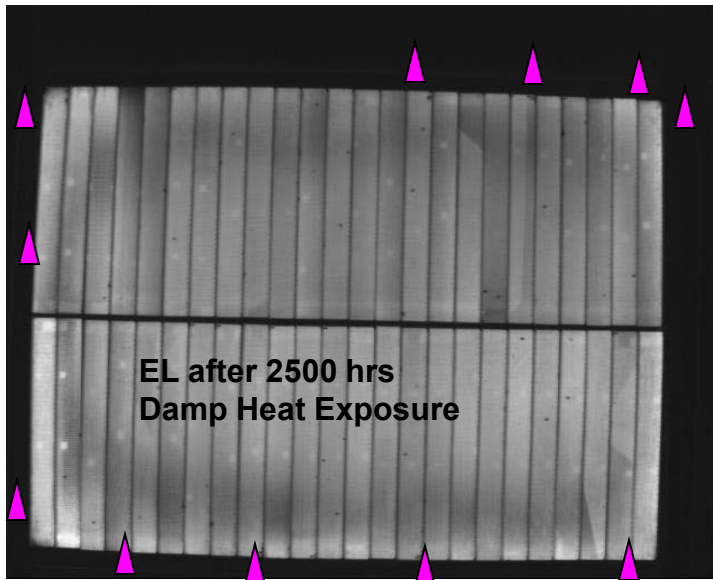


Figure 15. Recovery after the thermal exposure of damp heat accelerated tests with or without including high humidity in the tests.

Leaves no signs of moisture ingress
EL shows “uniform” changes in cells

Can CIGS be Moisture Hardened?

- Yes, but there are tradeoffs.
- I know that's unfulfilling, but that is the limit to what I can say...



References

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