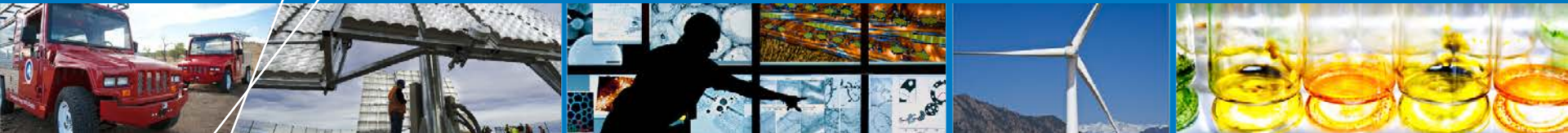


Testing modules for potential-induced degradation— a status update of IEC 62804



Peter Hacke

National Renewable Energy Laboratory (NREL)

PV Module Reliability Workshop

February 25-26, 2014

Golden, Colorado

NREL/PR-5200-61517

this presentation contains no confidential information

Scope

Testing modules for potential-induced degradation— a status update of IEC 62804

- **Mechanisms**

- Covers:

- Measuring potential-induced degradation
- Polarization

- Does not cover:

- Electrochemical corrosion
- Combined effects with wear out, delamination, etc.

- **Materials**

- Covers:

- p-base and n-base Si cells (~89% of the market 2011)

- Does not yet cover:

- Thin film modules
- No experiments so far in tandem or heterostructure devices

New in IEC 62804 project (key items)

- **IEC 62804 draft has been revised to be a method for test**
TEST METHOD FOR DETECTION OF POTENTIAL INDUCED DEGRADATION OF PHOTOVOLTAIC (PV) MODULES
 - No pass/fail criteria
 - Contains a foil test and a damp heat test
 - Provides details on how to set up tests
 - Provides stress conditions for use as baseline allowing for comparisons
 - International task group
 - M. Koehl (Germany)
 - C. Liciotti (Italy)
 - F. Rummens (Belgium)
 - F. Fabero Spain)
 - K. Berger (Austria)
 - Y. Eguchi (Japan)
 - P. Hacke (USA)

Outline of talk

- Comparison of stresses and degradation rate for 25° C / foil and 60°C/85% RH damp heat test
- Illumination factor on PID rate
- Measurement techniques and stress levels discussion

Outline of talk

- **Comparison of stresses and degradation rate for 25° C / foil and 60°C/85% RH damp heat test**
- Illumination factor on PID rate
- Measurement techniques and stress levels discussion

Damp heat and foil methods – setup

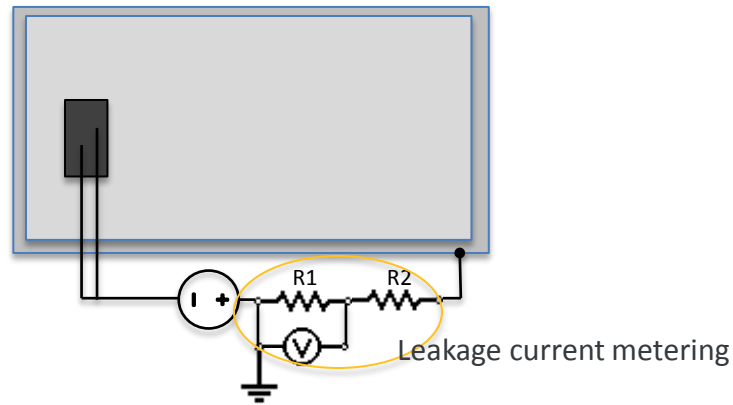


Damp Heat



Foil

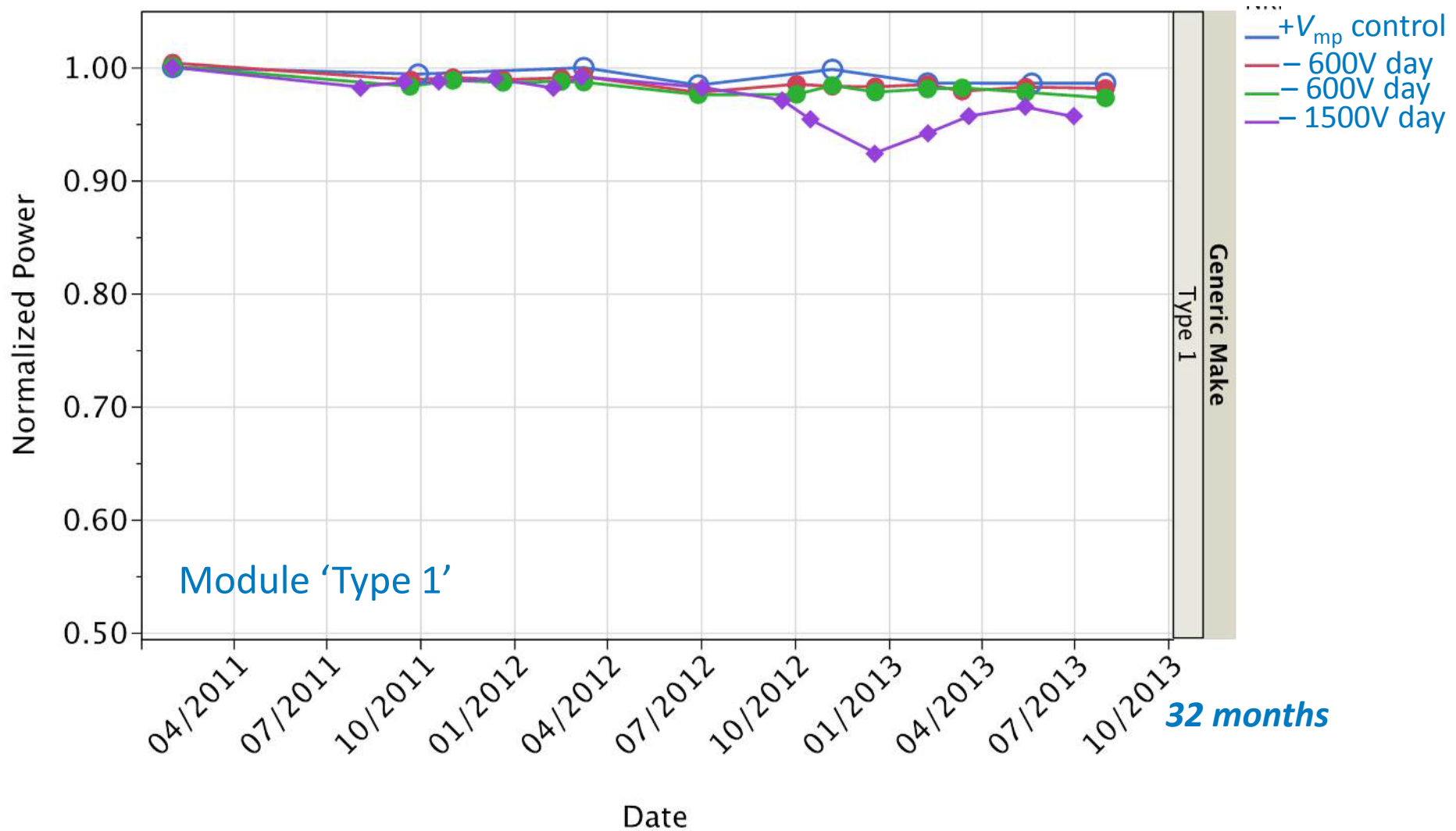
Bagdahn, Fraunhofer CSP
PV Japan, 5-7 Oct 2012



Damp heat and foil compared - background

- DH test (60°C/85%RH/96h/Vsys)
 - Does not defeat PID solutions based on the frame design
 - Rear rails, limited area edge clamps
 - Includes the environmental factor of humidity
 - Exposes effects of glass quality, texture, leakage current pathways, moisture ingress to an extent
- Foil test (25°C/168 h/Vsys)
 - Applies even grounding potential over the module surfaces
 - More representative of very heavy soiling
 - Favored by those seeking a simple test
- Tests are not comparable, stress state is different

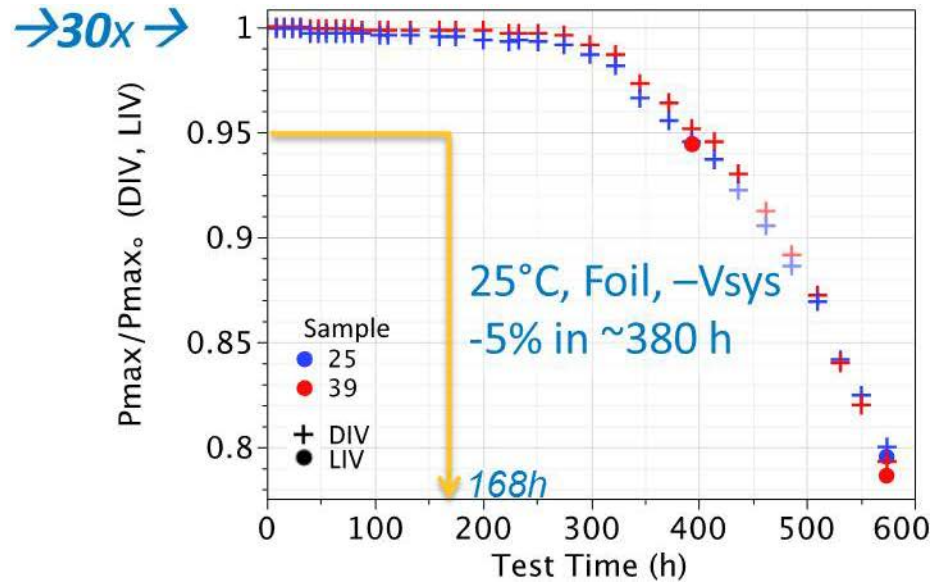
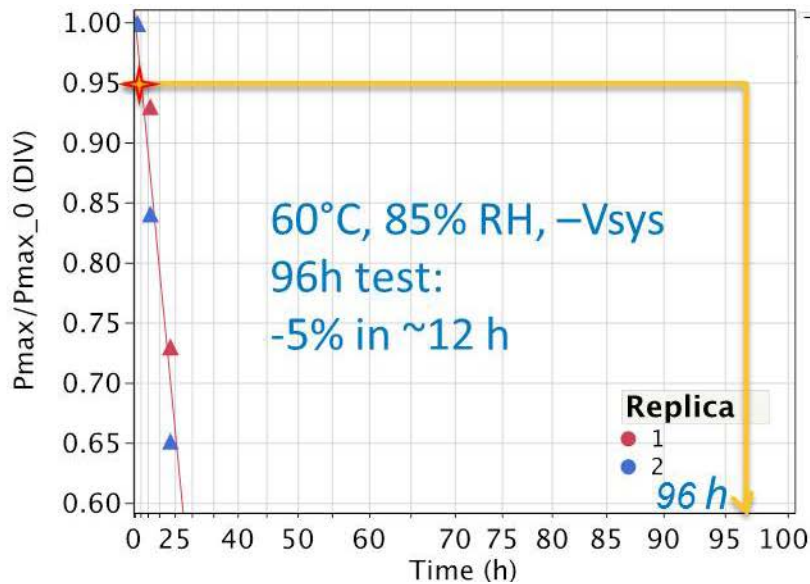
60°C/85%RH/96h/-V_{sys} stress condition origin



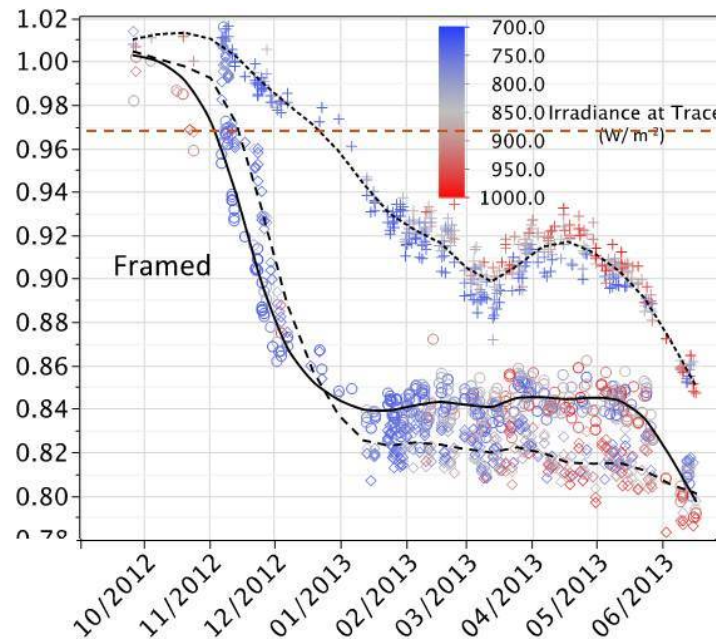
To date, chamber test successfully sorts 7 module designs (31 modules) for PID in the field

Hacke et al, 2013 E PVSEC (Paris)

Damp heat and foil compared - 1



Module replicas start fail
in ~ 92 days under
-V_{sys} in Florida



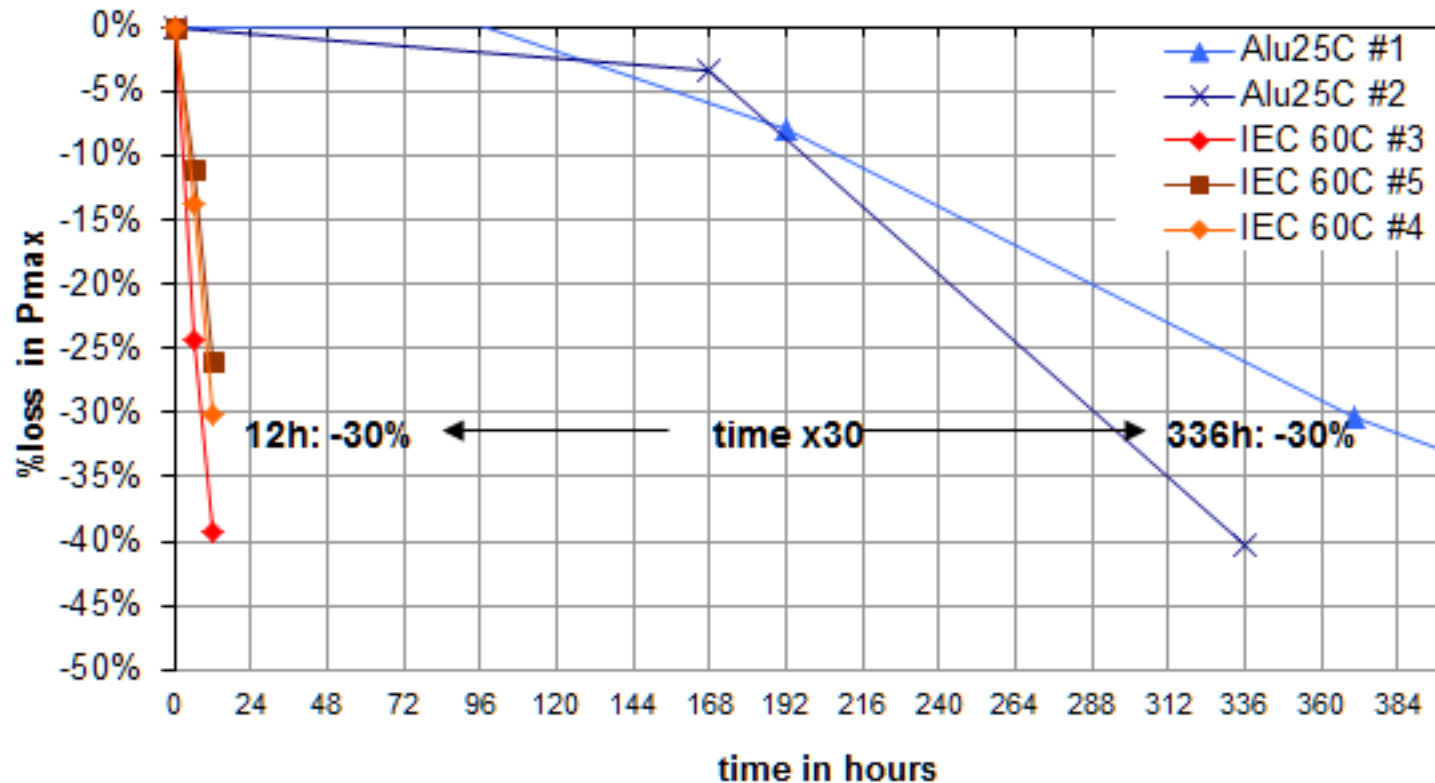
Framed, commercial mc-Si
module

Hacke et al, 2013 E PVSEC (Paris)

Damp heat and foil compared - 2

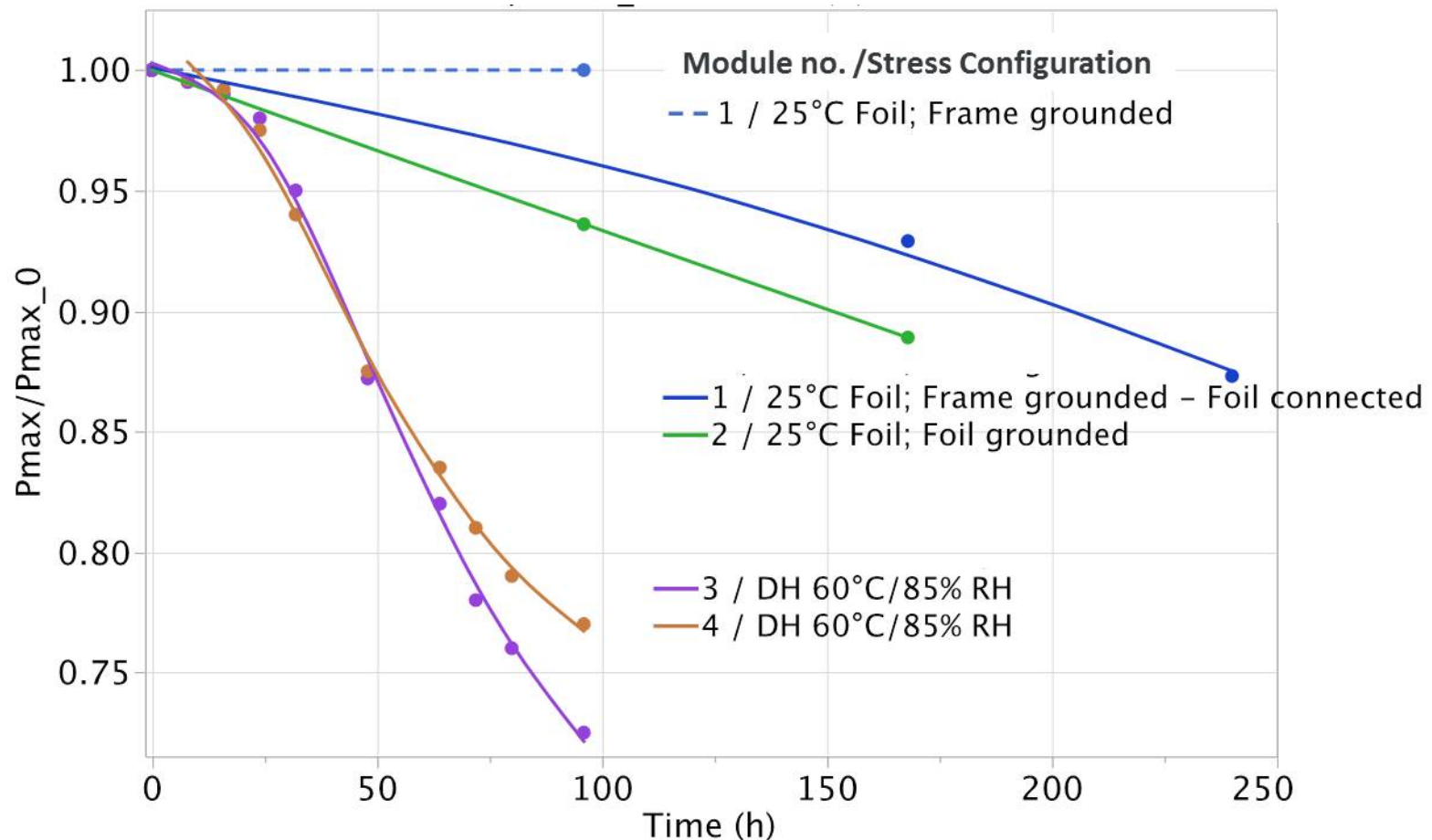
S. Janke. S. Pingle, SOLON, unpublished

ALU RT 25°C PID vs. 60°/85% PID
%change in Pmax



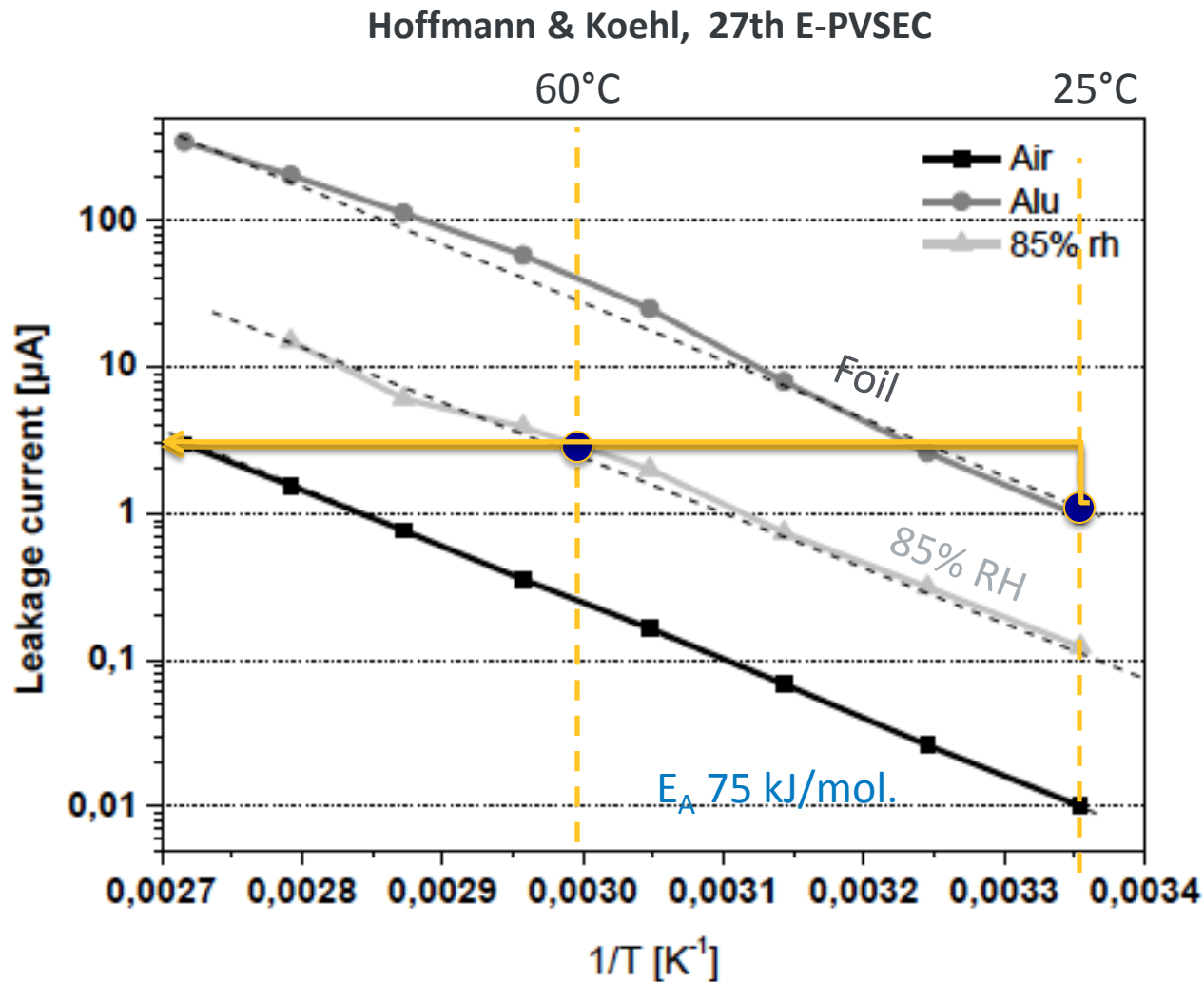
Damp heat and foil compared - 3

Prof. Mani, S.Tatapudi, C. Anderson (ASU), to be published



- Significant boost in 25°C foil method PID rate by defeating insulating coating on frame; ie, removing frame anodization
- Al foil method still produces ~4 times slower degradation than the 60°C/85% RH condition

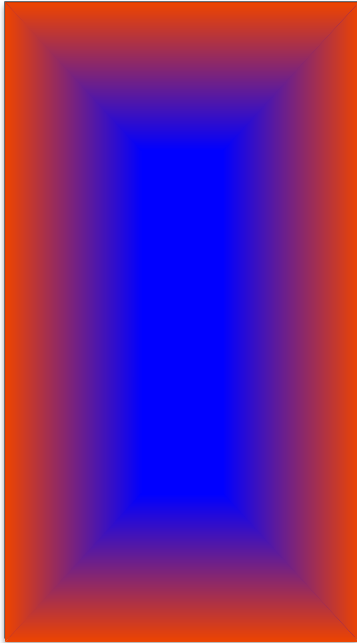
Damp heat and foil compared - 4



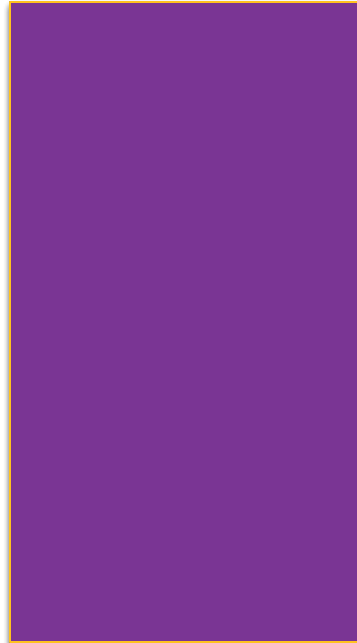
Leakage current at 60° C/85% RH approximately 3x that of 25° C Al foil

Different stress configurations of DH, foil

Damp Heat



Foil

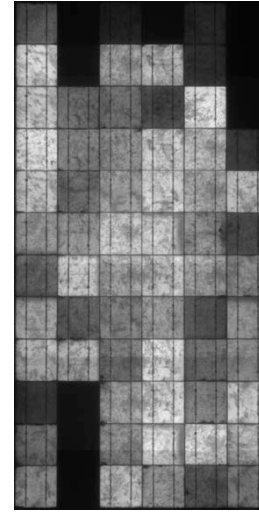


Low stress

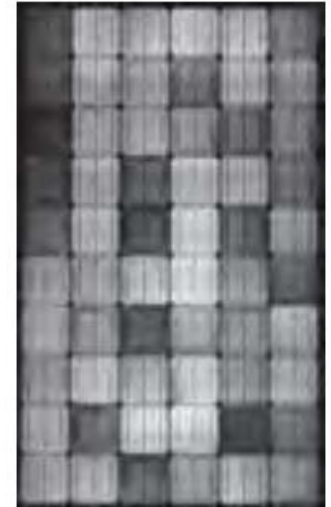


High stress

Damp Heat



Foil



CONCEPT

EL by Sascha Dietrich et al,
Fraunhofer CSP

- Many defects, conductive encapsulant
- Many defects, resistive encapsulant
- Few defects, conductive encapsulant

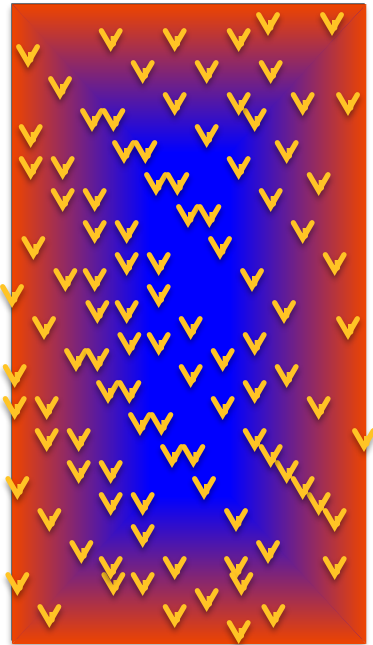
Defects, V. Naumann model of Na at stacking faults:



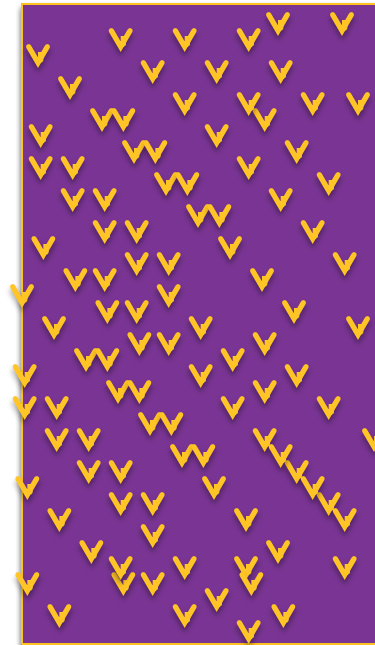
Different stress configurations of DH, foil

CONCEPT

Damp Heat



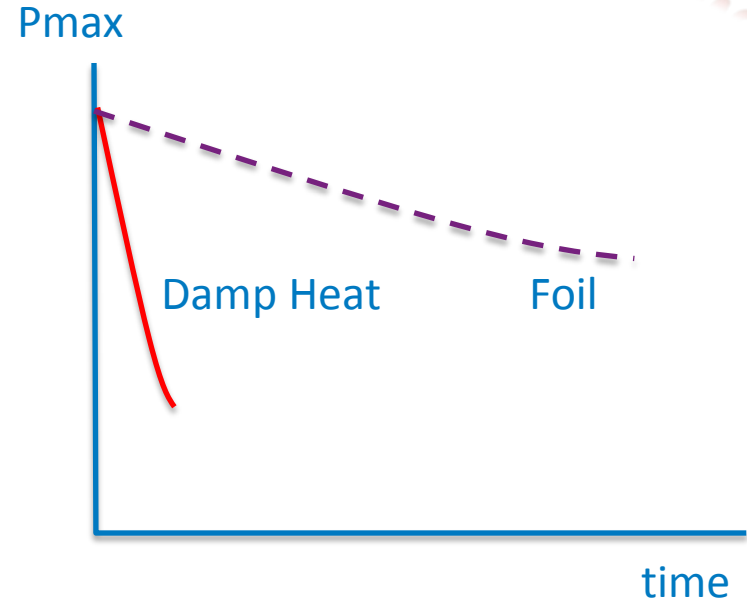
Foil



Low stress



High stress



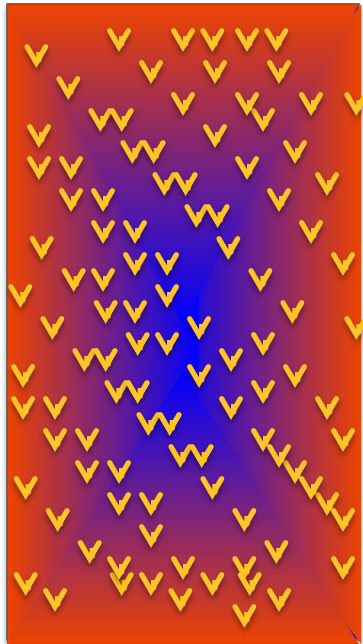
- *Higher T overcomes activation energy*

- Many defects, conductive encapsulant
- Many defects, resistive encapsulant
- Few defects, conductive encapsulant

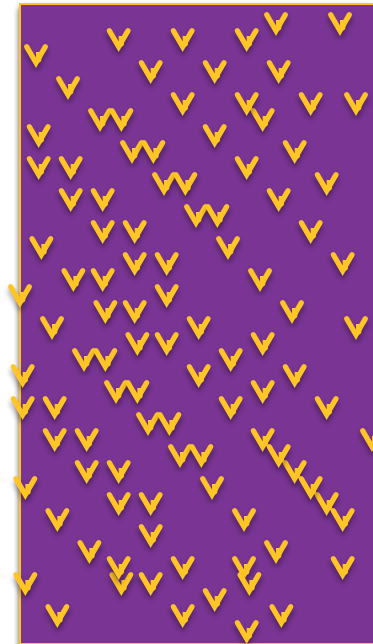
Different stress configurations of DH, foil

CONCEPT

Damp Heat



Foil

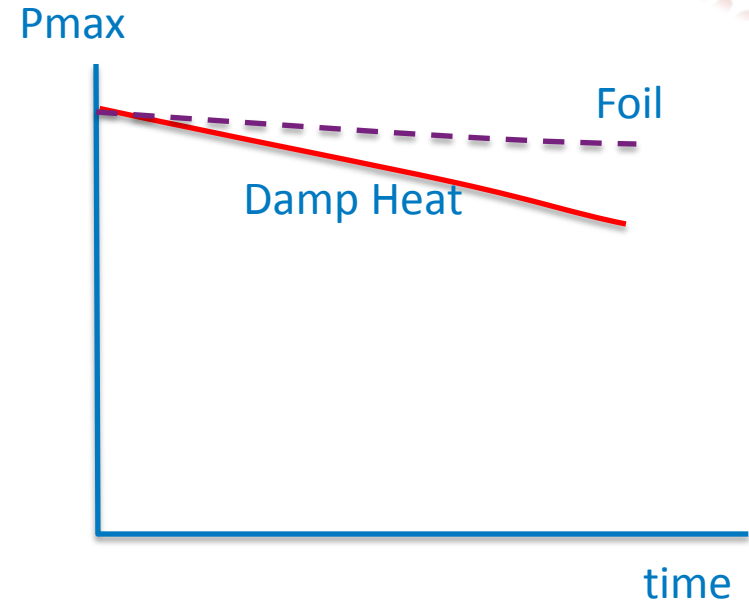


Low stress



High stress

- Many defects, conductive encapsulant
- **Many defects, resistive encapsulant**
- Few defects, conductive encapsulant

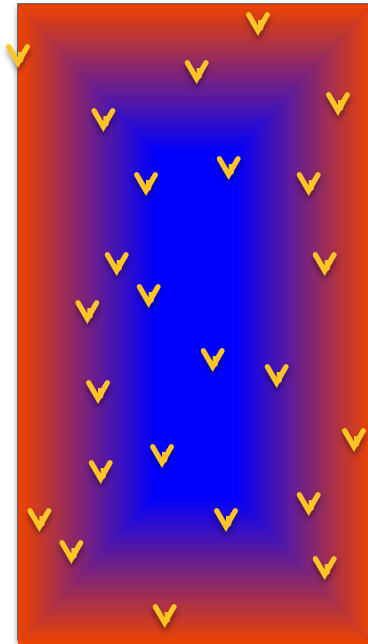


- *Higher T overcomes activation energy*
- *Resistive encapsulant leads to more distribution in the grounding and stress (less charge transfer into the module)*

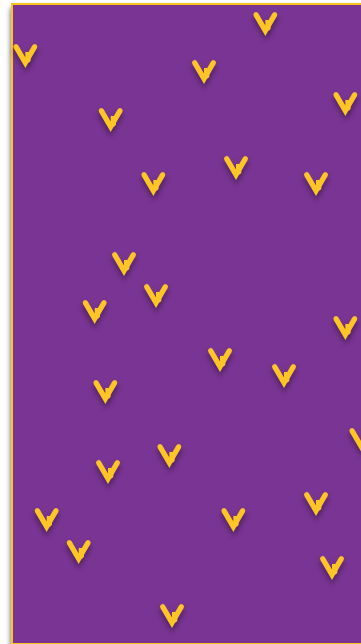
Different stress configurations of DH, foil

CONCEPT

Damp Heat



Foil

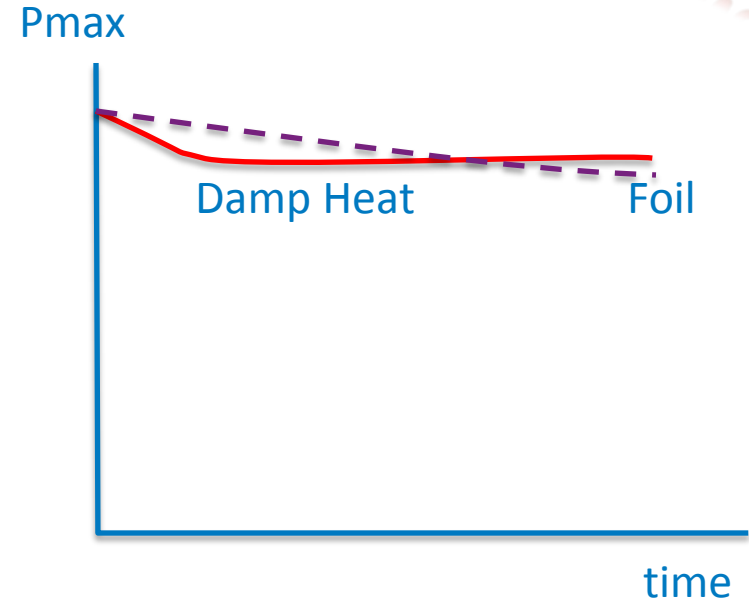


Low stress



High stress

- Many defects, conductive encapsulant
- Many defects, resistive encapsulant
- **Few defects, conductive encapsulant**

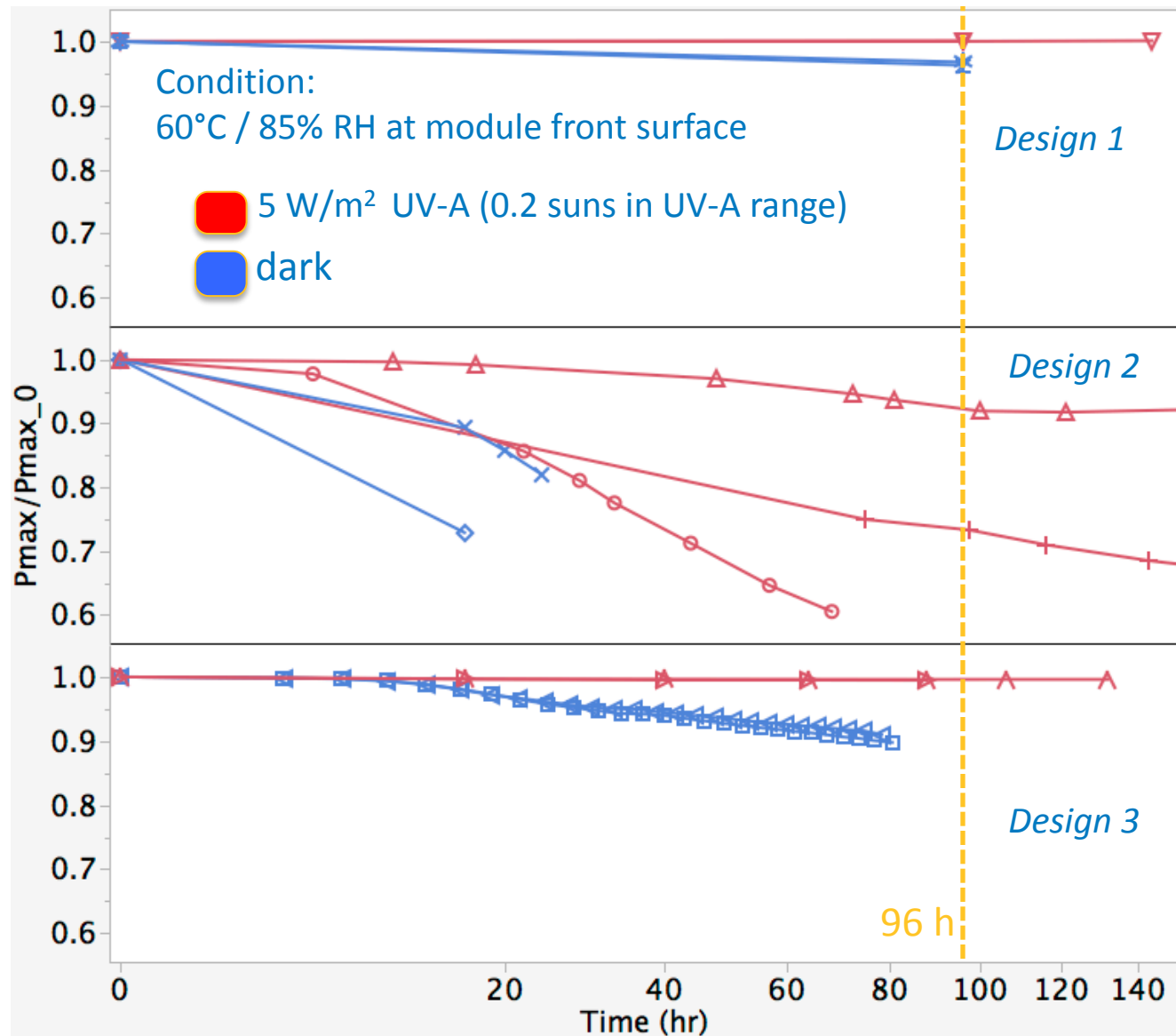


- *Higher T overcomes activation energy*
- *Defects covered in 'high stress' region in DH saturate; foil however eventually reaches to all defects.*

Outline of talk

- Comparison of stresses and degradation rate for 25° C / foil and 60°C/85% RH damp heat test
- **Illumination factor on PID rate**
- Measurement techniques and stress level discussion

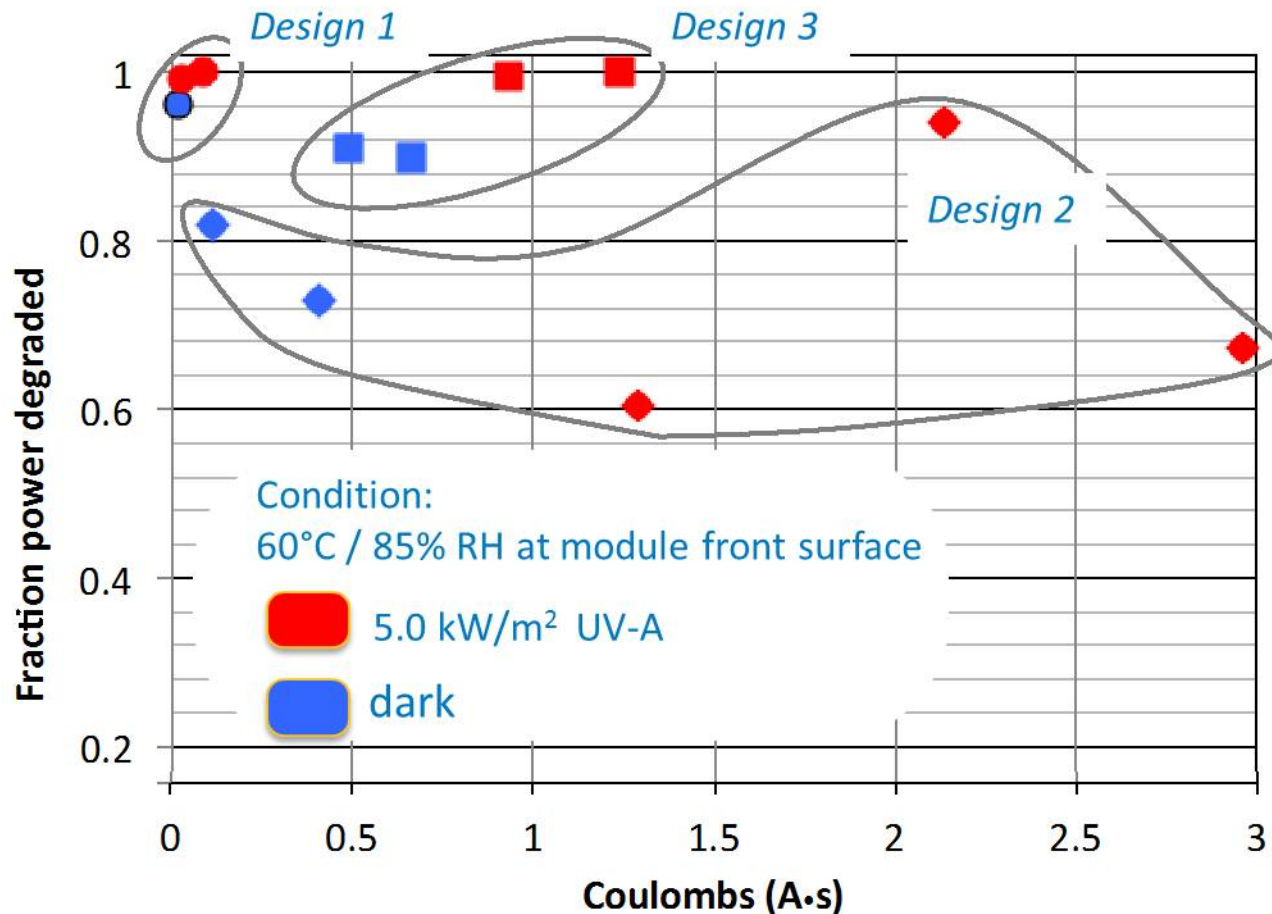
Chamber in-situ UV-A light: PID retardant



- T Chamber decreased and RH increased to maintain 60°C/85% RH on surface.
- Leakage current with UV at or above dark condition



Extent of PID with and without simultaneous 0.2 sun UV-A vs Coulombs



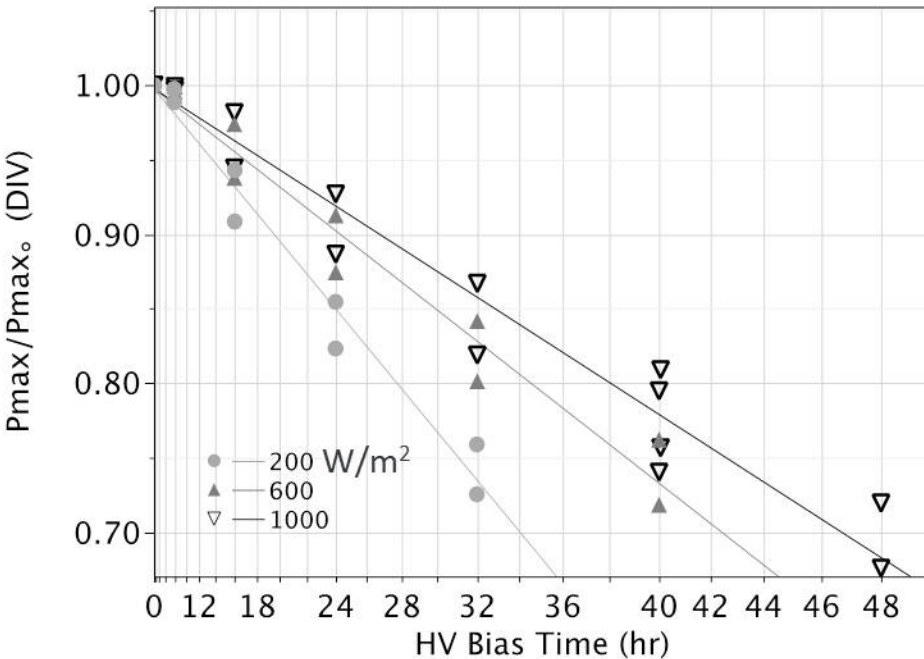
- With more stress (leakage current - time product) under illumination, there is the same or less PID.
- For a given leakage current charge measured in chamber, we expect less (possibly no) degradation under illumination, such as outdoors
- Focus then becomes how much they degrade outdoors, accelerated tests are just correlations, and leakage current not a universally representative indicator of degradation
- Possible mechanism: UV creates radicals that scavenge the most deleterious ions (e.g., Na⁺)

Outline of talk

- Comparison of stresses and degradation rate for 25° C / foil and 60°C/85% RH damp heat test
- Illumination factor on PID rate
- **Measurement techniques and stress level discussion**
 - Power of module in low light undergoing PID
 - Removing non-equilibrium conditions and leakage current spikes in DH
 - Motivation for higher stress levels

Low light impact, chamber and field tests

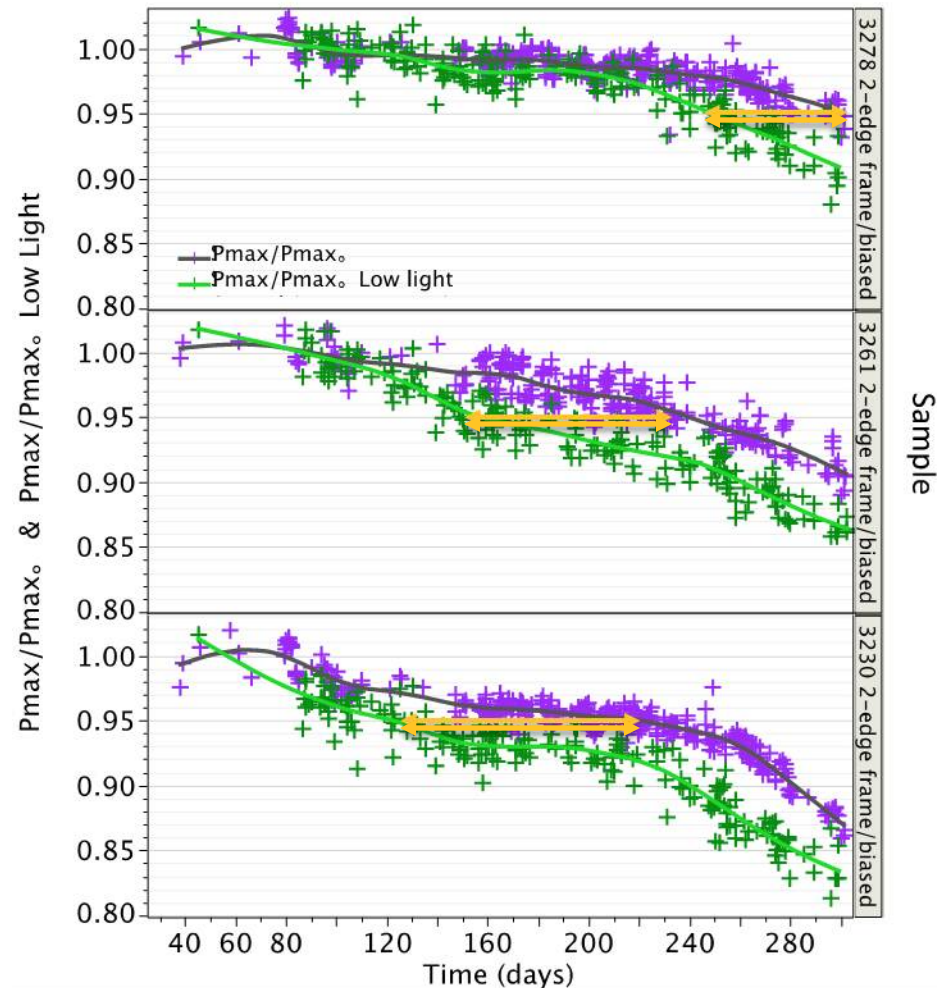
Indoor chamber tests



Time to 5% degradation in **28%** less time
At 200 W/m^2 than at 1000 W/m^2

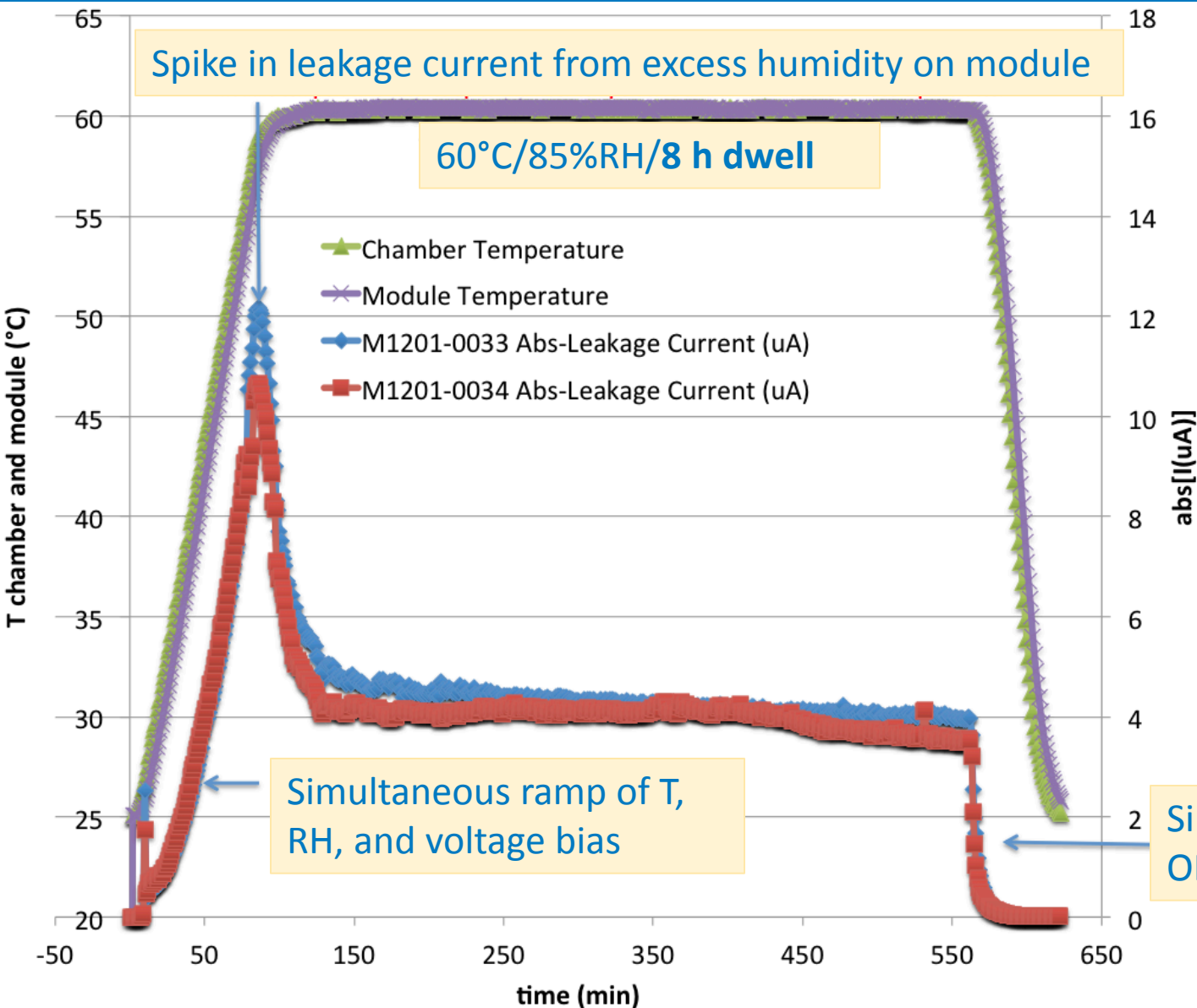
Also see:
G. Mathiak *et.al.*, TÜV-R
27th EU-PVSEC

Outdoor tests



Time to 5% degradation in **17%, 35%, and 42%** less time than the full light curves

Voltage applied on start, then combined T, RH Ramps (early draft sequence)

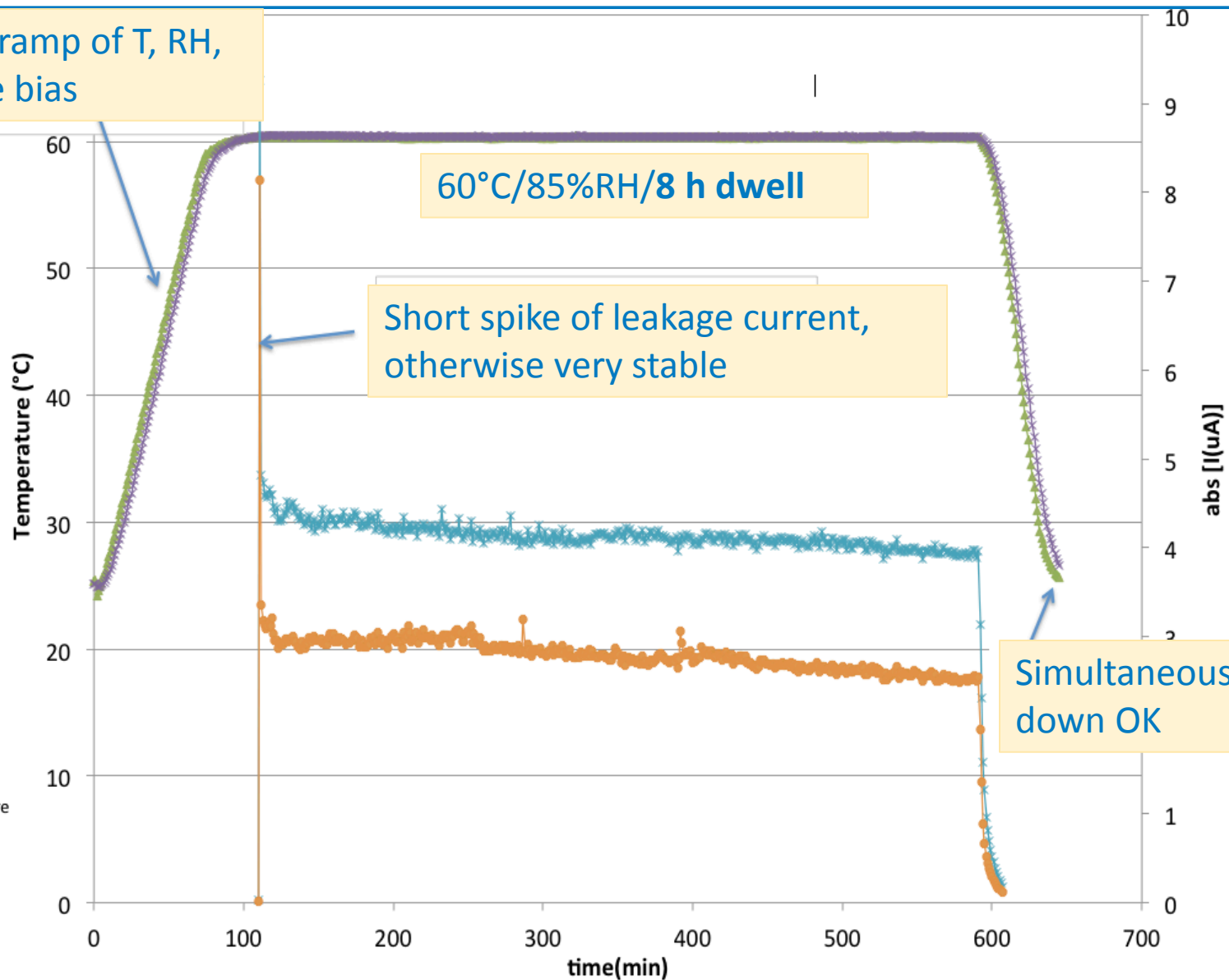


Leakage current spike, if different from chamber to chamber could conceivably contribute to poorer reproducibility & excess stress

Also see: G. Mathiak, *et.al.* TÜV-R 27th EU-PVSEC

T ramp/dwell → RH ramp → V ramp (later draft sequence)

Sequential ramp of T, RH, and voltage bias



Possible futures of the stress level

- **DH PID test**

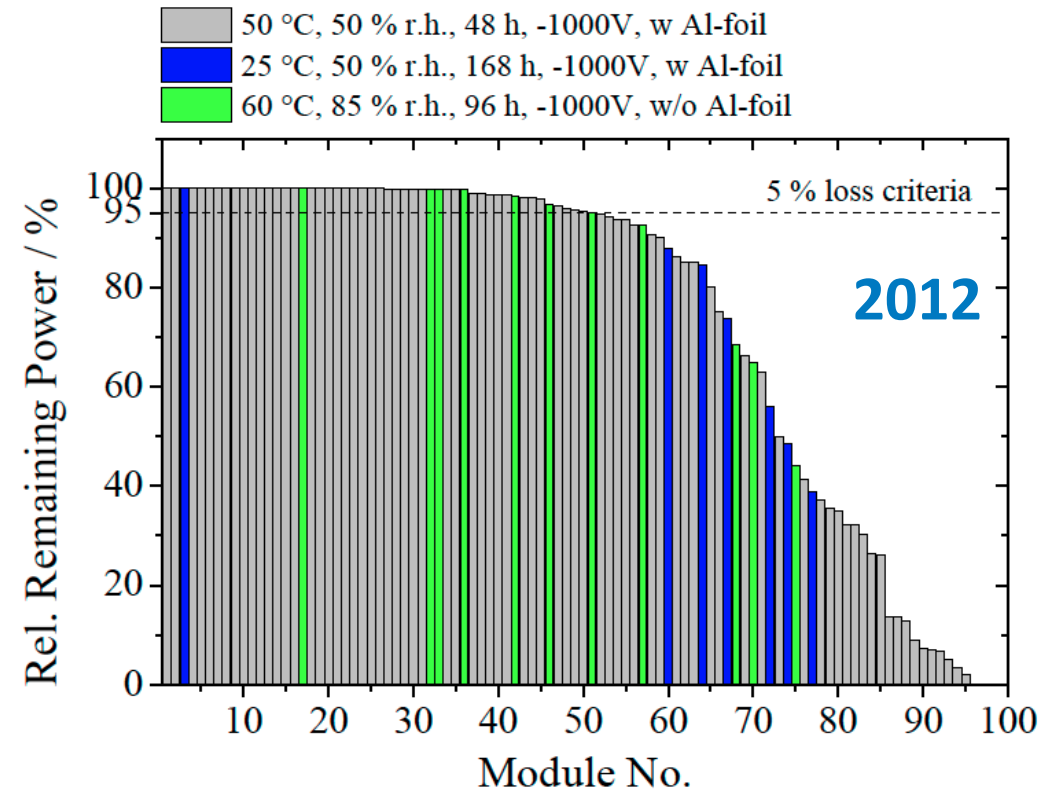
- To detect low light degradation when it manifests in STC power, and to
- add additional stress, making up for the removal of the excess humidity on startup
 - 1.35-1.5 X increase in nominal stress level
 - Damp heat test 60°C→65°C stress levels

- **Foil PID test**

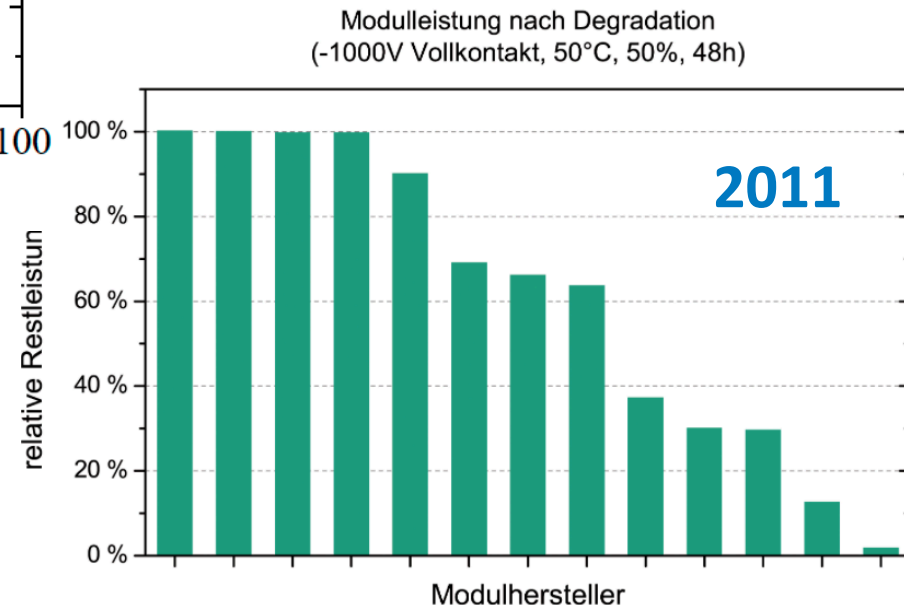
- *Minimum* 3x increase in stress level to bring it closer to 60°C DH test stress level
- *Minimum* 4.0x to 4.5x increase in stress level to bring it to 65°C/ 85% RH
- Must manually defeat the frame insulation to short the frame to the glass (what humidity would normally do)

MORE DATA NEEDED

PID in c-Si modules becoming the minority



Fraunhofer CSP data



2013, 2014 should be even better

PID in c-Si modules becoming the minority

- The 'norm' in China for qualifying PID resistance is 85°C/85%RH/96h/-V_{sys} for manufacturers paying attention to it
- Companies and labs frequently testing with foil at elevated (50°C -60 °C) temperatures
- Module manufacturers already moving beyond the proposed stress levels

Thank you for your attention

The Alliance for Sustainable Energy, LLC (Alliance), is the manager and operator of the National Renewable Energy Laboratory (NREL). Employees of the Alliance, under Contract No. DE-AC36-08GO28308 with the U.S. Dept. of Energy, have authored this work. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for United States Government purposes.