HOLISTIC RELIABILITY: ACCELERATED TESTING OF ADHESION

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DuPont: The Leading Specialty Material Supplier in PV

Solamet® metallization pastes

Driving higher energy conversion efficiency

Tedlar® backsheet films

Protecting PV modules

Elvax® and Ionomer encapsulants

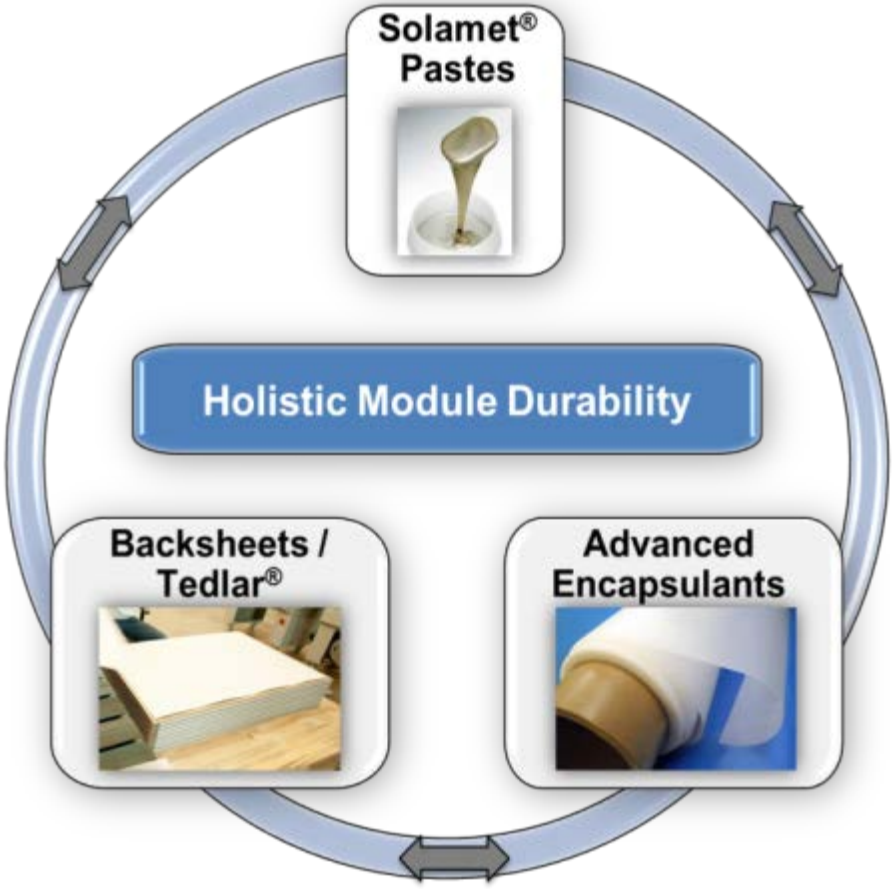
Delivering long-term protection of cells

Rynite® PET Zytel® Nylon composite materials

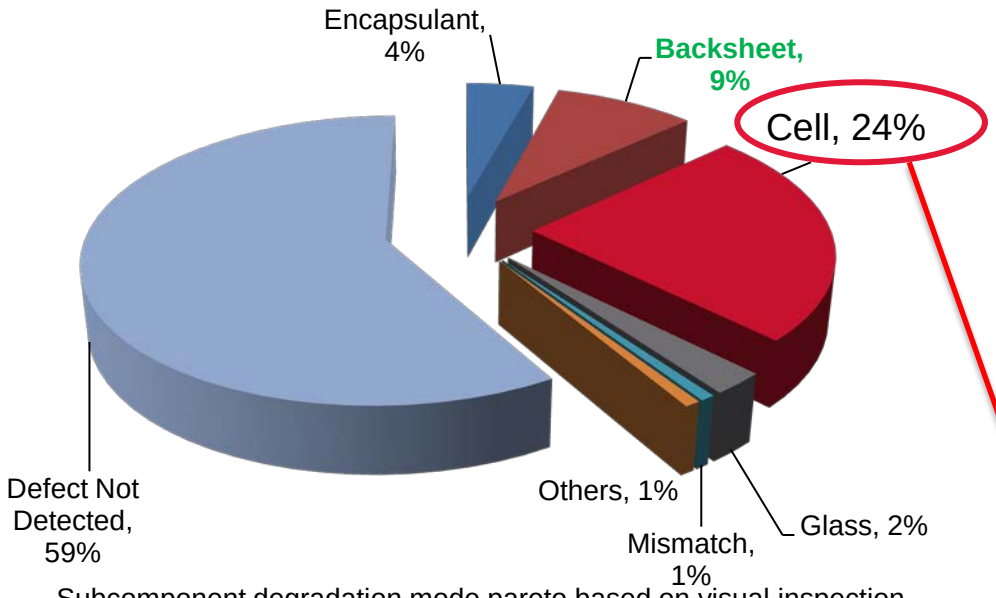
Reducing system costs and speed up installation

DuPont Holistic Cell and Module Durability Program

- Develop **test protocols** that differentiate materials with regards to durability
- Evaluate **durability for PV materials,** their interactions and synergies in module
- Provide **science-based understanding** of materials-related lifetime performance
- Develop products with **highest durability** to deliver more power output to **maximize ROI**



Field Studies Reveal Quality Issues



Subcomponent degradation mode pareto based on visual inspection

DuPont Field Module Program

- Inspected >60 global installations (>200 MW & 1.5 million modules) in NA, EU, & AP ranging from 0-30 years installed
- Data includes c-Si modules from > 45 module manufacturers

IEEE PVSC (New Orleans, 2015, A. Bradley et al)

Cell and Interconnect Reliability

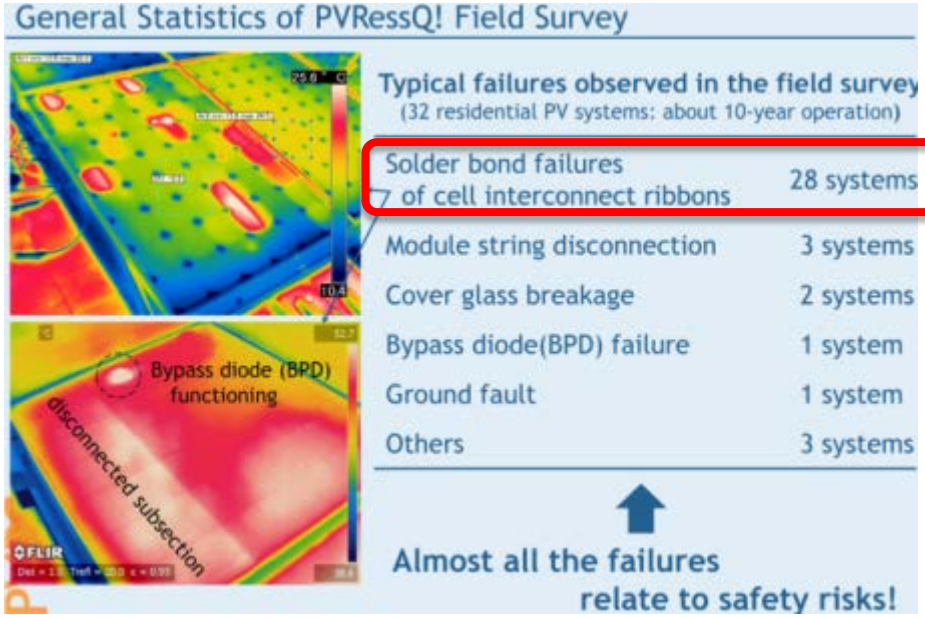
- Little understanding of how the **different components** in the module **interact**.
- Metallization formulation **changes every 1-2 yrs**.
- Need **science based understanding** of what modulates **metallization failures!**

2/3rds of defects in inspected modules attributed to the **cell** and **metallization**.

Materials Selections Help Mitigate Risk

- Unreliable materials can cause premature power degradation, module and system failures, and safety issues
- Adopting proven, high quality metallization pastes, encapsulants and backsheet materials are critical to long term module performance and safety

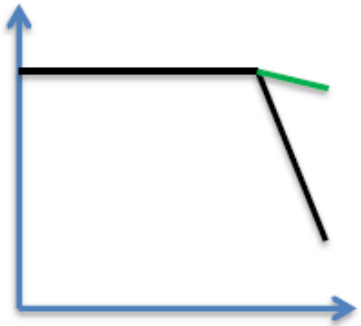
Fabrice Didier, EU PVSEC – Investors day, September 26th, 2012.



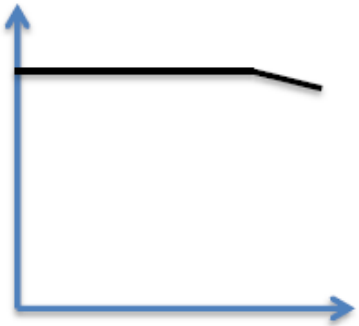
Kazuhiko Kato, PV Module Failures Observed in the Field - Solder Bond and Bypass Diode Failures, AIST, Japan, presented at Tokyo QA Forum, 2011.

Shortcomings of Extended Qualification Stress Testing

Power Loss



Damp Heat



Thermal Cycling, Humidity Freeze, UV

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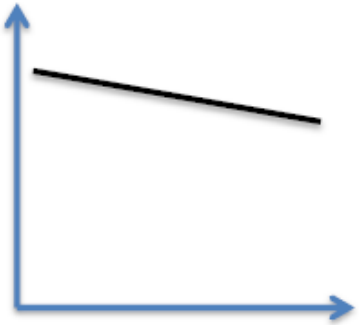
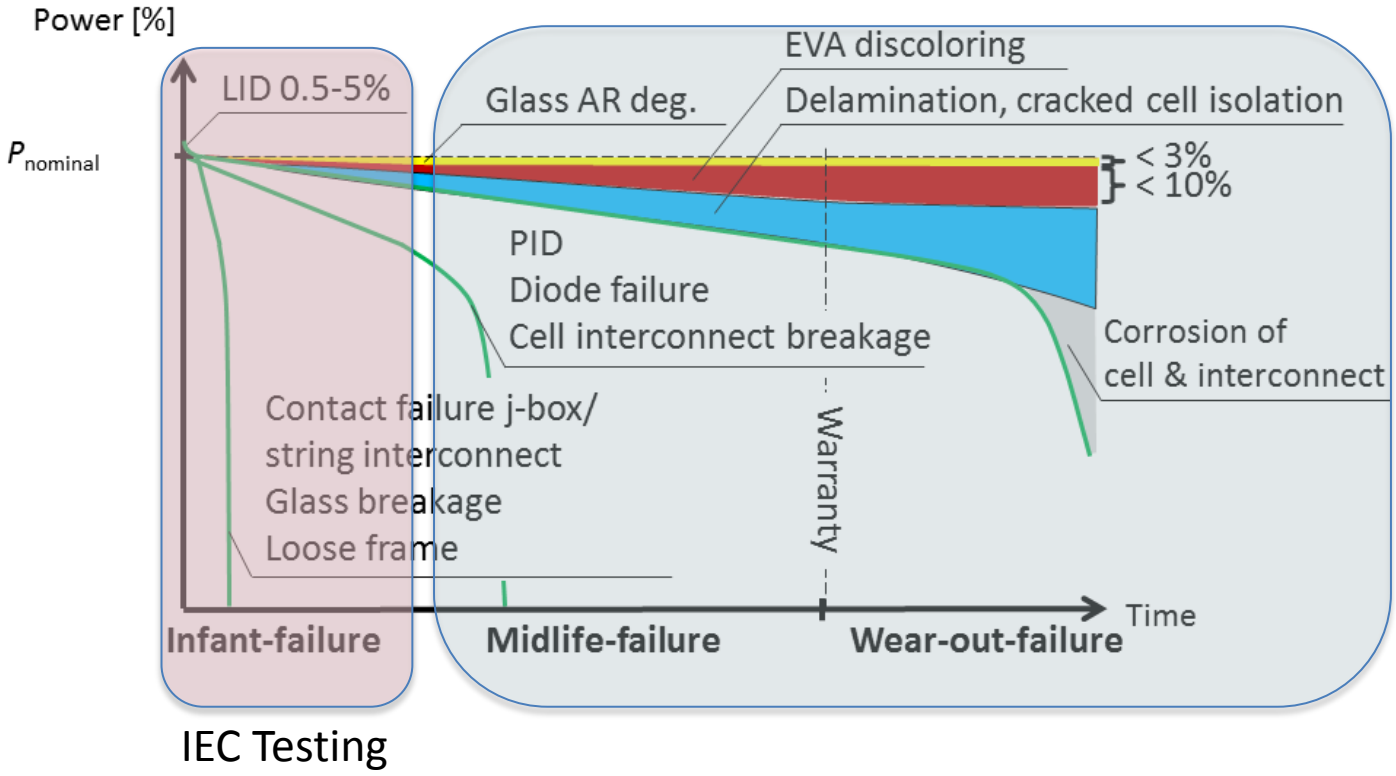


Field

- Current accelerated tests do not adequately predict fielded performance
  - Power loss mechanism is **differen**t from the **field**
  - e.g. Hydrolysis damage occurring beyond DH1000 is **not observed in the field**

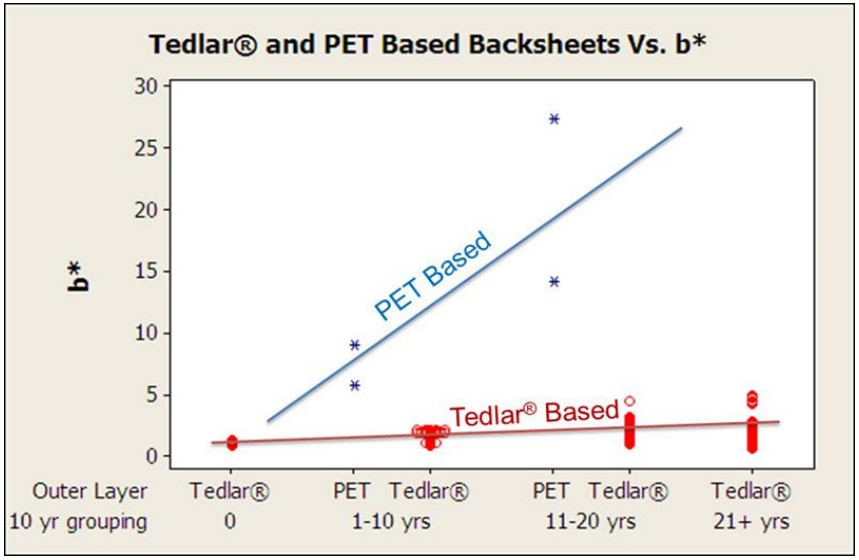
Standard Reliability Testing

IEA International Energy Agency, PVPS report **T13-01:2014**



- Infant-mortality failures occur in the **beginning of the working life of a PV module**.
- IEC testing useful for **infant-mortality detection**.
- Questionable if IEC testing will **predict module midlife to end of life failure.**

Development of Relevant Accelerated Test Methods

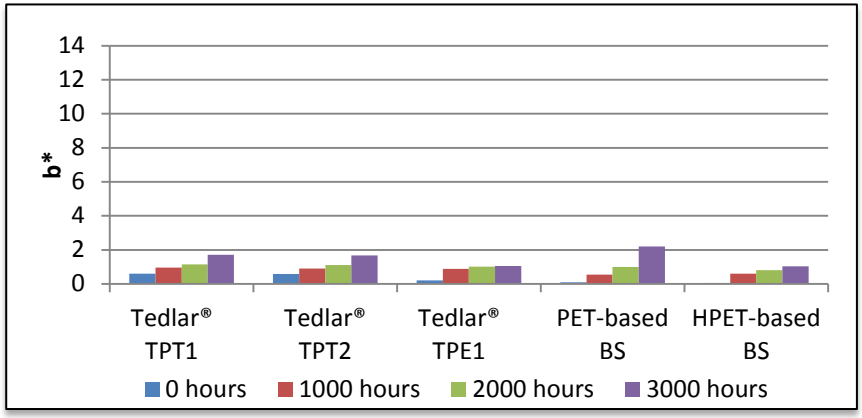


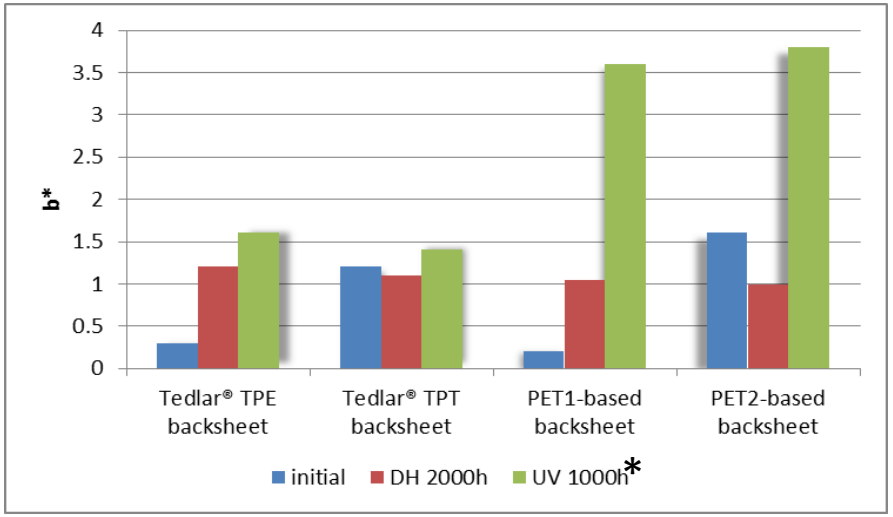
- **Damp Heat is over-tested**
- **UV Exposure is under-tested:**
  → UV exposure from module front and back needs to be incorporated
- **Sequential and Combined tests better match field observations**

Yellowing of Fielded Modules:

→ High degree of yellowing in PET Modules

→ Almost no yellowing in Tedlar® PVF Modules





Extended Damp Heat test:

→ Yellowing of PET is NOT observed

Test with DH, UV

→ UV matches field data better than DH

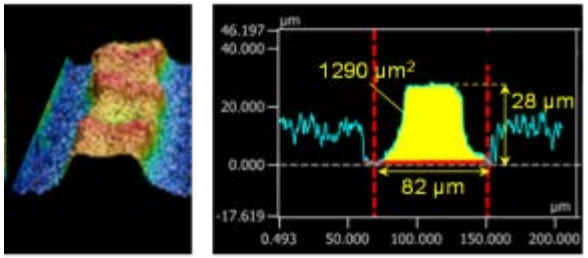
*UVA (65W/m2 (250-400nm), 70C BPT, continuous)

Risk of Low-Laydown Architectures

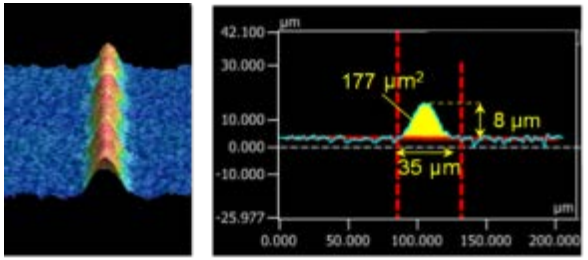
Motivation:

- Modern low-laydown structures might **pose risk for durability**

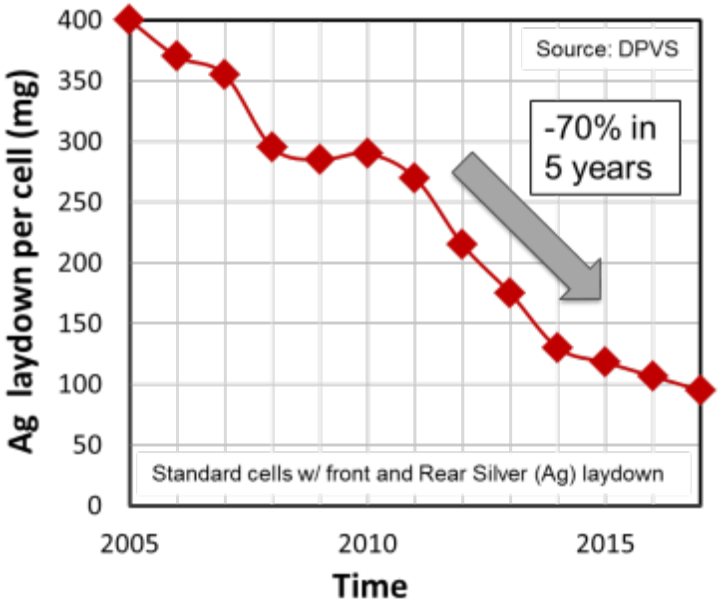
Ag lines from 4-5 yrs ago



Ag lines from today



Ag laydown reduction over time



Goals:

- Provide **critical limit** to durability for laydown
- Deliver cost-saving metallization architectures, while **excluding compromises in long-term stability**

Role of Adhesion on Module Durability

Motivation:

- Demand for high adhesion between paste and ribbon is common
- Justification for pull force targets often not clear
- Adhesion testing method is varied and **not standardized**
- Mono-Si vs multi-Si adhesion is deferent due **to surface structure!**

Goals:

- **Understand mechanisms** of adhesion and relevance for durability
- Identify range of adhesion **safe for reliability**
- Develop accelerated tests that:
  - Simulate **long term field** exposure
  - Will predict **long term field performance**
  - Further refine pastes that have these features

Paste laydown – How to drive Adhesion

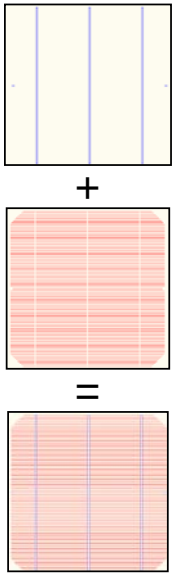
Double-print Method

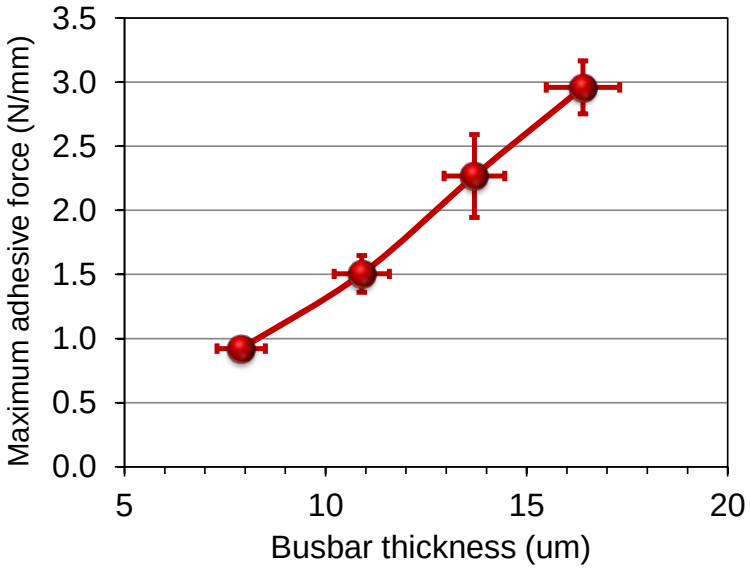
Vary busbar thickness; fingers constant

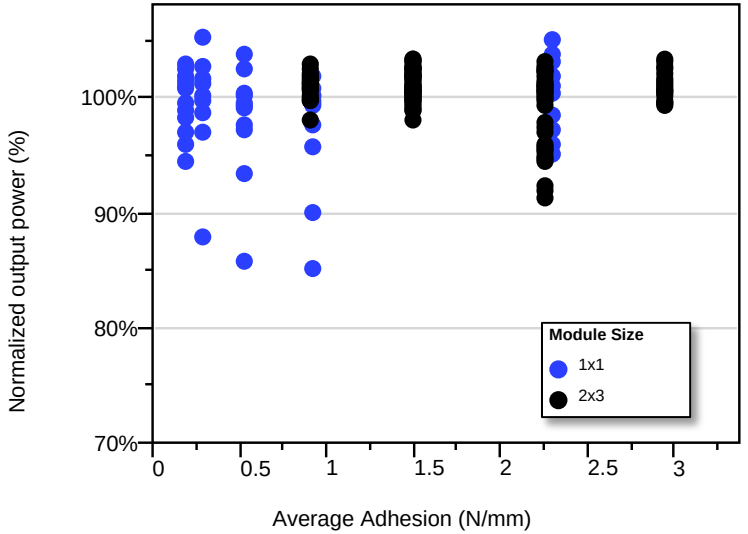
→ **Busbar thickness drives adhesion**

→ Wide adhesive force range: **0.3 – 3N/mm!**

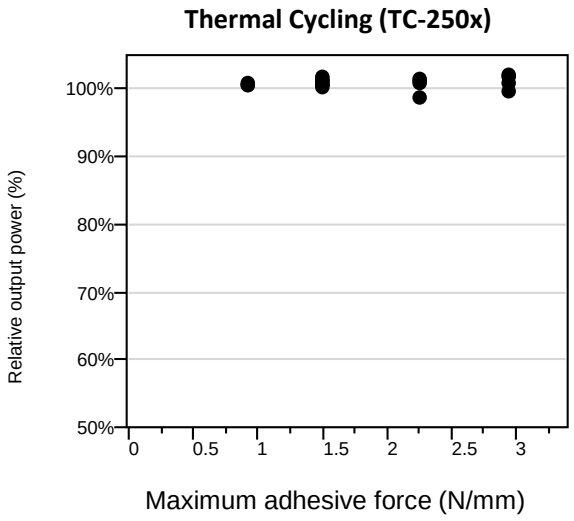
→ Is there an impact on module durability?

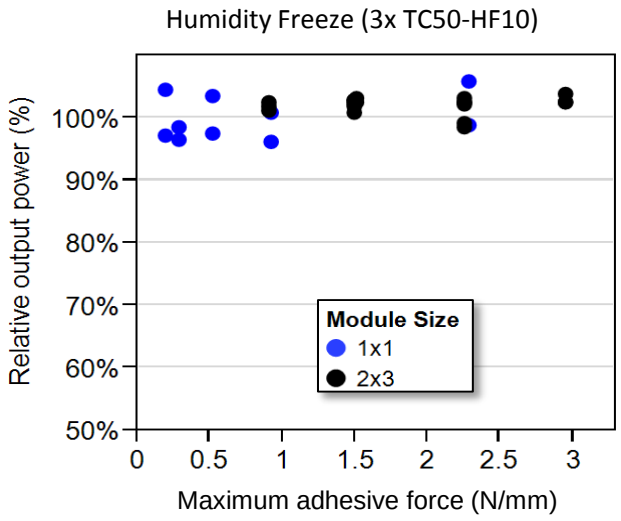


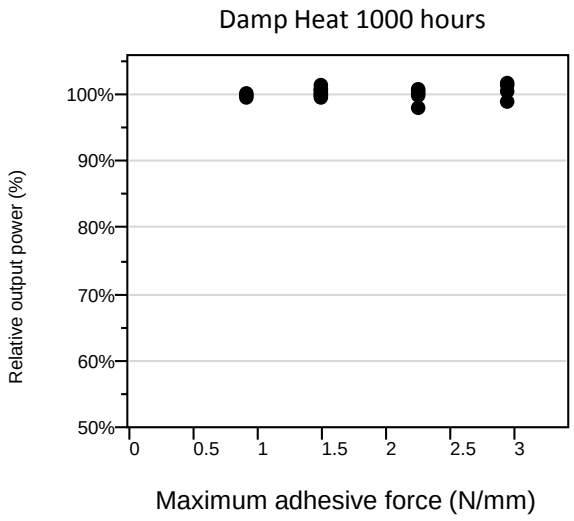




IEC Based Stress Testing

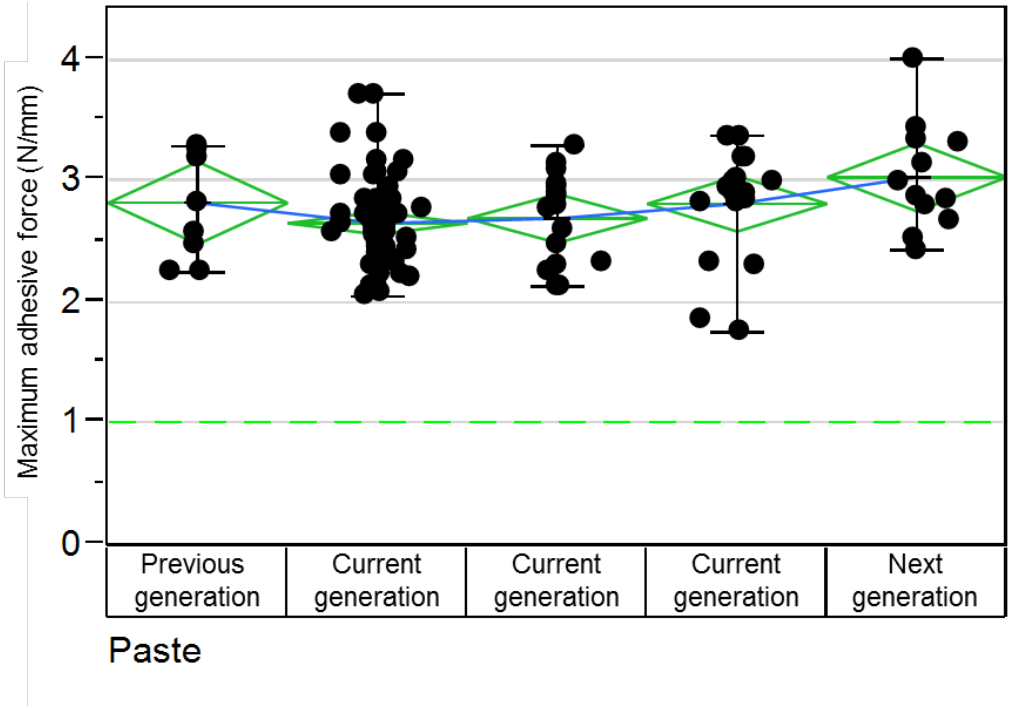






- Paste-driven adhesion does **not affect module durability** under Standard Tests
- Tests are currently extended (TC>500, Sequential testing, etc.)

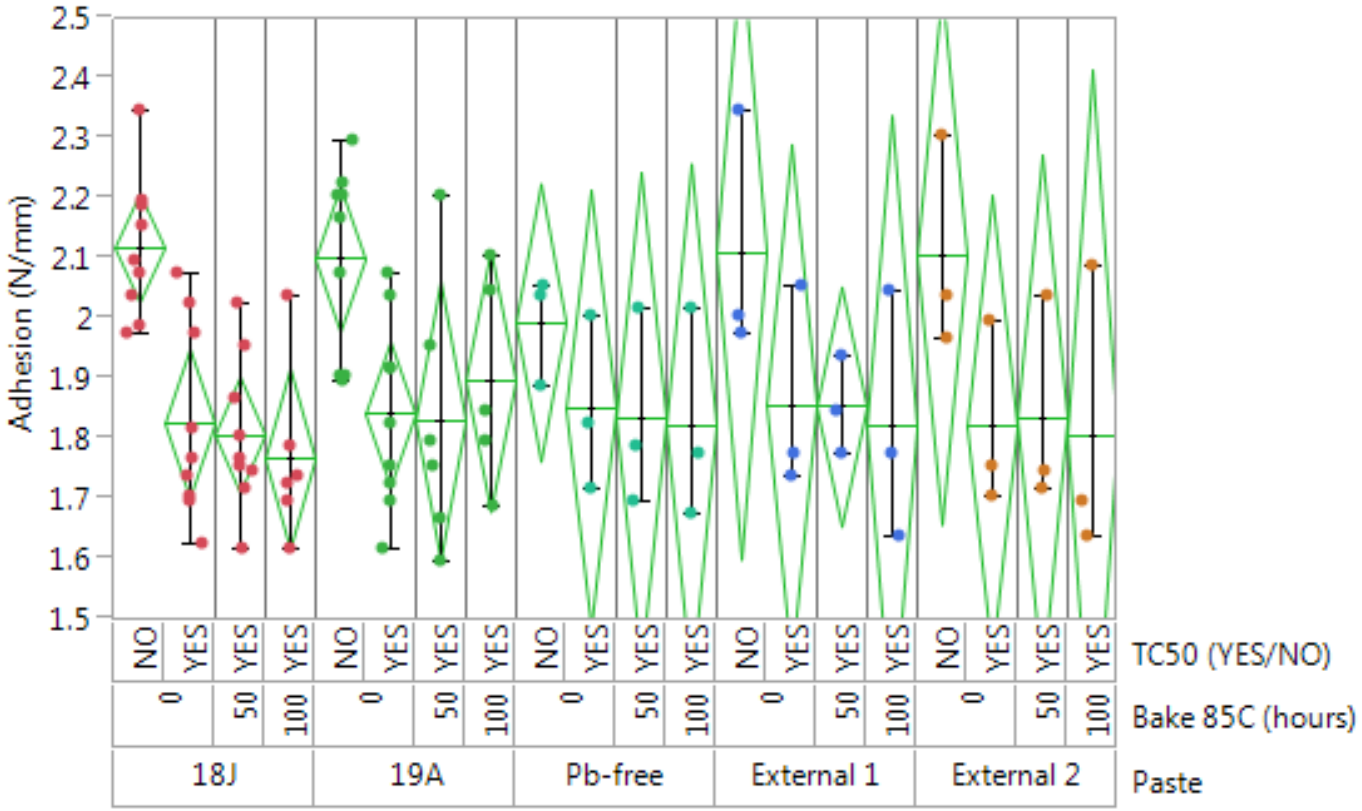
DuPont Pastes Show High Adhesion



✓ Adhesion for all DuPont pastes exceeds requirements considered safe for durability

Impact of High Temperature on Adhesion: 85ºC + TC50

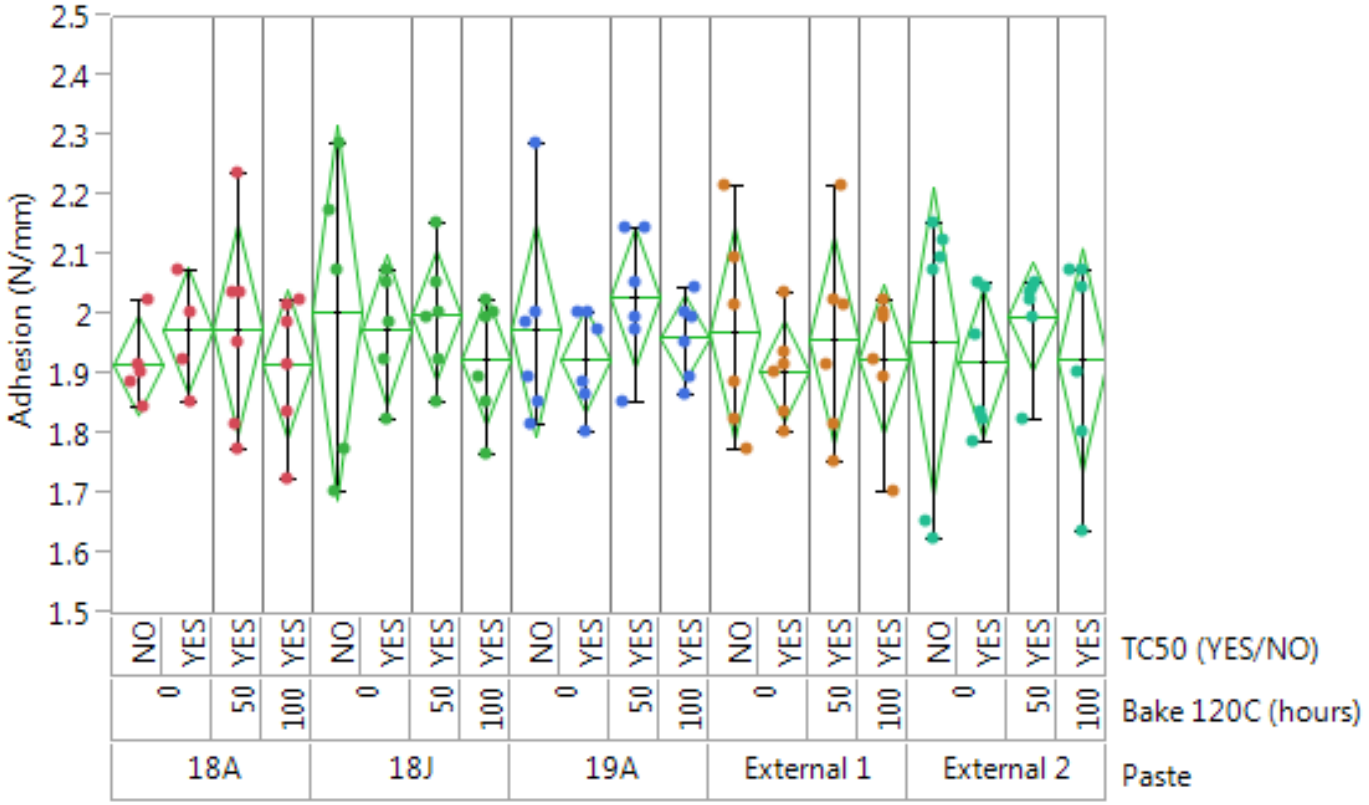
Bake at 85ºC for varying time, then measure adhesion



TC 50 does have an impact after 85ºC bake.
Still above 1N/mm for all pastes.
Does this infer long-term reliability?

Impact of High Temperature on Adhesion: 120ºC + TC50

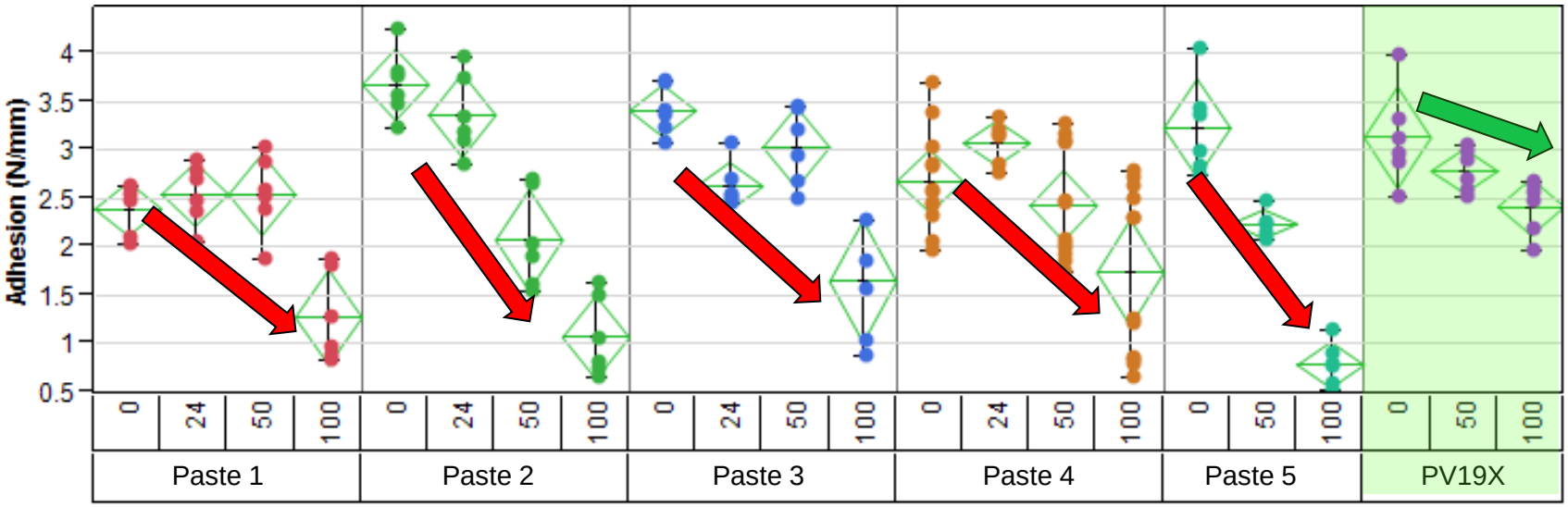
Bake at 120ºC for varying time, then measure adhesion



TC 50 doesn't have an impact after 120ºC bake?
Still above 1N/mm for all pastes.
Does this infer long-term reliability?

Impact of High Temperature on Adhesion

Borrowing from Microelectronics industry a test method
Bake at 150ºC for varying time, then measure adhesion



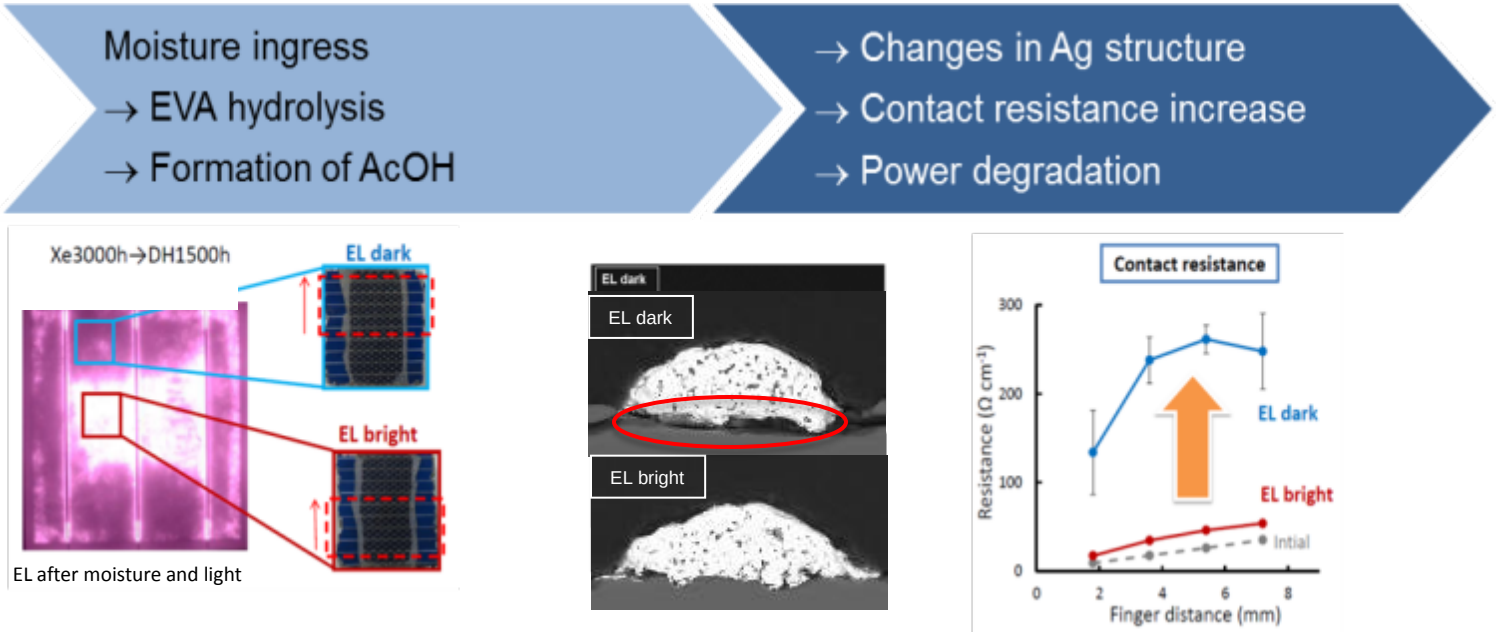
(Adhesion after exposure to 150℃ for varying durations)

The latest generation Solamet® PV19x retains highest adhesion after exposure to 150°C
Is this a fielded module accelerated relevant test?

Understanding and Control of Corrosion

Motivation:

- Corrosion is critical failure mode for pastes



Trang Ngo, 62th JSAP Spring Meeting, 2015

Goals:

- Assess **corrosion resistance of Solamet®** using relevant tests
- Understand effects and develop **superior pastes**

Summary

- **Adhesion:**
  - **DuPont** is studying role of metallization pastes for module durability.
  - **Adhesion of 0.9 N/mm** passes 3x IEC 61215.
  - **Paste-driven adhesion** component does not affect module durability under IEC-Based Test Conditions .
  - **All DuPont pastes** exceeds requirements considered safe for durability.
- **Aged Adhesion:**
  - 85°C followed by TC50: Change is seen; Why? Will this provide accelerated testing of metallization materials that is relevant?
  - 120°C followed by TC50: No change detected; Why? Is this relevant or applicable to the module with respect to long-term reliability?
  - 150°C followed by TC50: Big change seen; What is the reason? Is this relevant based on the multitude of data from the microelectronics world?
  - How will **metal contact corrosion** combined with **temperature cycling** affect reliability?
  - What will be the affect as **laydowns are further pushed down**?
  - Can we develop/adopt a relevant testing standard to **solve the time issue**?

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