ADHESION and THIN-FILM MODULE RELIABILITY

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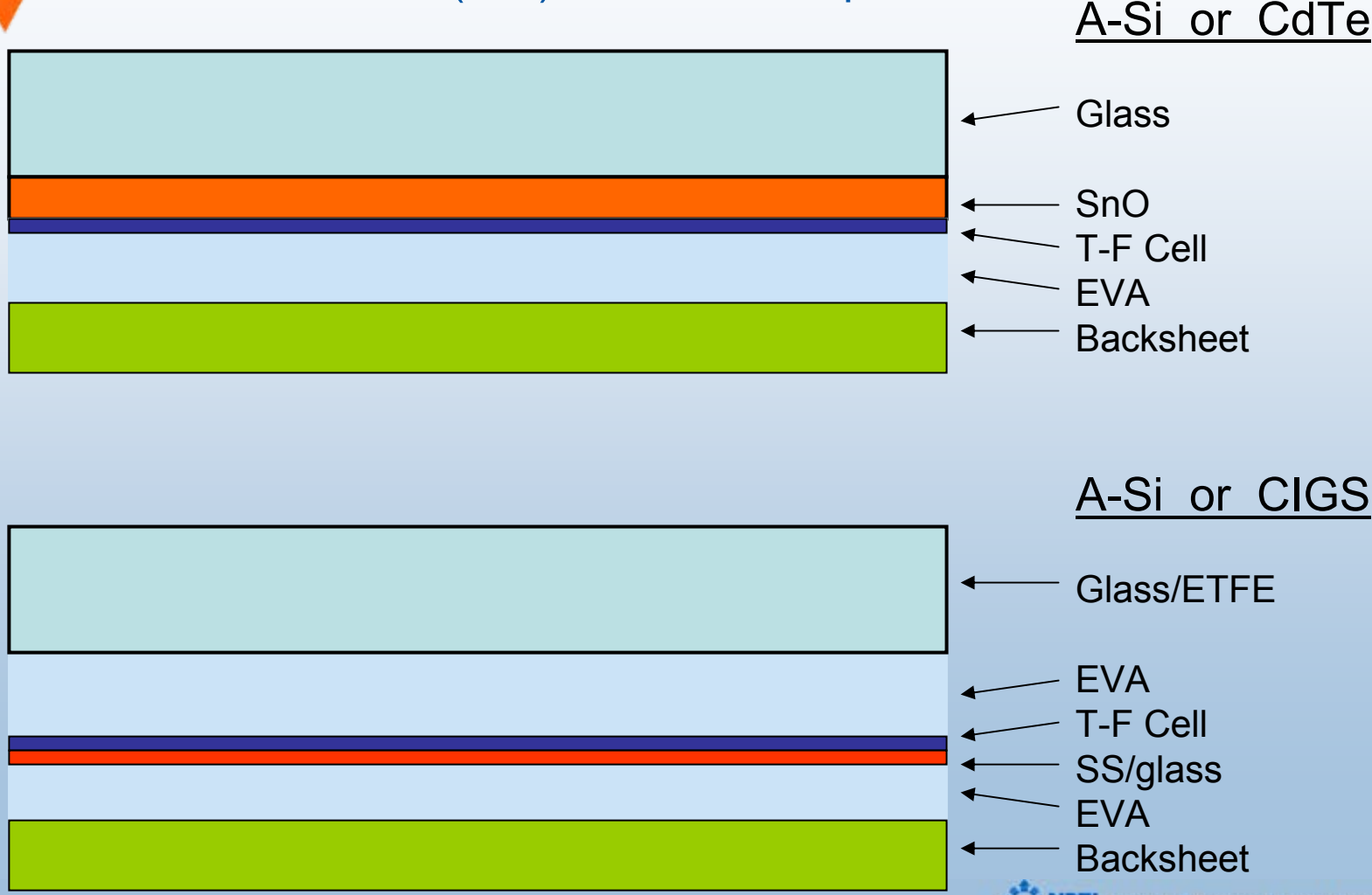
Outline

We measure the weakest adhesion between layers of various thin-film (T-F) modules/samples.



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- We measure the weakest interlayer adhesion between layers of various thin-film (T-F) modules/samples.
  - An Instron mechanical testing unit is used to measure peel strengths at 90° or 180° on laminations of three T-F technologies,
    - before and after damp heat / UV
    - and at elevated temperatures.
  - ASTM D3359 - scratch and tape pull test to evaluate cell adhesion strengths.

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  - In some cases, a scratch and tape pull test to evaluate inter-cell layer adhesion strengths.

- Measure effect of higher temperature and relative humidity (RH) adhesion/cohesion.

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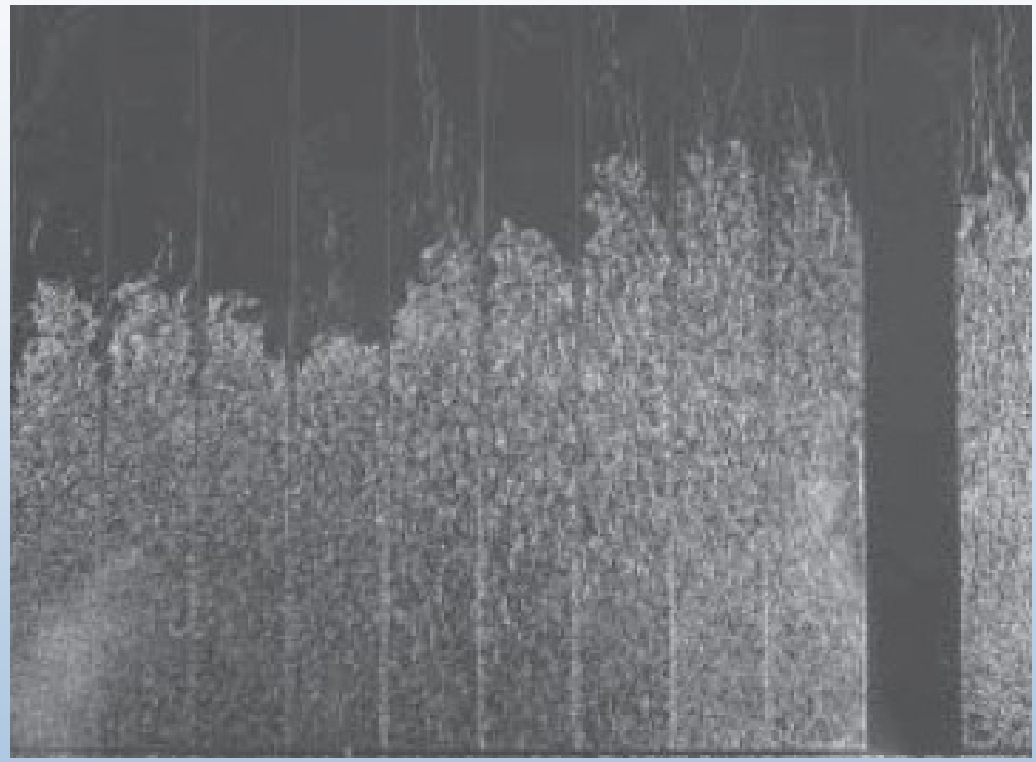
  - An Instron mechanical testing unit is used to measure peel strengths at 90° or 180° on laminations of three T-F technologies,
    - cell contact layers to glass,
    - contact layers to the semiconductor,
    - encapsulant to cell, glass, or backsheet, etc.
      - before and after damp heat / UV
      - in one instance at elevated temperatures.
  - In some cases, a scratch and tape pull test to evaluate inter-cell layer adhesion strengths.
- Effect of higher temperature and relative humidity (RH) adhesion/cohesion.
- Adhesion's effect on thin-film (T-F) module reliability.

SnO_2 Delamination

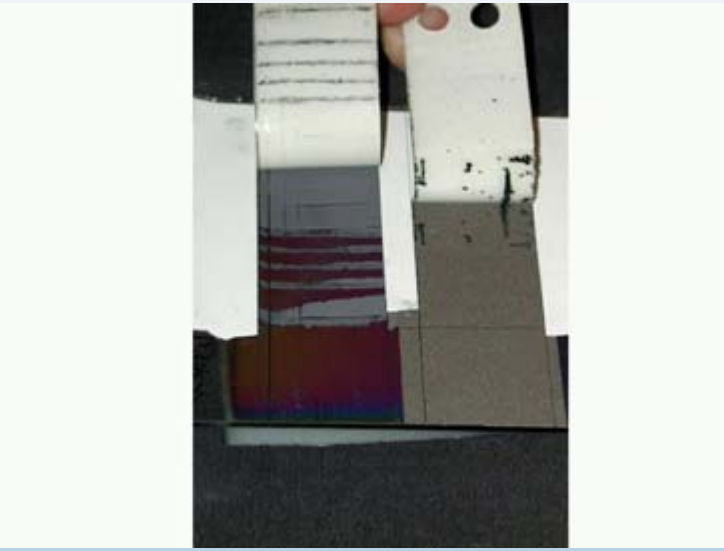


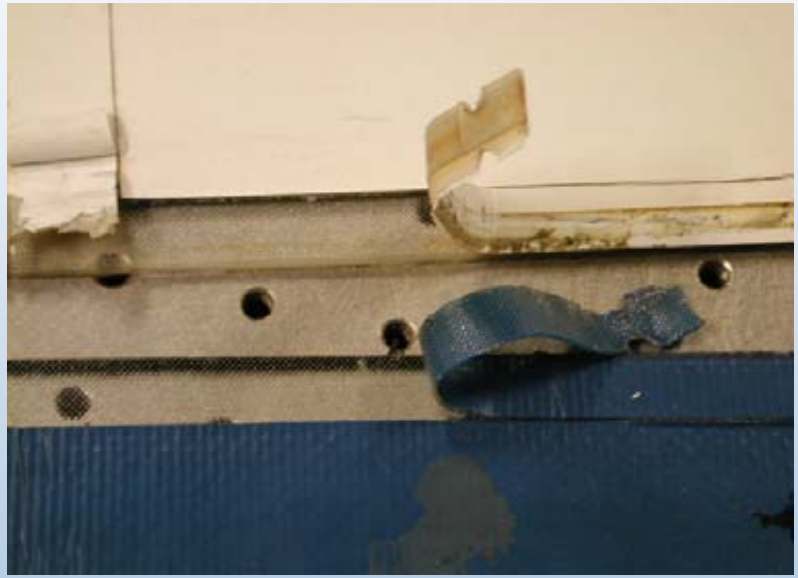
Cause: Heat, humidity, and high voltage,

Bubble-type Delamination

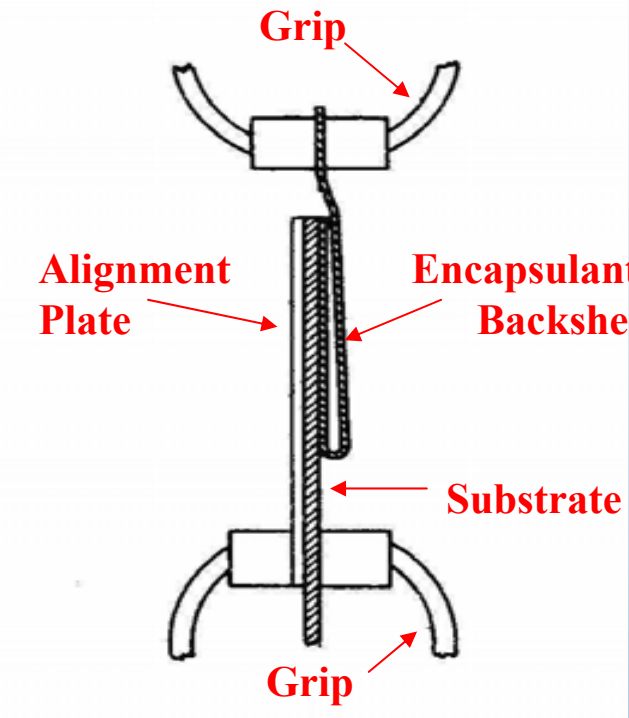
Cause: Heat and tensile stress.

Adhesion Pull Samples





Instron Peel Test



180 °

Adhesion Strength Table

Device: Source	Failure Interface	Weathering		Peel Strength (N/mm)
		Time	Type	
a-Si: A	EVA / a-Si	0	none	3.8
	EVA / a-Si	92 h	85/85	3.1
SiOxNy / Ni paste/ Graphite/ CdTe: B	EVA / SiOxNy	0	none	5.6
	SiOxNy / Ni paste	256 h	85/85	4.5

3-h dry-out after removal from 85° C/85% RH

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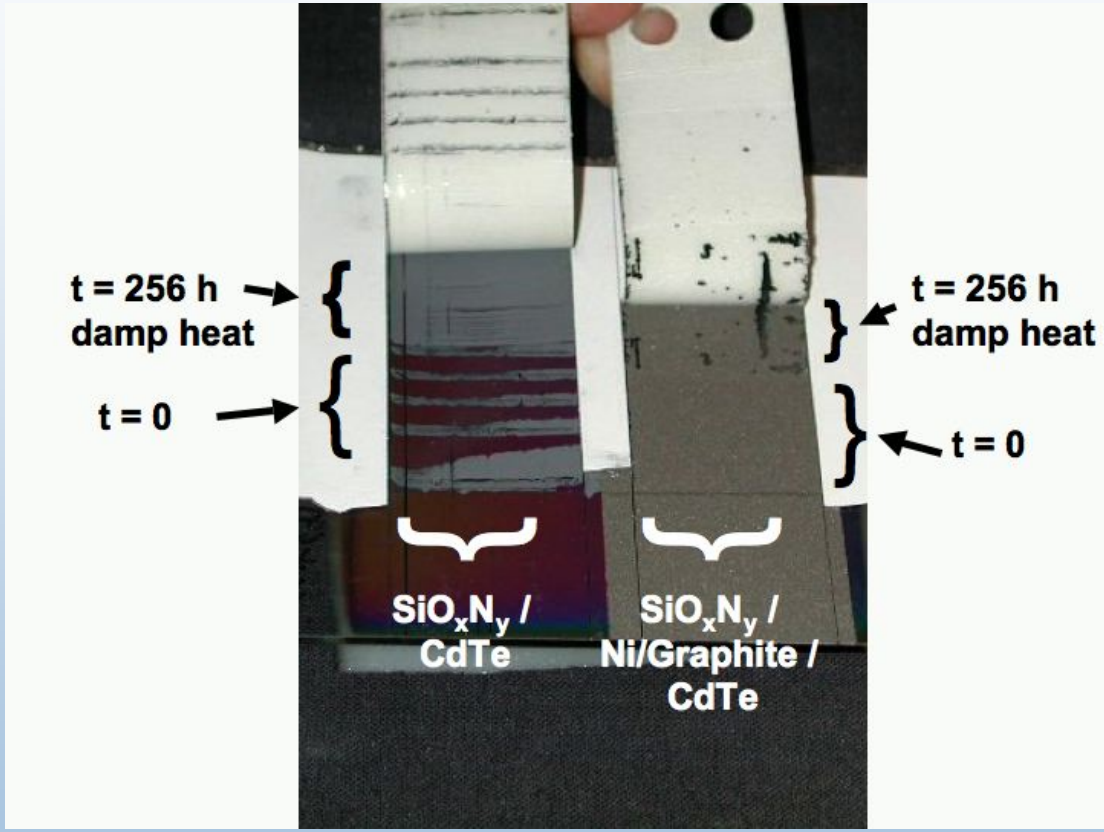
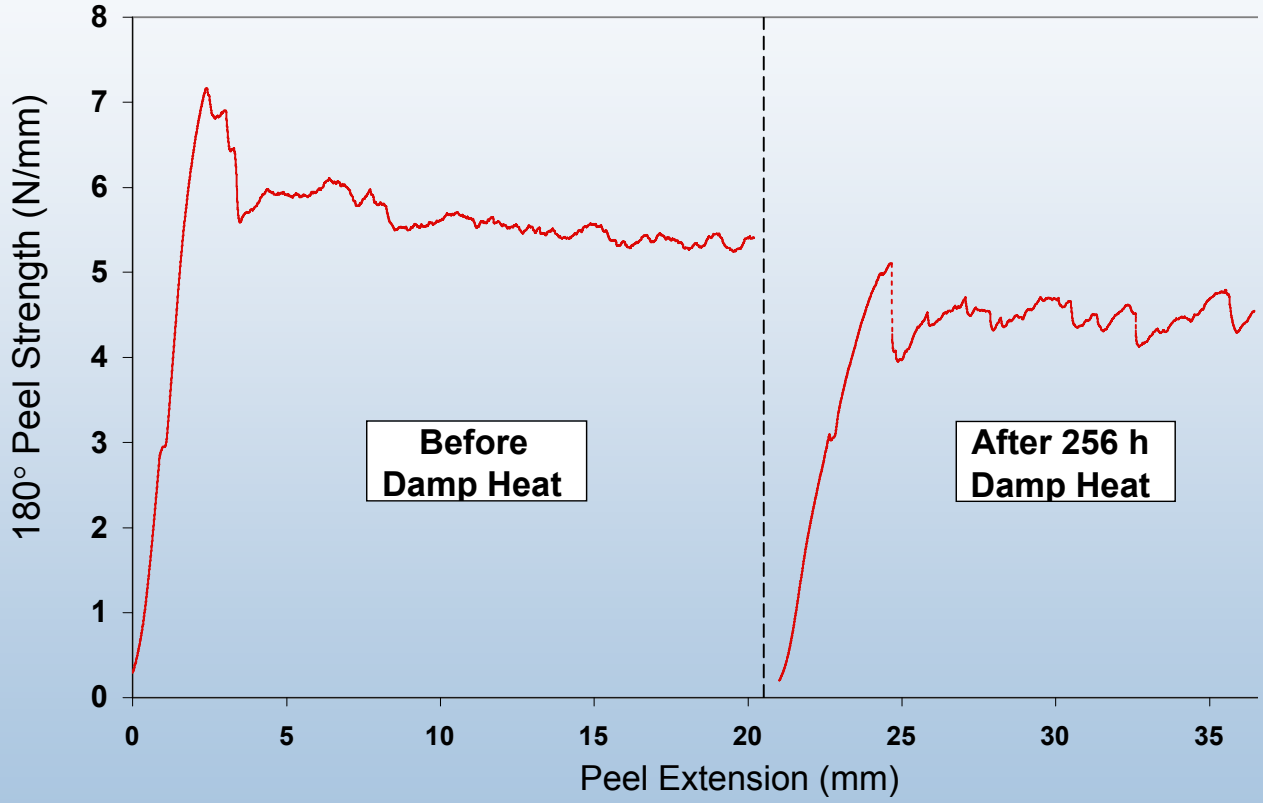
	SiOxNy / Ni paste	256 h	85/85	4.5
SiOxNy / CdTe: B	EVA / SiOxNy	0	none	7.0
	SiOxNy / CdTe	0	none	2.0
	SiOxNy / CdTe	256 h	85/85	0.3
SiOxNy / CdTe: C	EVA / SiOxNy	0	none	6.4
	EVA / SiOxNy	256	85/85	4.9
CdTe: C	EVA / Metal-CdTe	0	none	1.1
CdTe: C	EVA / Metal-CdTe	256	85/85	0.6
CdTe: C (left)	EVA / Metal-CdTe	0	none	1.0
(middle)	EVA / Metal-CdTe	0	none	0.7
(right)	Metal / CdTe	0	none	0.06
CIGS:D1	CIGS / Mo	0	none	0.05
CIGS:D2 60□C 80□C	EVA / CIGS EVA / CIGS EVA cohesive	0 0 0	none none none	7.0 1.1 0.05

Device: Source	Failure Interface	Weathering		Peel Strength (N/mm)
		Time	Type	
CIGS: E	EVA / CIGS	0	none	0.9
CIGS	CIGS / Mo	0	none	0.3
CIGS	EVA / CIGS	258 h	85/85	0.6
CIGS	Tefzel / EVA	258 h	85/85	0.02
CIGS	Stainless / EVA	258 h	85/85	0.5
CIGS	EVA / CIGS	7 mo	Cocoa, FL	0.8
CIGS	EVA / CIGS	16 mo	Golden, CO	0.9
CIGS	Stainless / EVA	16 mo	Golden, CO	0.8
TPE/EVA/ Glass: F control	EVA / Glass	0	none	5.5
	EVA / Glass	16 h	85/85	3.8
TPE/EVA/ Glass: F exposed	EVA / Glass	7 yr equal	UV lamp	2.0
	EVA / Glass	+ 16 h	85/85	1.5
Tedlar/EVA/ Glass: G control	EVA / Glass	0	none	3.2
	EVA / Glass	17 h	85/85	1.8
Tedlar/EVA/ Glass: G exposed	EVA / Glass	7 yr equal	UV lamp	0.4
	EVA / Glass	+ 17 h	85/85	0.4
Scotch Tape/Glass	Tape / Glass	0	none	0.08
ASTM Tape/Glass	Tape / Glass	0	none	0.4

CdTe:B cell peel tested



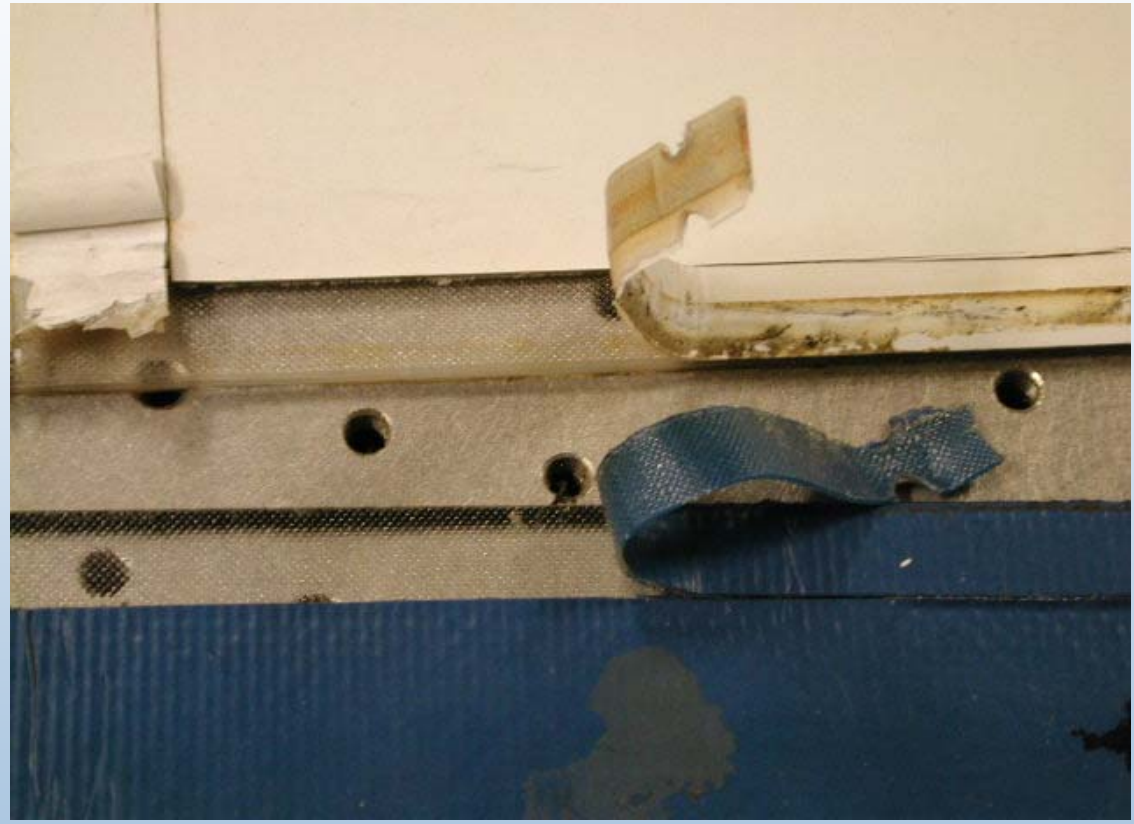
Instron peel data: CdTe cell



Instron peels: two Si-modules

F1, Control: 5.5 (N/mm)

G1, Control: 3.2 (N/mm)



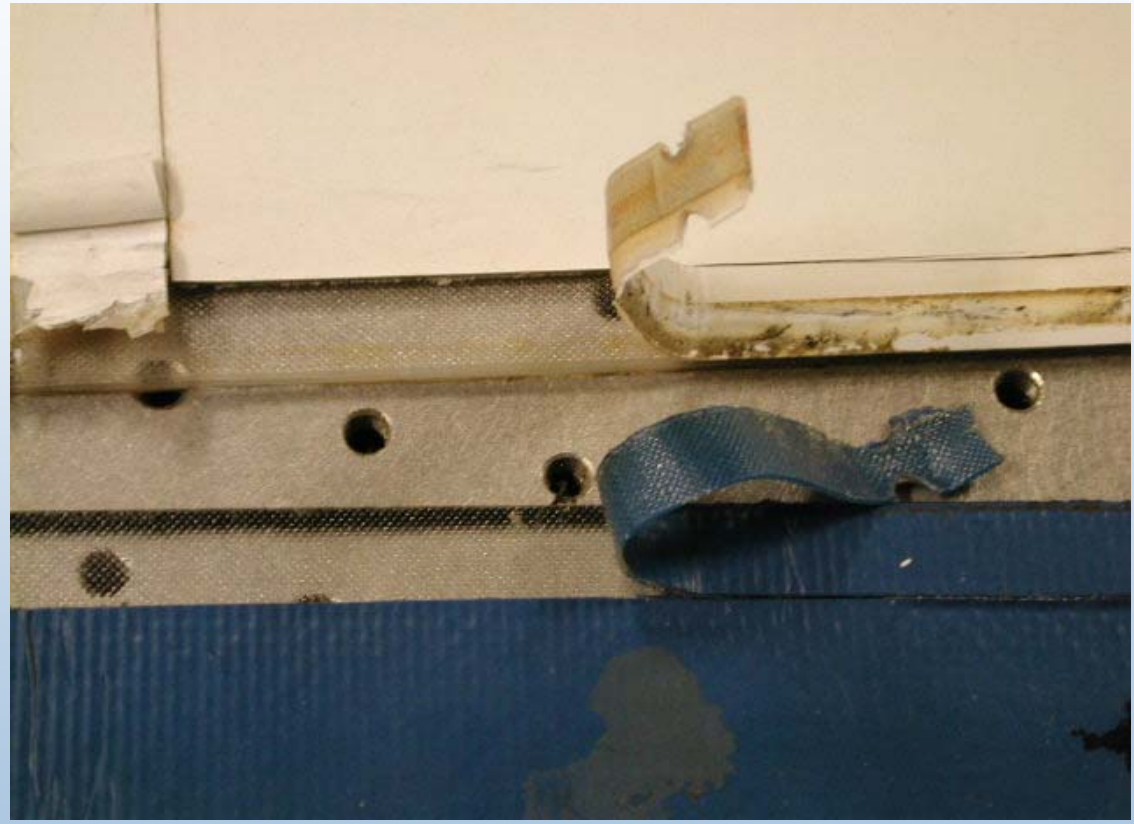
Instron peels: two Si-modules

F1, Control: 5.5 (N/mm)

F2, 7 yr UV: 2.0

G1, Control: 3.2 (N/mm)

G2, 7 yr UV: 0.4



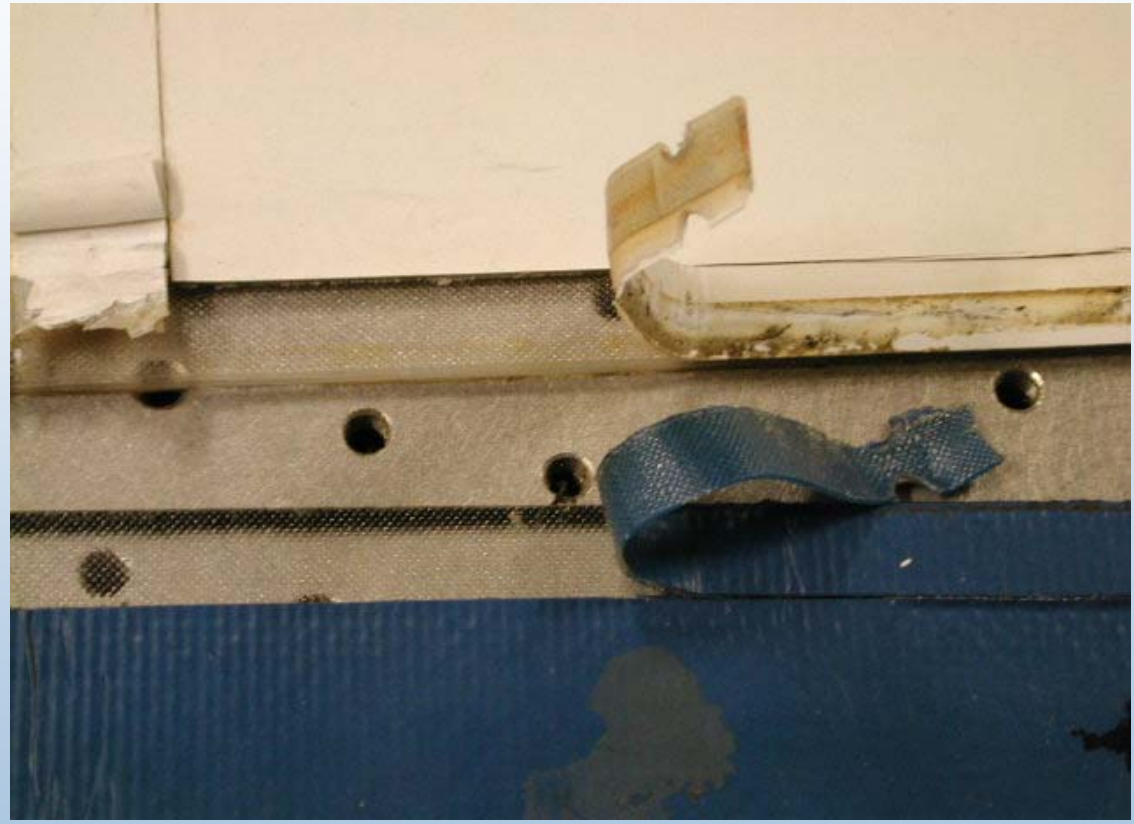
Instron peels: two Si-modules

F1, Control: 5.5 (N/mm)
Plus 16h DH: 3.8

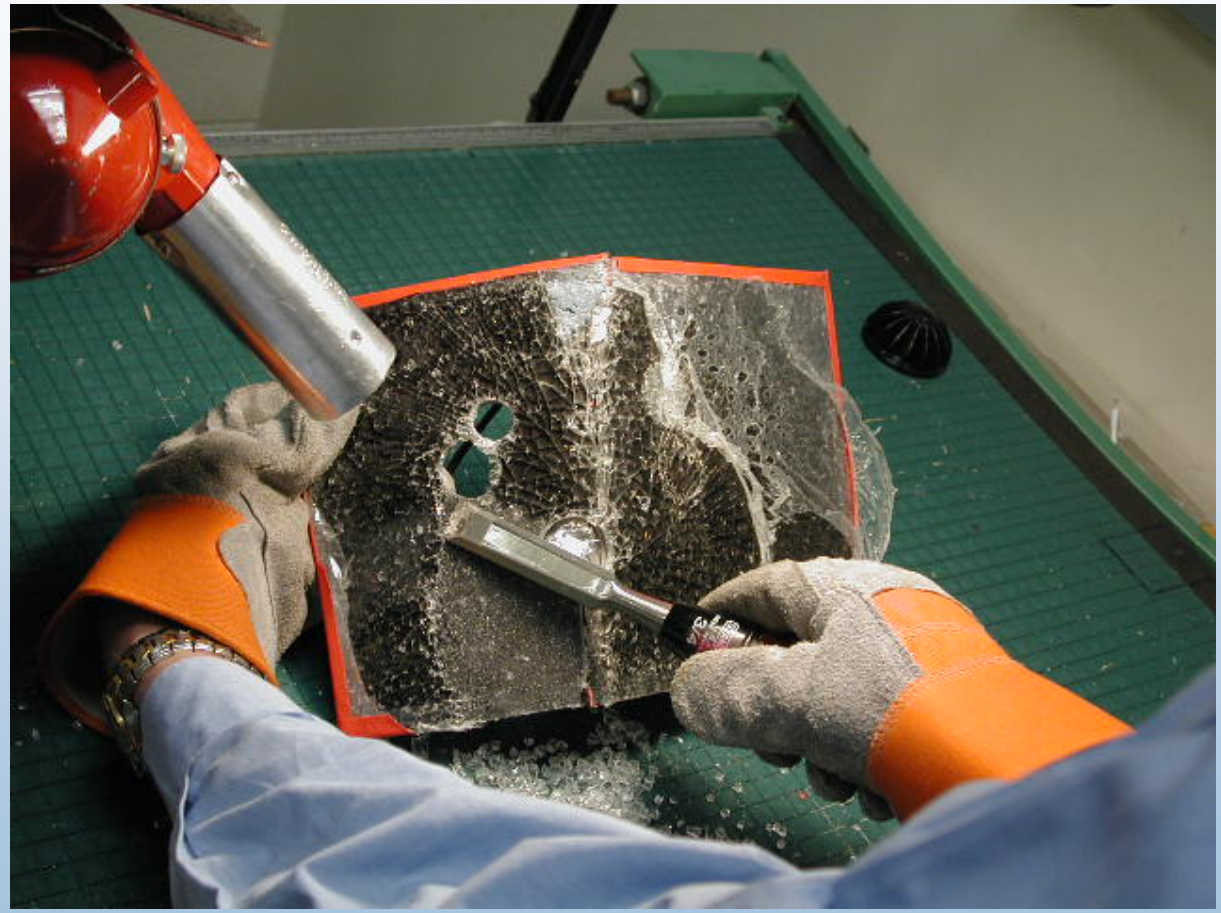
F2, 7 yr UV: 2.0
Plus 16h DH: 1.5

G1, Control: 3.2 (N/mm)
Plus 16h DH: 1.8

G2, 7 yr UV: 0.4
Plus 16h DH: 0.4



CIGS:D2 De-encapsulation



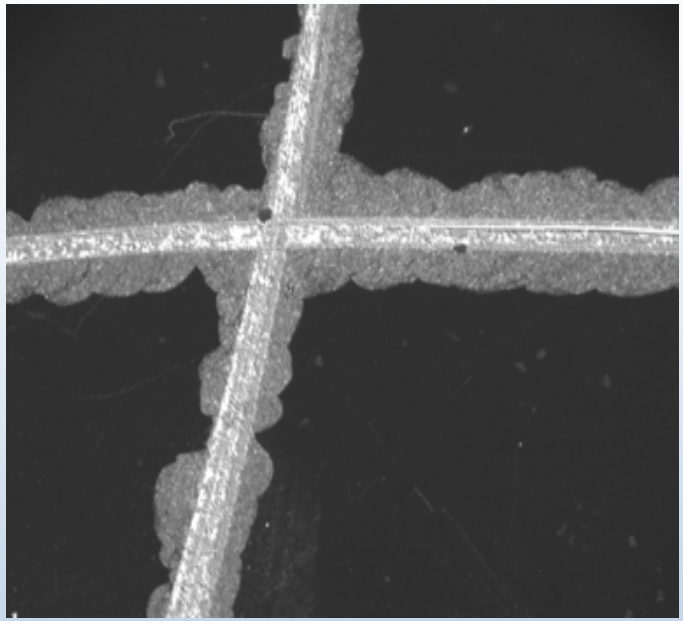
EVA Peel Strength vs. Temperature

CIGS:D2

Temperature	Failure	180° Peel Strength (N/mm)
25°C	EVA / CIGS	7.0
60°C	EVA / CIGS	1.1
80°C	EVA cohesive	0.05

Bubble-type Delamination

ASTM D 3359-02 scratch test



CIGS:D2

>7 N/mm

A lattice pattern is scratched into the coated surface with six or seven lines in each direction.

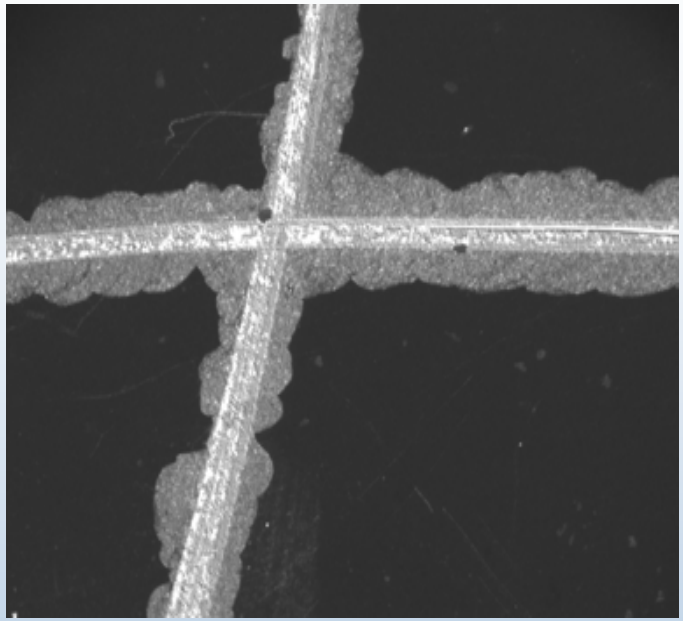
Any loose fragments are brushed away.

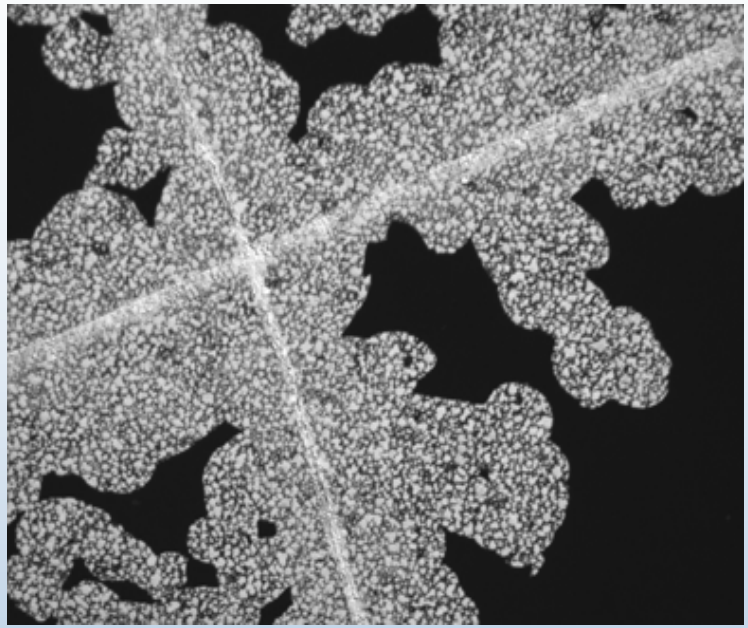
The ASTM qualified tape is pressed firmly to that area.

Within 30 to 90 s, the tape is pulled back at a 180° angle.

The ASTM-designated tape would exert a force of 0.4 N/mm on any cell material disturbed or loosened by the scratch

ASTM D 3359-02 scratch test





CIGS:D2

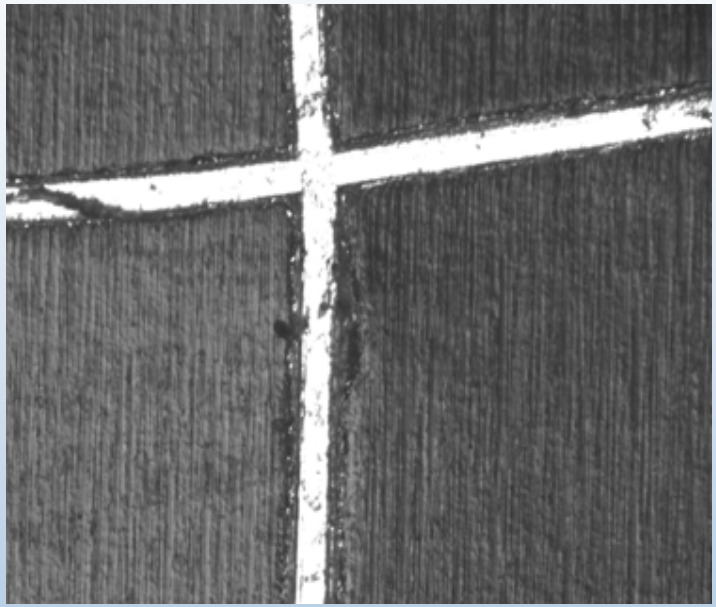
>7 N/mm

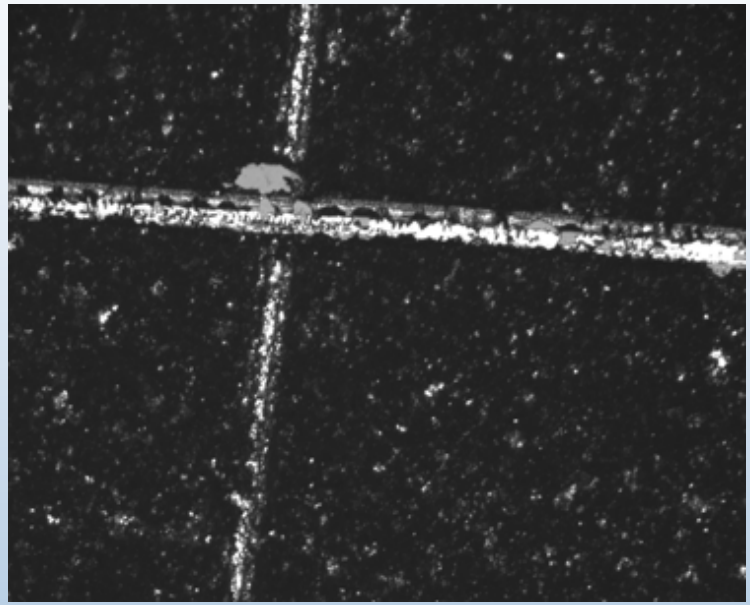
CIGS:D1

0.05 N/mm (CIGS/Mo)

Tarrant, D. E.; Gay, R. R. (1995). Research on High-Efficiency, Large-Area $CuInSe_2$-Based Thin-Film Modules: Final Subcontract Report, 16 August 1993 - 30 June 1995. 99 pp.; NREL Report No. TP-413-8121. (83014.PDF)

ASTM D 3359-02 scratch test





a-Si:A

> 3.8 N/mm

CdTe:B

> 5.6N/mm

Summary

- Measured interface peel strength values of various T-F module technologies and how they are affected by environmental stress; some were quite low.

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- Adhesion at higher T and RH, and after extended UV and RH exposure show a reduction in strength.
  - Minimum adhesion strength defined at higher T and RH.
  - The softening of EVA near 85 °C can lead to failure.

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Measured interface peel strength values of various T-F module technologies and how they are affected by environmental stress; some were quite low.

Adhesion at higher T and RH, and after extended UV and RH exposure show a reduction in strength.

A minimum adhesion strength defined at higher T and RH.

The softening of EVA near 85 ° C can lead to failure.

Achieve highest adhesion possible for corrosion and water ingress reduction.

Summary

- Measured interface peel strength values of various T-F module technologies and how they are affected by environmental stress; some were quite low.
- Adhesion at higher T and RH, and after extended UV and RH exposure show a reduction in strength.
  - A minimum adhesion strength perhaps at higher T and RH.
  - The softening of EVA near 85 °C can lead to failure.
- Achieve highest adhesion possible for corrosion and water ingress reduction.
- Interlayer adhesion in a T-F cell can be quite small and within a T-F technology the ASTM D 3359-02 “Measuring Adhesion by Tape Test” can be useful as a screening test.