



Module Technology: Current Practice and Issues



**MRS Workshop on
Photovoltaic
Materials and
Manufacturing Issues**

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PURPOSE OF MODULE PACKAGE

- **Mechanical support – hold the cells in place pointing toward the sun.**
- **Dielectric protection – keep high voltage away from people and keep current from flowing out of the array circuit (to ground or in a loop).**
- **Protect the cells, diodes and interconnects from the weather (UV, rain, humidity, hail etc.)**
- **To couple as much light energy as possible into the solar cells (at all angles at the wavelengths that the cell can utilize).**
- **To minimize the temperature increase of the cells.**

Module Package Should

- Be qualified to IEC 61215 or 61646.
- Be safety certified to UL 1703 if being sold in US.
- Be safety certified to IEC 61730 parts 1 and 2.
- Have at least a Class C fire rating if it is going to be used on a building.
- Carry an extended warranty. (25 years is typical for crystalline silicon – would expect at least 20 years for a thin film product)

TYPICAL CONFIGURATIONS

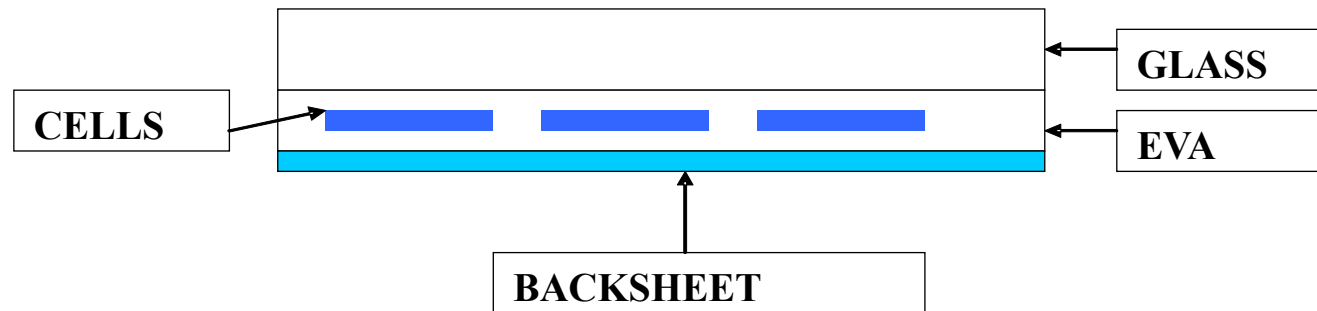
Glass Superstrate

- **Glass/encapsulant/cells/encapsulant/backsheet**
- **Glass/thin film cells/encapsulant/backsheet**
- **Glass/encapsulant/thin film cells/glass or other substrate**

Flexible

- **Transparent frontsheet/encapsulant/thin film cells/flexible substrate**

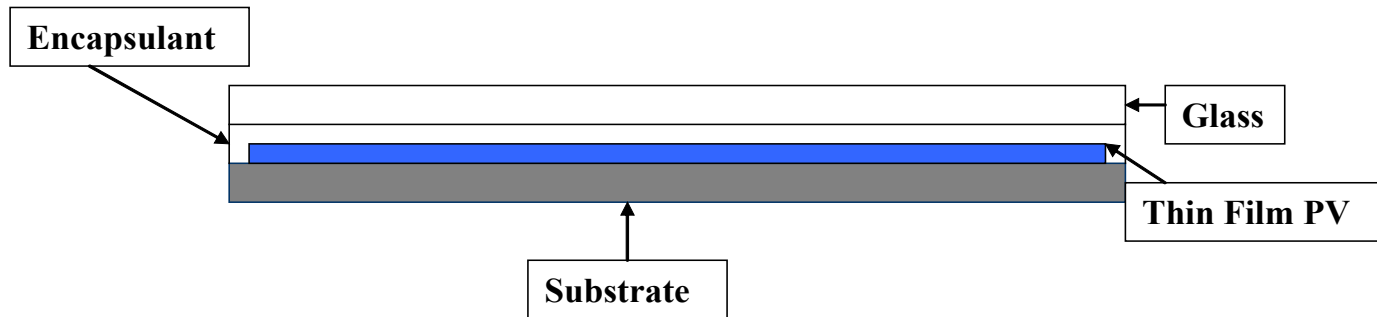
Glass/encapsulant/cells/encapsulant/backsheet



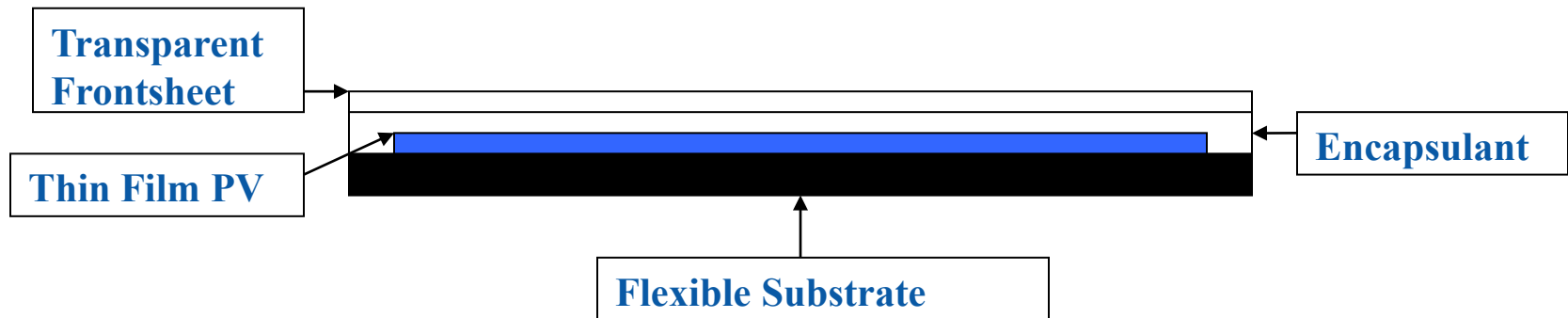
Glass/thin film cells/encapsulant/backsheet



Glass/encapsulant/thin film cells/substrate



Transparent frontsheet/encapsulant/thin film cells/flexible substrate



Typical component selection for Cr-Si

- **Superstrate – Glass**
- **Substrate or Backsheet – Tedlar and /or PET**
- **Encapsulant – EVA**
 - (also PVB, TPU and Ionomers)
- **Edge Seal – usually none**

Typical components for Thin Films

- **Superstrate – Glass**
- **Substrate - Glass**
- **Encapsulant – EVA**
 - (also PVB, TPU and Ionomers)
- **Edge Seal – PIB (polyisobutylene) with additives**

Status of Packaging Technologies – Cr Si

- More than 20 years of field experience with the present package.
- Modules easily pass the IEC 61215 Qualification Test
- EVA discoloration from 1990's appears to have been solved, but must be revisited every time a new EVA formulation or supplier appears.
- Adhesion of encapsulant to glass and backsheet appears adequate for 25 year life as long as processing is under control.
- Annual module degradation rates of $< 0.5\%$ per year are being reported.

Status of Packaging Technologies – Thin Films

- **Edge seals appear to do a good job of keeping moisture away from sensitive thin film layers.**
- **Most modules pass the IEC 61646 Qualification Test**
- **Recent thin film modules appear to suffer much less degradation than earlier types.**
- **Many thin film modules are now sold with a 25 year power warranty, matching today's crystalline silicon modules.**

Issues

- **Cost** – We would like to reduce module cost so lower encapsulant material cost and process costs would be an advantage.
- **Minimize degradation rate** – Understand why today's modules are degrading and reduce or eliminate the degradation.
- **Lifetime** – **Why stop at 25 years?** Can modules be built to survive 40 or even 50 years?

Evaluating Cr-Si for Improving Performance

- With Cr-Si most known failure mechanisms are evaluated using the accelerated tests within the qualification sequence.
- To assess long term performance the test durations must be increased considerably.
- When that is done, good quality crystalline Si modules can survive 10 times as many thermal cycles as the qualification test calls for with minimum degradation.
- UV testing using the methodology developed by STR to study EVA discoloration shows that today's formulations do not suffer discoloration or optical loss over levels that STR estimated was equivalent to 25 years of outdoor exposure.
- On the other hand after 2 to 3 times as much damp heat exposure, EVA encapsulated Cr-Si modules with breathable backsheet start to suffer severe degradation of fill factor and output power.
- So it appears that moisture induced degradation is likely to be one of the mechanism that leads to module failure and may be a major culprit in the power degradation observed in today's modules.

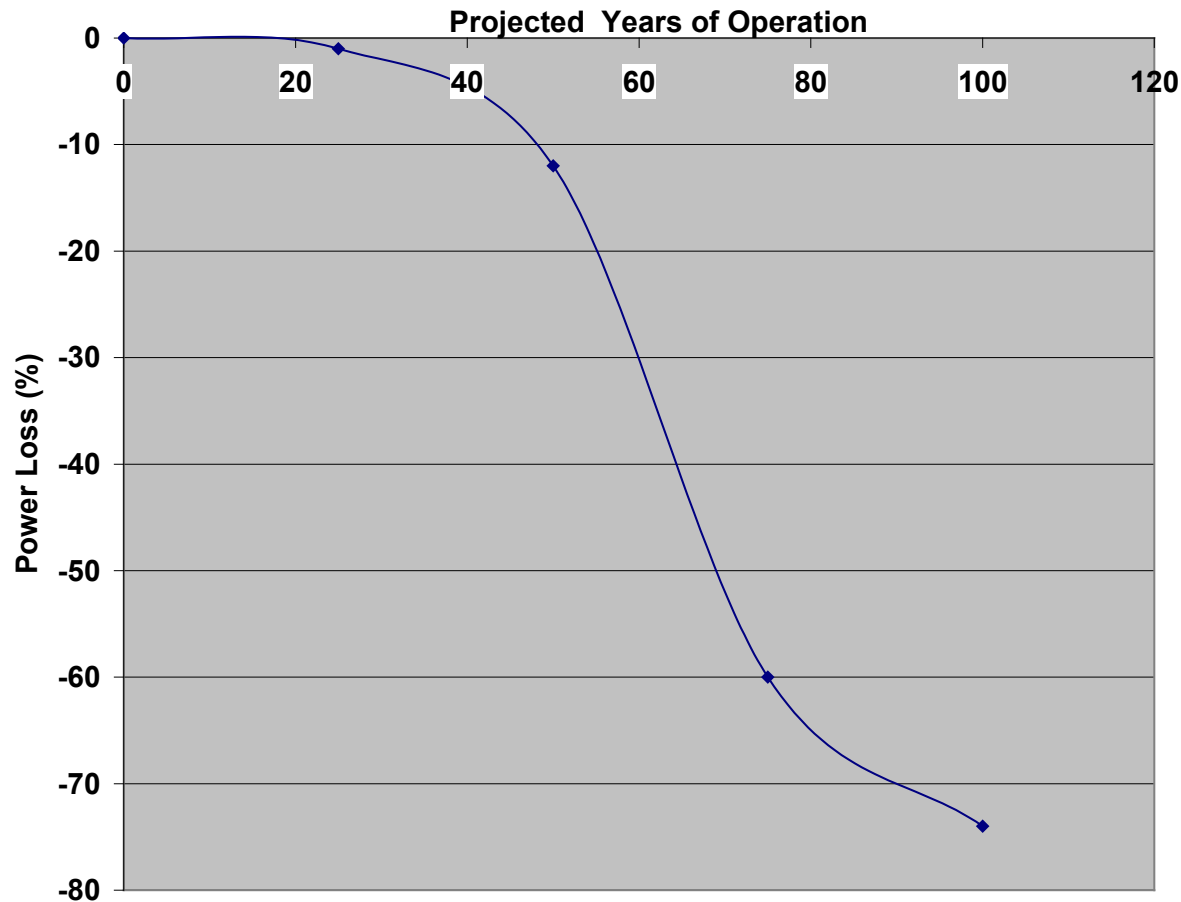
Long Term Thermal Cycle Testing

200 Cycles = 10 Years in Golden, CO

Thermal Cycles	Module A Pmax (W)	Module A % Change in Pmax	Module B Pmax (W)	Module B % Change in Pmax	Module C Pmax (W)	Module C % Change in Pmax
Start	165.3		159.5		161.6	
500	161.3	-2.49%	158.1	-0.9%	160.6	-0.6%
1000	163.1	-1.3%	159.1	-0.3%	160.7	-0.5%
1500	158.9	-3.9%	157.3	-1.4%	159.3	-1.4%

Damp Heat Induced Degradation

Based on 20 Years = 1000 hours at 85 C/85% RH



Extending Test Duration for Cr-Si Modules Qualified to IEC 61215

Manufacturer	DMLC/TC/HF	1250 Hr DH	500 TC
A	Pass	Fail	Fail
B	Pass	Fail	Pass
C	Pass	Fail	Fail
D	Pass	Fail	Pass
E	Pass	Fail	Pass
F	Pass	Pass	Pass
G	Pass	Fail	Pass
H	Pass	Pass	Pass
J	Pass	Fail	Pass
K	Pass	Pass	Pass

Cr-Si Performance – Replacing EVA

- We can replace EVA with alternate encapsulant like silicone, urethane, or ionomer. This has its own issues:
 - Cost –most cost more than EVA
 - Long term reliability – do we trade one problem for another?
 - Degradation rate – Will the change improve the overall degradation rate?
- **Some preliminary data indicates that with use of silicone encapsulants Cr-Si modules do not suffer long term degradation in damp heat.**
- The main issue with using a new encapsulant is the lack of long term field data and its correlation with the accelerated tests.
- Without the field data we can never be 100% sure that the new material will work better (or even match) the performance of the EVA.

Cr-SI Performance – Improving EVA

- An alternate route to improving lifetime and reducing degradation rates is to figure out why/how the cells degrade in EVA after long term damp heat and then to alleviate the problem.
- Historically degradation of cells in EVA has been attributed to generation of acetic acid and its attack upon the cell metallization system. But there are 2 problems with this explanation:
 1. There is no visual evidence of corrosion of the front grid lines after long term damp heat testing even though fill factors are reduced.
 2. Experiments from 1980's indicated that neither acetic acid nor acetic acid vapors attacked the grid lines on solar cells.

Cr-SI Performance Improvements

We have 2 possible routes to improve the package

- Replace EVA with an encapsulant that allows the module to survive long term damp heat and then see if these modules actually perform better in the field.
- Determine the damp heat degradation mechanism in EVA modules and develop improvements to the system to stop the degradation.

Today we should be trying both because it is not clear which will lead to longer module lifetime and low degradation rates.

Issues for Newer Technologies

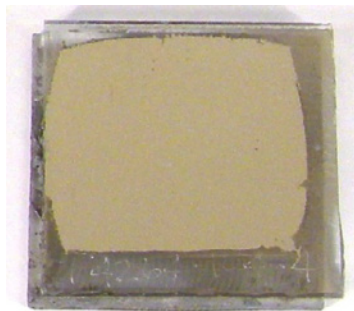
- What about those PV technologies that do not have 20 or 25 years of field experience?
- Does passing the qualification test prove that the modules will survive for 20 or 25 years?
- **No, because we do not know what failure mechanisms are likely to occur in these products over this time period.**
- Without knowing the failure mechanisms it is not possible to identify the stress tests necessary to evaluate the product.

Polyisobutylene Edge Seals - Slow Ingress of Moisture

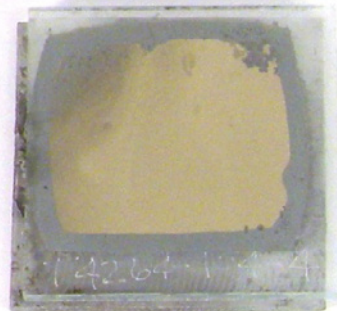
Thanks to Mike Kempee - NREL

Delaminations

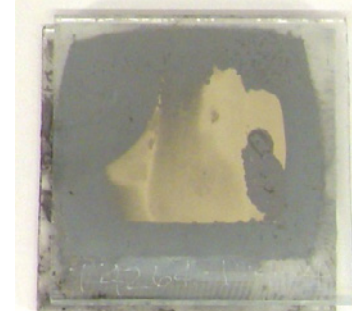
PIB #1



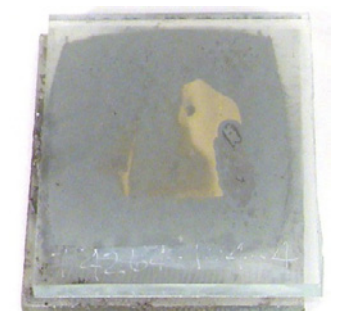
0 h



163 h



652 h



1230 h

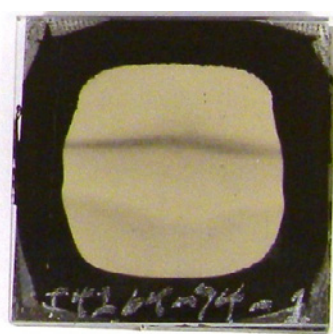
Ca Detector Exposed to 85 C/85% RH

Reactions

PIB #2



0 h



1490 h



2780 h



4664 h

Evaluating Thin Films for Improving Performance

So the major issues with today's thin film products are:

- What is the expected lifetime?
- What degradation rates will the modules experience?
- Will the edge seals survive for 25 years and continue to provide the necessary protection to the moisture sensitive components

TF needs:

1. **Data on what failure mechanisms are occurring.**

This is exactly the type of information that is not being supplied by the large commercial thin film module manufacturers!

2. **Accelerated test procedures that adequately stress edge seals.**

Do we have to develop these tests or can we borrow them from a related industry (for example from IGUs)?

SUMMARY

- As the volume of the PV market grows the issues of module lifetime, failure rates and degradation rates become more important.
- These issues represent financial risk to PV investors.
- Quantifying the risk levels and implementing solutions to improve the performance are key to the overall commercial success of PV.