Optimized Module Packaging for Silicon Heterojunction Solar Cells and Increased PID Resistance

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1. Potential Induced Degradation (PID)

Potential-Induced Degradation (PID) - potential difference between grounded frame and cell.

→ showed as severe performance loss on PV modules (70-80% and even more in worst cases).

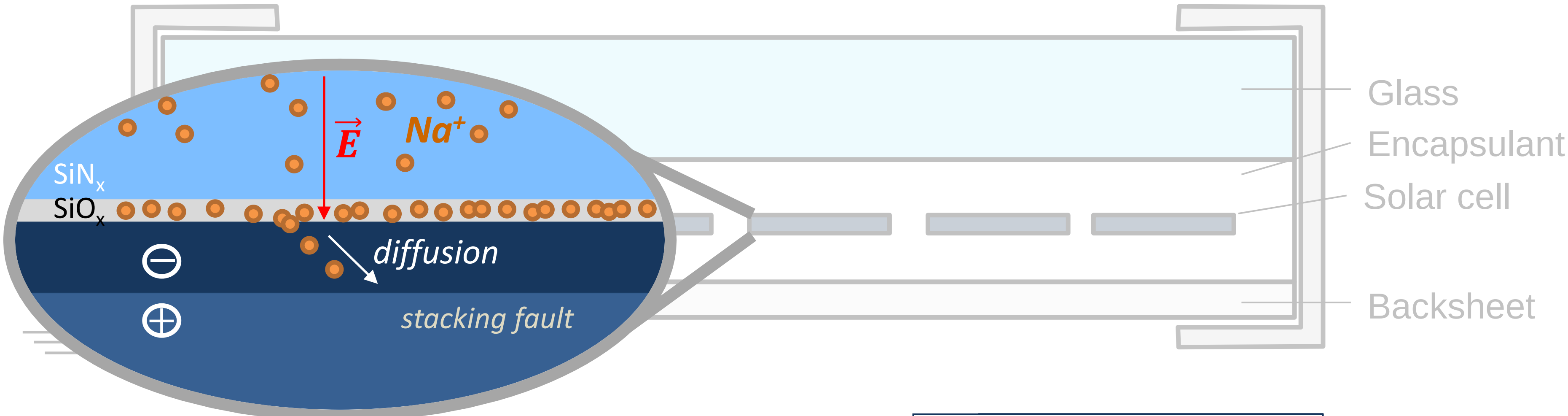
Factors:

- Cell technology (standard p-type/n-type c-Si and thin-film technologies).
- Climatic conditions (temperature, humidity...).
- Voltage polarization (positive or negative).
- Module materials.

1. PID in conventional c-Si modules

PID in standard p-type c-Si solar cells → negative voltage between frame and cell.

- Leakage current drives positive ions (Na^+) from e.g. glass to cell, causing reduction of shunt resistance.



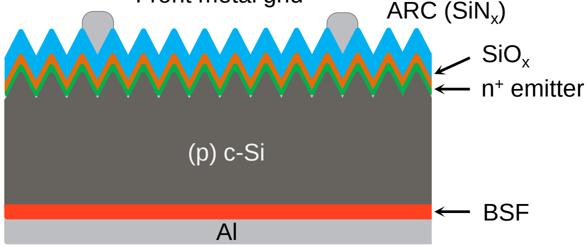
V. Naumann et al., SolMat (2014)

Solutions:

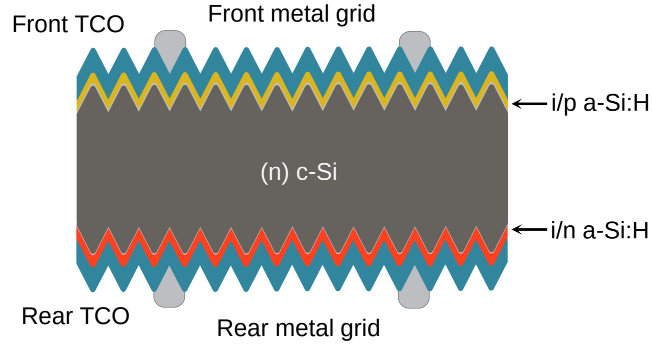
- PID-free cells
- High-volumen resistivity encapsulants (e.g. polyolefins).
- Special glass with reduced Na content
- …

1. PID in Silicon Heterojunction (SHJ) modules

Al-BSF



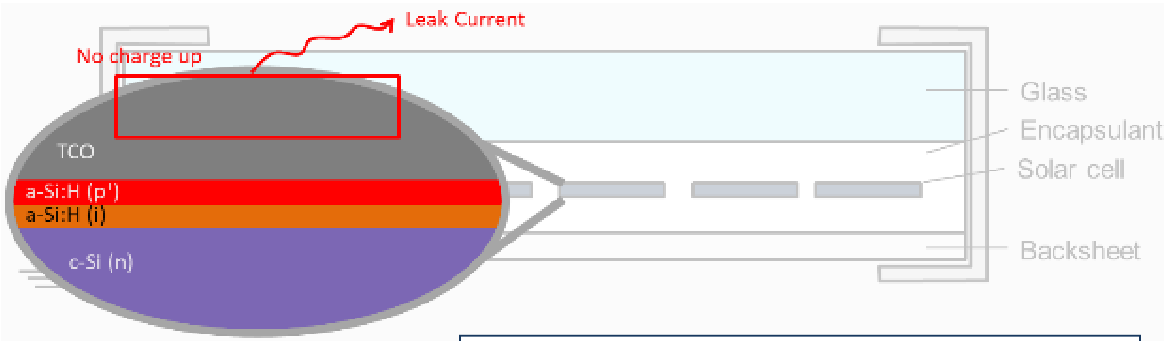
SHJ



- Better passivation
- ↓ Processing temp.
- ↓ Thickness, ↓ cost
- ↑ V_{OC}
- ↓ Temp. coefficient

PID: thought to be PID-free until very recently [1].

- 2018 (JAIST) → degradation of TCO due to precipitation of metallic In in the IWO [2].
- Very dry conditions (<2% RH) – not representative of outdoor environmental conditions.



T. Ishiguro et al., PV Reliability Workshop (2013)

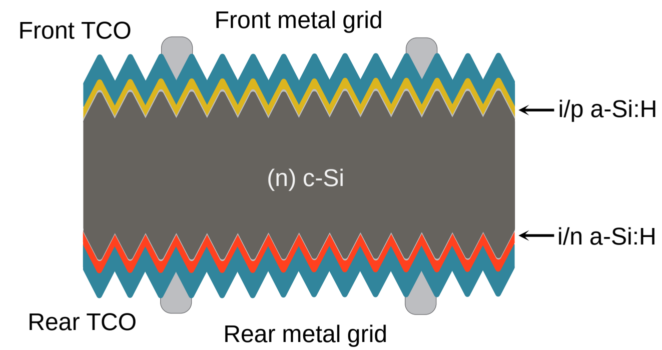
We study PID in SHJ solar cells with:

- **Cost-effective materials → EVA**
- **A focus on the effect of humidity**

[1] *T. Ishiguro et al., PV Reliability Workshop (2013)*
[2] *Yamaguchi et al., Prog. Photovolt. (2018)*

2. Experimental Work

Temperature / RH	Module Configuration	Voltage
85°C / 85 %	G/G	-1000 V (x2)
		0 V (x2)
		+1000 V (x2)
	G/G – ES	-1000 V (x2)
		0 V (x2)
		+1000 V (x2)



Encapsulant used: high volumen resistivity ethylene-vinyl acetate (EVA)

SHJ solar cells

G/G: glass/glass
G/G-ES: glass/glass with edge sealant

G/G

G/G - ES

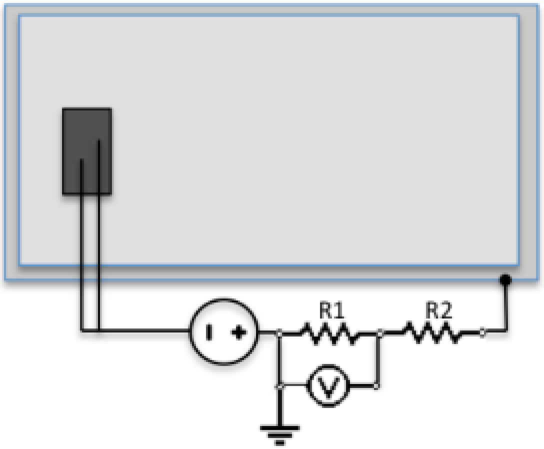
2. Experimental work – PID Test Setup

Climatic Conditions		
Temperature [°C]	Relative Humidity [%]	Time [h]
85	85	96 +

IEC TS 62804-1:2015:
60°C/85°C, 85% RH, 96h

Electrical Conditions:

- 1-cell mini-modules in short circuit
- -1000 V/+1000 V applied
- Frame grounded (0 V)
- **Leakage current** measured by voltmeter across resistor R1



P. Hacke et al., IEEE PVSC (2011)

3. Results – Module Level

Temperature / RH	Module Configuration	Voltage
85°C / 85 %	G/G	-1000 V (x2)
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	G/G – ES	-1000 V (x2)
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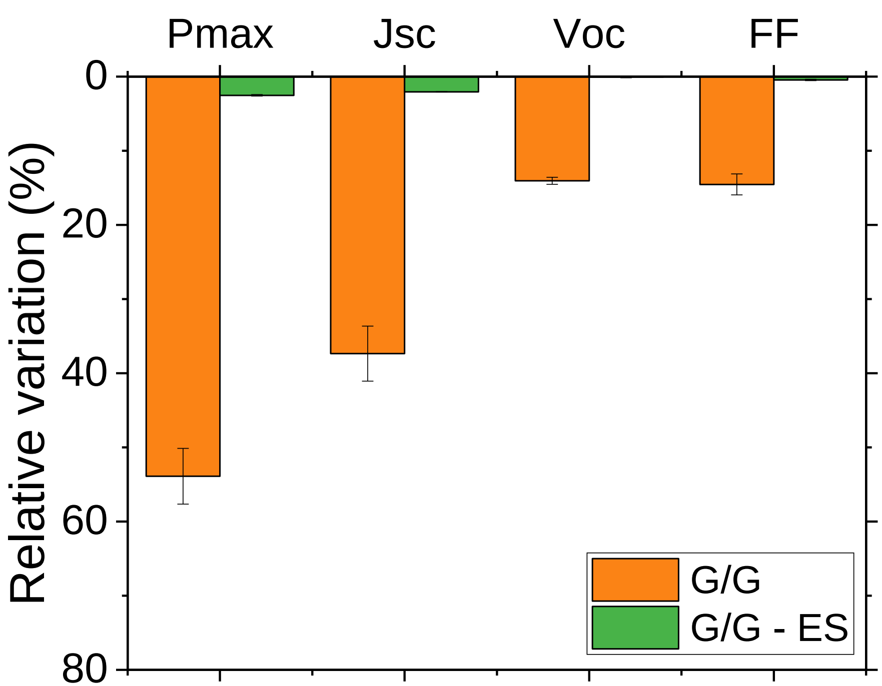
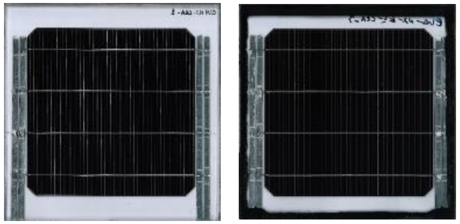
PID at 85ºC/85% RH/-1000 V for 800 h



G/G-ES configuration prevents moisture ingress

- **G/G-ES modules do not degrade after 800 h of test.**
- G/G modules pronte to PID after 800 h:
  - ↓ 54% in $P_{max.}$
  - Main affected parameter → $J_{SC.}$
  - V_{OC} and FF also degraded.

3. Results – Module Level



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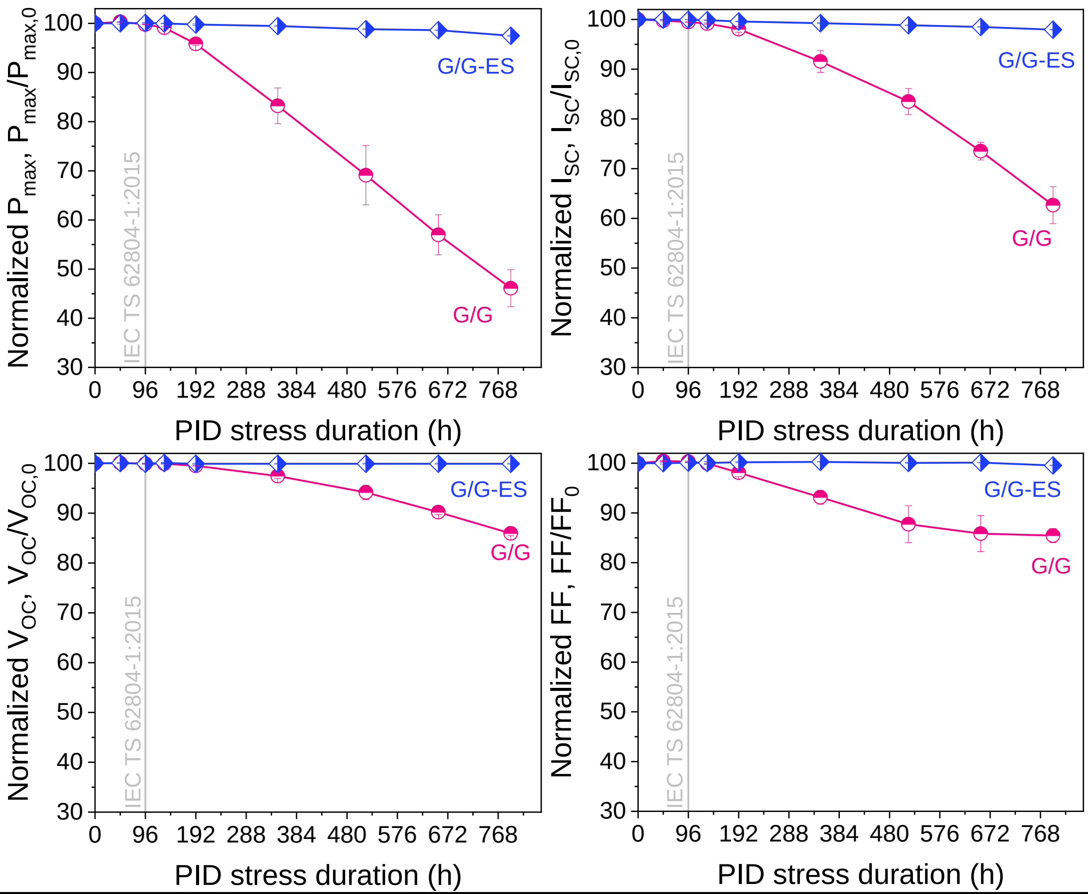
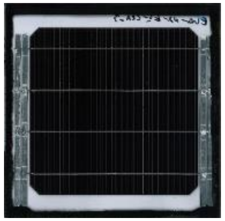
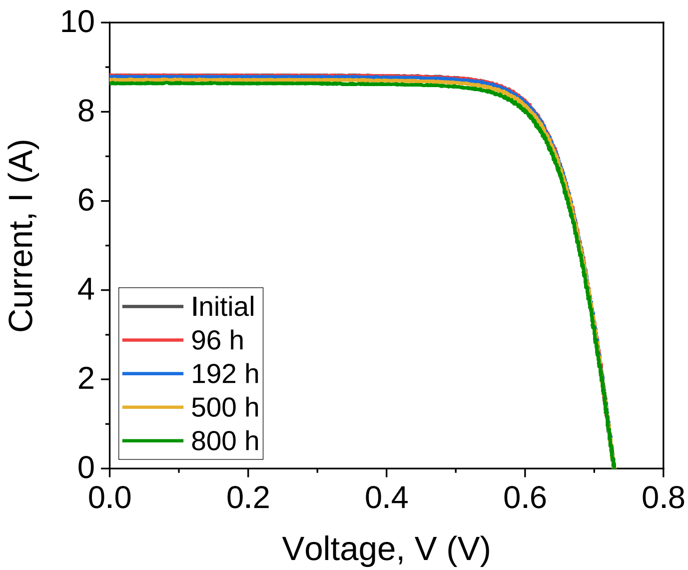


- IEC TS 62804-1 → 96 h of test ✓
- **G/G modules**:
  - Degradation after 192 h <5%.
  - ↓ J_{SC} and ↓ V_{OC} → accelerated after 192 h.
- **G/G-ES modules**: no degradation at all after 800 h.

3. Results – Module Level





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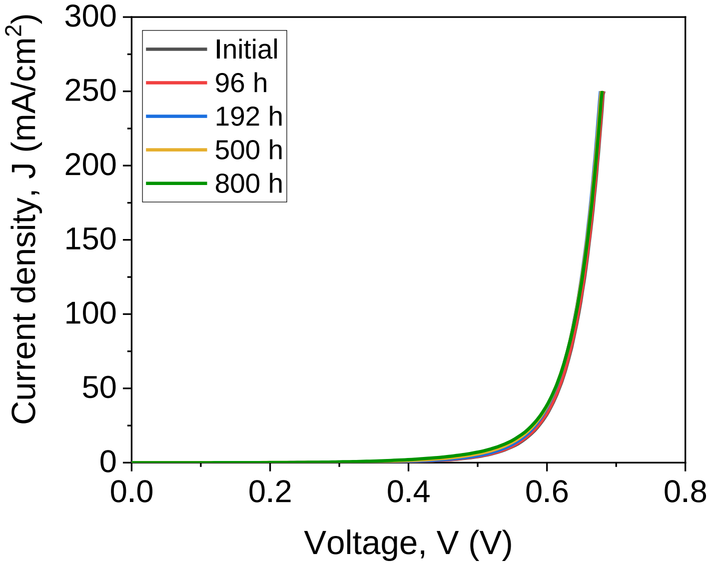
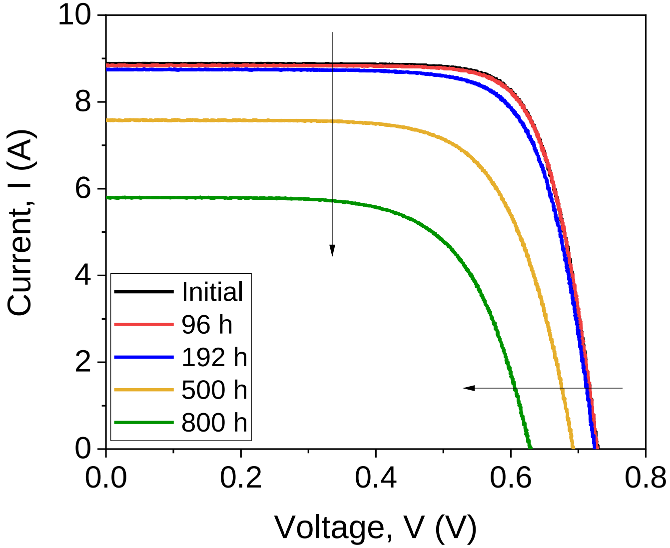
G/G-ES configuration prevents moisture ingress



Both the light and dark I-V curves are **stable** even after **800 h of test** (8 times the 96 h of IEC TS)

3. Results – Module Level



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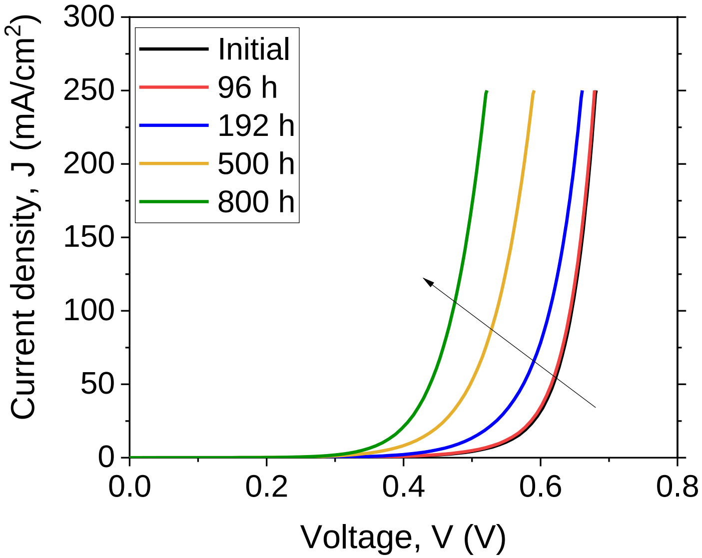
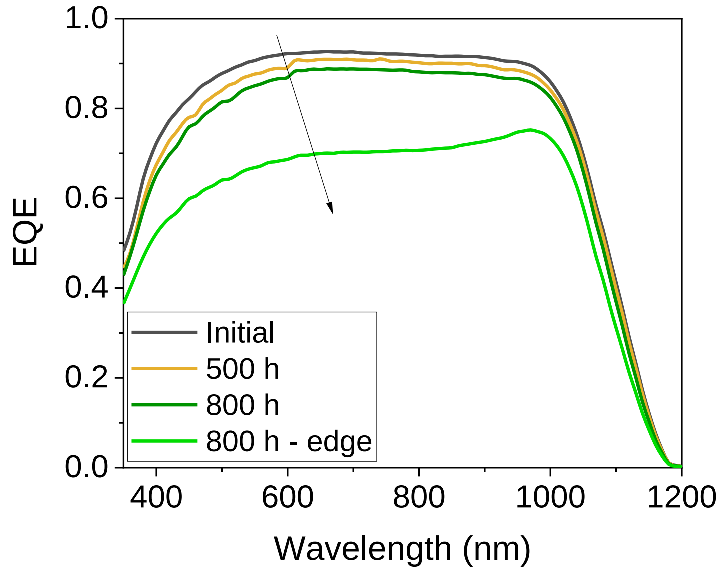
- Degradation after 192 h (light I-V)
- ↓ J_{SC} and ↓ V_{OC}
- Degradation at short wavelengths → front surface recombination.



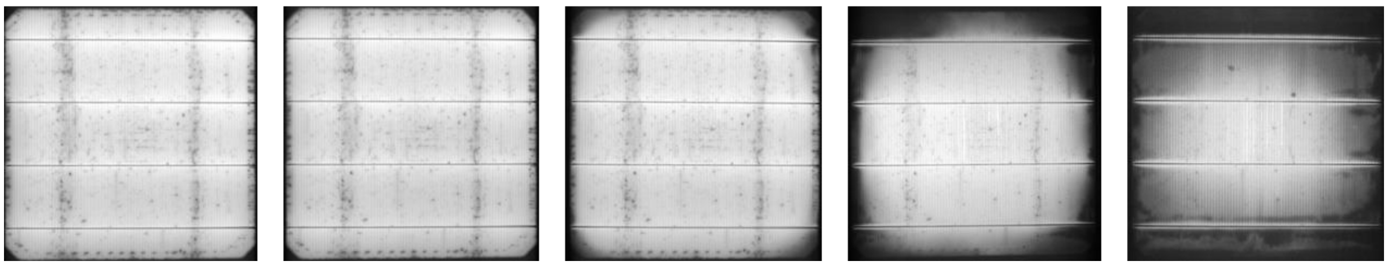


3. Results – Module Level

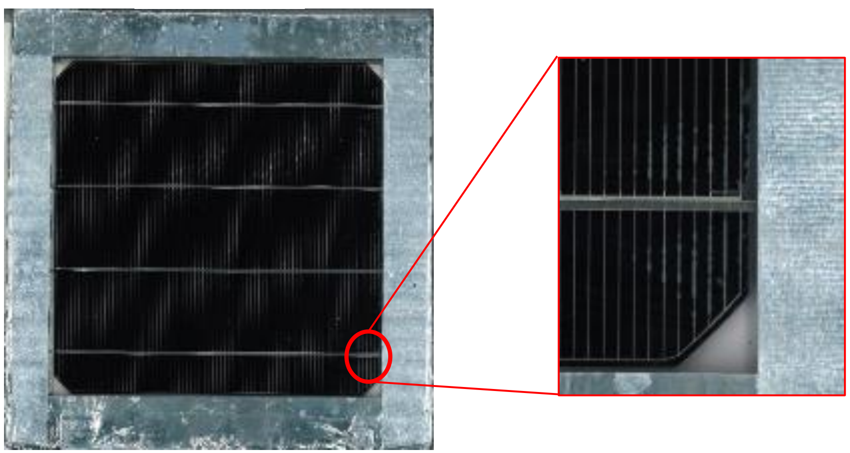
Encapsulant	Temperature / RH	Module Configuration	Voltage
EVA	85°C / 85 %	G/G	-1000 V (x2)
			0 V (x2)
			+1000 V (x2)
		G/G – ES	-1000 V (x2)
			0 V (x2)
			+1000 V (x2)

Electroluminescence

Initial 96 h 192 h 500 h 800 h

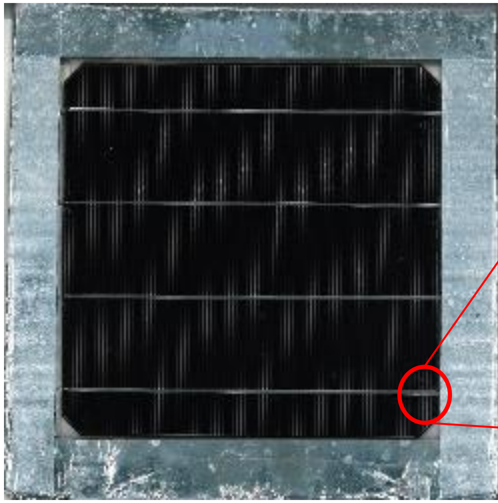


800 h

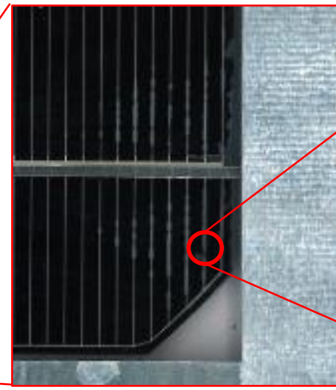


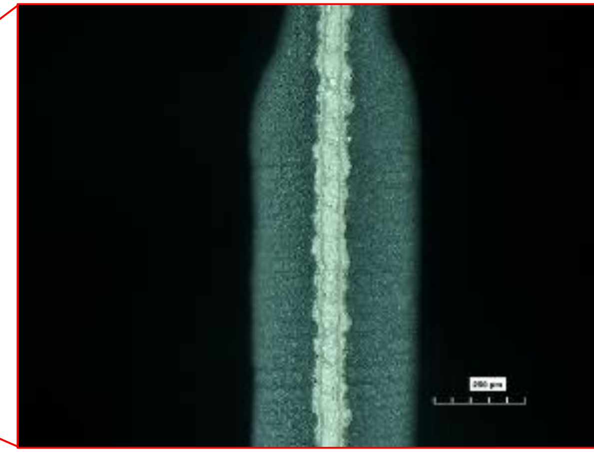
- Degradation starts at the edges, where moisture ingress begins.
- After 800 h of test → current injection strongest on busbars.

3. Results – Cell Level



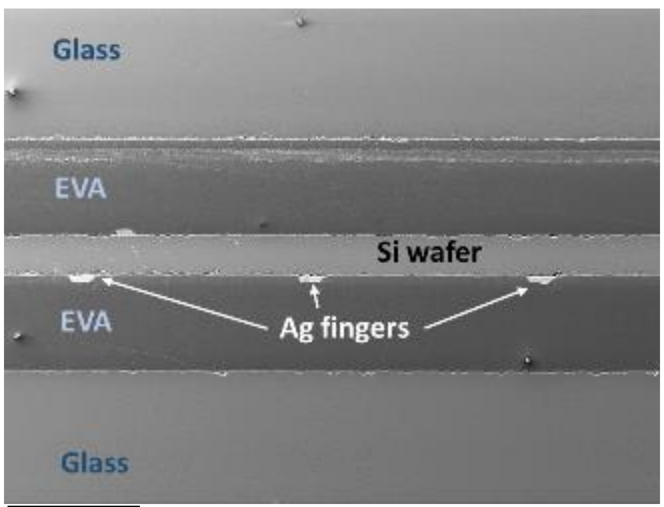
Optical microscopy



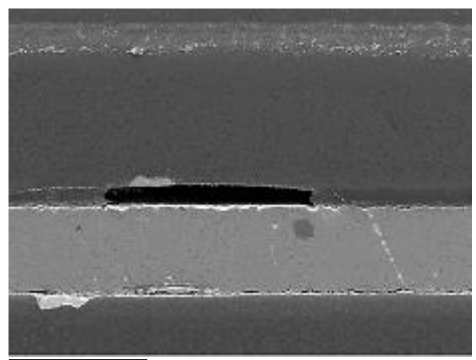


delamination around fingers

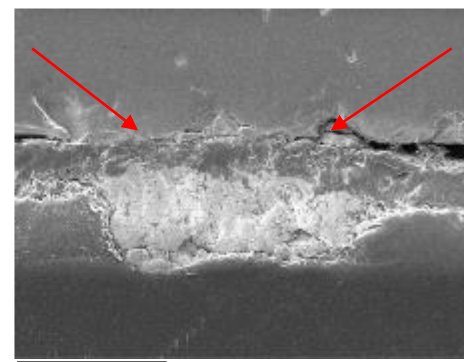
Scanning Electron Microcospy



500 µm



250 µm



50 µm

Resin between fingers and cell → previously delaminated

**SEM measurements were performed by Dr. F. Lisco*

4. Conclusions

PID tests in SHJ modules:

- Tests performed at 85ºC/85% RH.
- High-volume resistivity EVA.
- Comparison of G/G and G/G-ES module structures (edge seal prevents moisture ingress).

Results:

- **PID can be prevented** when using **G/G-ES** module configuration (after 800 h of test) → we can use EVA to encapsulate SHJ solar cells.
- **G/G modules**: the degradation starts after 192 h (they pass the 96 h of IEC TS), driven by a degradation in J_{SC}, V_{OC} and FF.
- Degradation due to passivation loss and recombination at the front surface.
- The degradation is directly linked to the moisture ingress into the module.

Thank you for your kind attention!

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