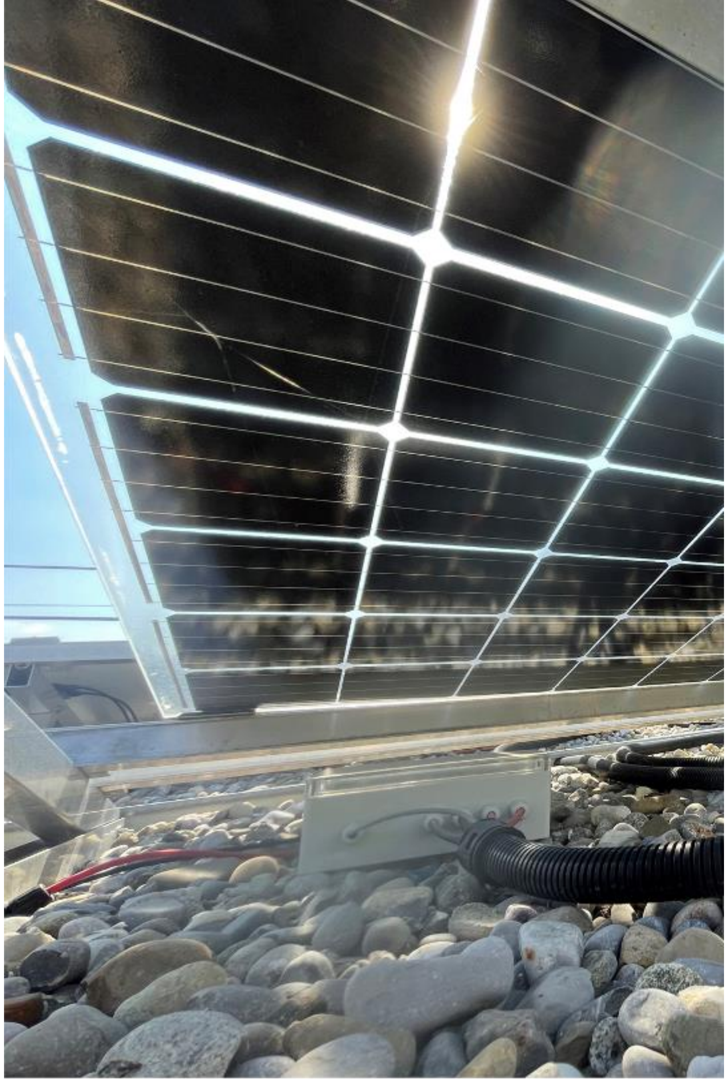
Long-term performance and reliability of silicon heterojunction (SHJ) solar modules

Alessandro Virtuani, Olatz Arriaga-Arruti, Luca Gnocchi, Christoph Ballif

École Polytechnique Fédérale de Lausanne **(EPFL)**
Swiss Center for Electronics and Microtechnology (CSEM)
Neuchâtel, Switzerland

NREL pvrw,

Feb. 28th, 2024



Outline

1. Introduction
2. Long term reliability of SHJ cells/modules
3. Sensitivity to Moisture and potential induced degradation (PID) of SHJ (a microscopical model)
4. Sensitivity to UV
6. Conclusions

Targeting extended PV service lifetimes

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RESEARCH ARTICLE

WILEY PROGRESS IN PHOTOVOLTAICS

35 years of photovoltaics: Analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance—Part 1

Alessandro Virtuani[1] | Mauro Caccivio[2] | Eleonora Annigoni[1] | Gabi Friesen[2] | Domenico Chianese[2] | Christophe Ballif[1] | Tony Sample[3]

- Analysis of the first grid-connected PV plant in Europe (1982)

  - 300+ um-thick Si cells (Al-BSF), no passivating layers, low life-times, low Voc, low efficiency.

- **Main take-away messages**:

  - well-packaged cells/modules can make it to 35+ yrs (at least in temperate climates).

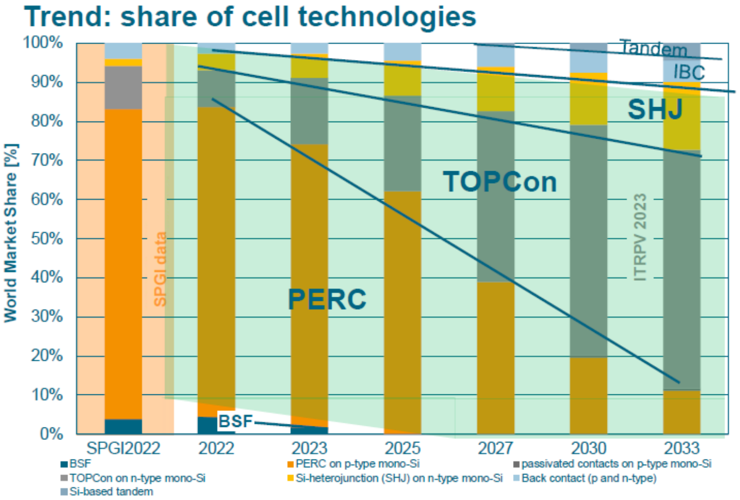
  - strong correlation between encapsulant aging and long-term performance.

  - BOM matters. A lot!

Also: EUPVSEC-2018, NREL pvrw-2021

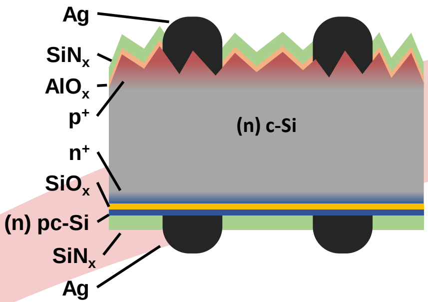
BOM: bill of materials

What's new on the market…

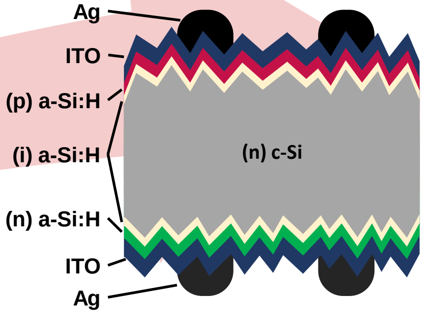


ITRPV (2023)

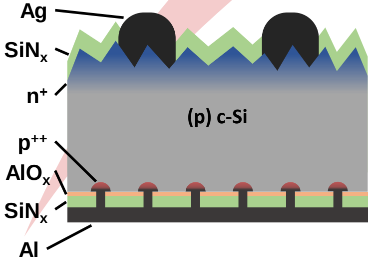
Tunnel Oxide Passivated Contact (TOPCon)



Silicon Heterojunction (SHJ)



Passivated Emitter and Rear Contact (PERC)



«With higher efficiencies there is more to lose» G. Hahn, EUPVSEC 2021

Current mainstream c-Si technology
(~80% market share)

Reliability of TOPCon cells/modules

pv magazine

Weekend Read: Getting to the bottom of TOPCon degradation

Should the industry be alarmed at the potential degradation susceptibility of tunnel oxide passivated contact (TOPCon) solar cells? Or are the problems easily addressed and more a reflection of rushed-to-market products? **pv magazine** contributor and consultant **Götz Fischbeck** reports.

SEPTEMBER 16, 2023 PV MAGAZINE

- “Some manufacturers may simply be a little overly ambitious to bring a product to market, most likely at a time when the full qualification and optimization […] in production have not been fully completed”.
- “Such an approach effectively **makes customers “beta testers”** of the newly released products”.

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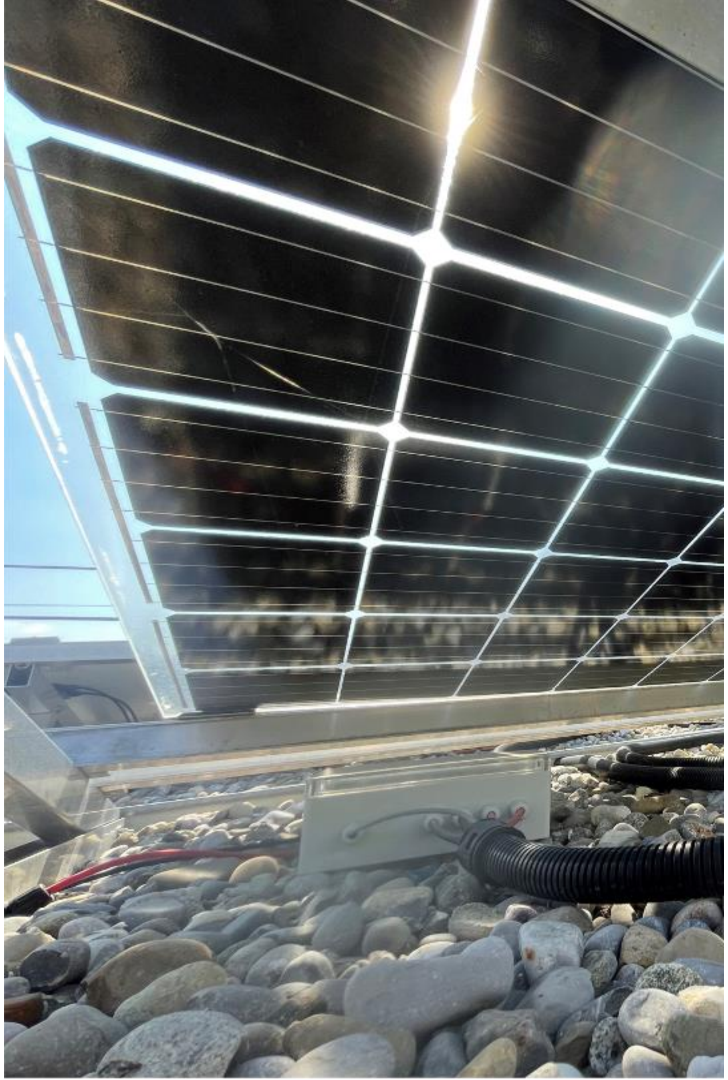

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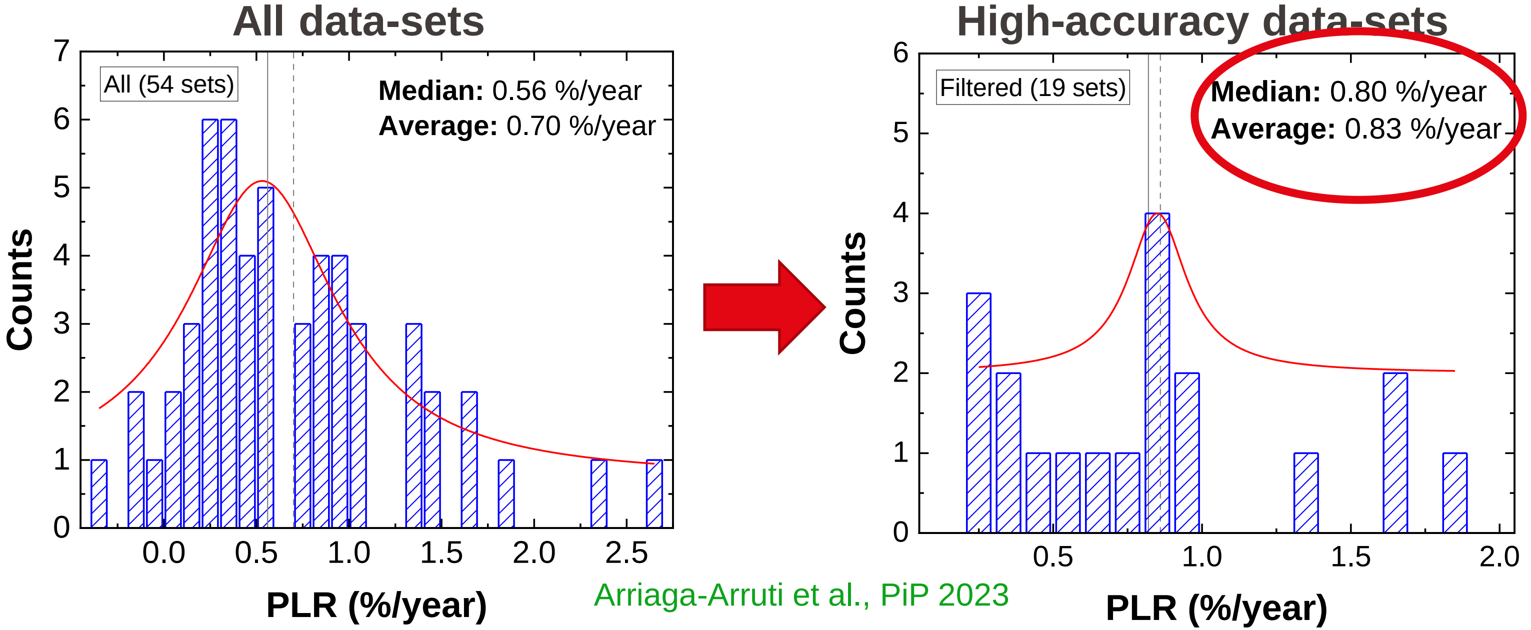
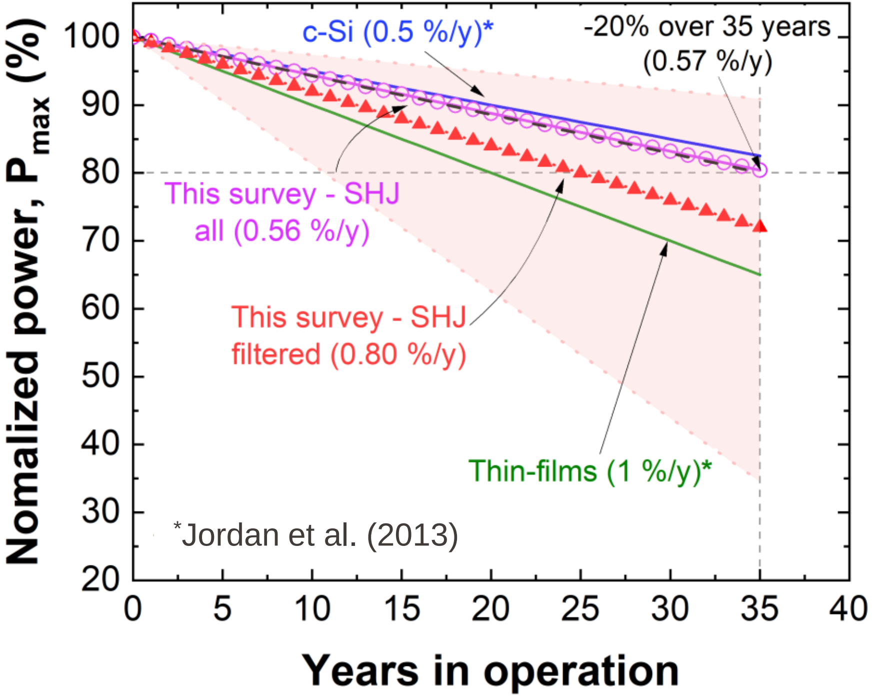
Performance Loss Rates (PLR) of SHJ Modules

- Meta-analysis from outdoor monitoring data.
- 54 data-sets from 14 publications.
- Mainly Sanyo/Panasonic HIT® modules.
- Limited statistics and temporal horizon (max. 10-15 years).



Arriaga-Arruti et al., PiP 2023

Potential weaknesses of the SHJ technology

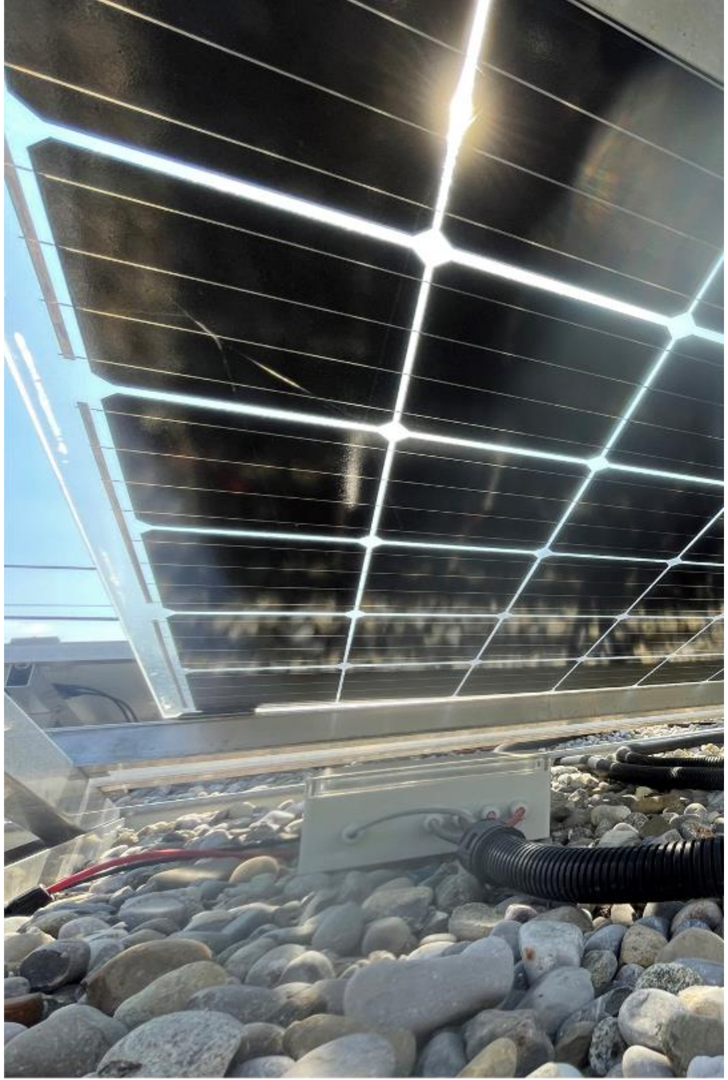


Arriaga-Arruti et al., PiP 2023

Degradation rates for SHJ (-0.8%/y) a bit higher than the ones commonly reported for c-Si (-0.5%/y).

Reported failure modes:

1. Voc losses
2. Moisture-induced degradation
3. Potential-induced degradation (PID)
4. UV induced degradation (UVID)



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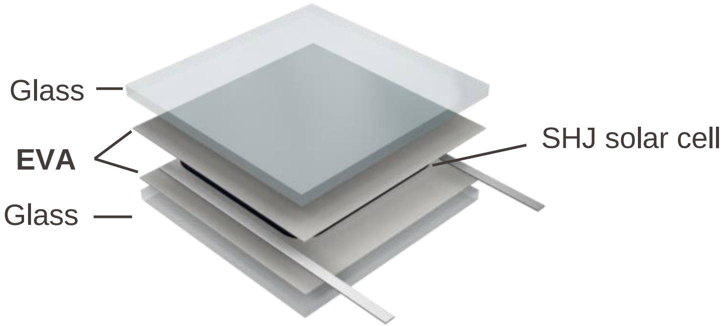
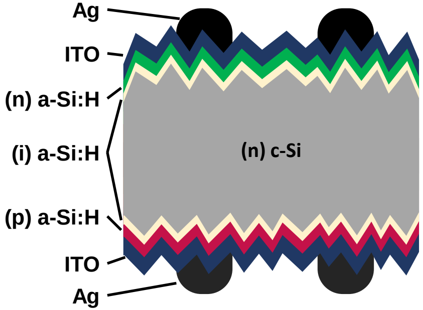
PV Modules & Experimental Setup

EVA: ethylene vinyl acetate
ECA: electrical conductive adhesive



20 cm x 20 cm

Bifacial rear-emitter SHJ (ECA-interconnects)



M2 size

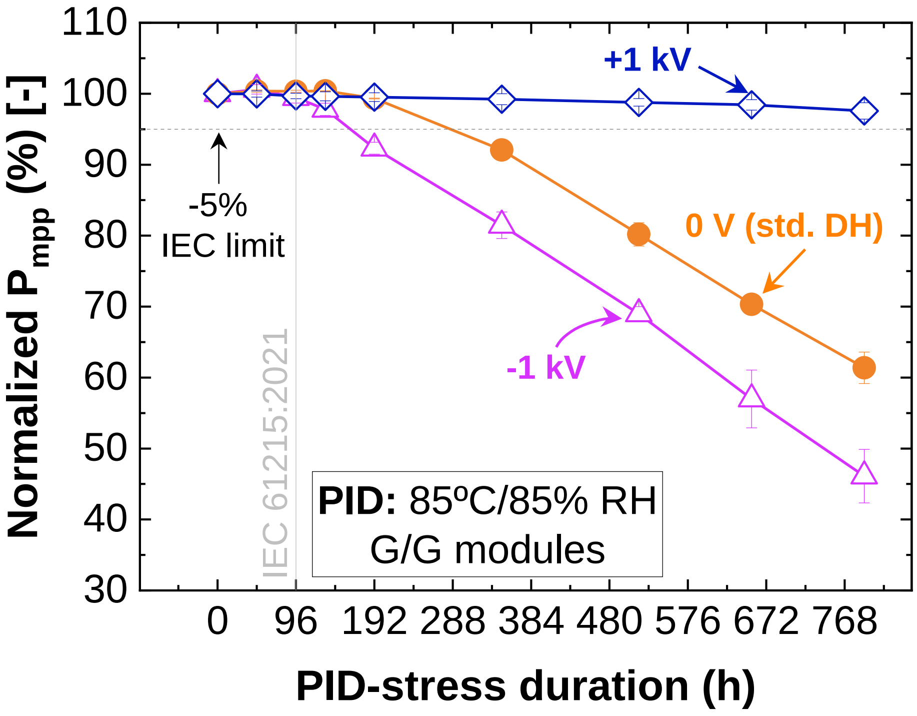
Characterization techniques:

- Light I-V
- Dark I-V
- EL
- PL
- EQE

Temperature / Relative Humidity	Encapsulant	Voltage	Duration
85ºC / 85% RH	Low-resistivity EVA	-1 kV	96 h*, 800 h
		0 kV (std. DH)	1000 h*, 2000 h
		+1 kV	96 h*, 800 h

IEC 61215-2:2021. Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures

Initial DH and PID Test Results



No degradation

Unexpected degradation kinetics and rates

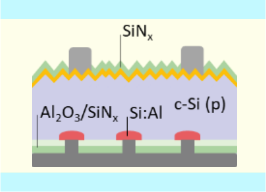
Increased degradation

- An electrical field is not needed to trigger degradation (DH).
- A positive (PID+) electrical fields prevents degradation.
- This points out at the role of positively charged ions (Na+, Ag+, ….)

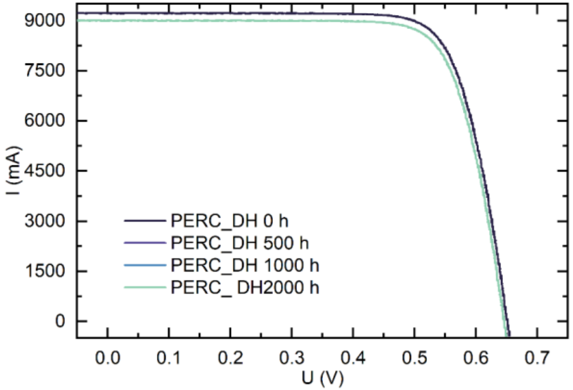
Extended DH test (2000 hrs)

Arriaga-Arruti et al., PiP 2023
Gnocchi et al., Cell Rep. 2023

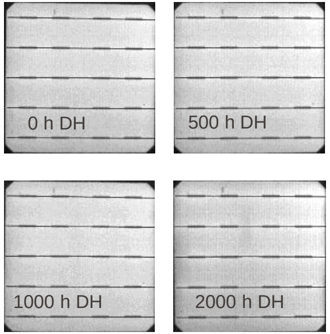
➢PERC



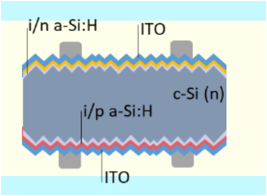
I-V curves

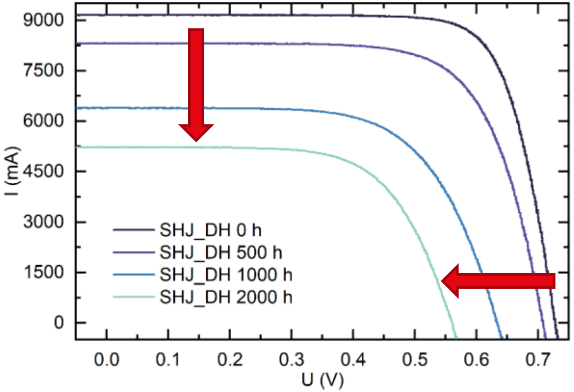


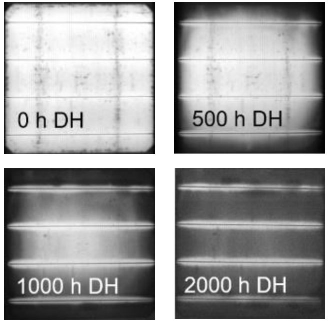
EL images



➢SHJ





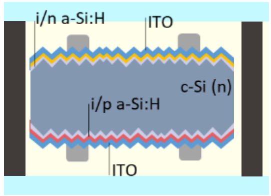


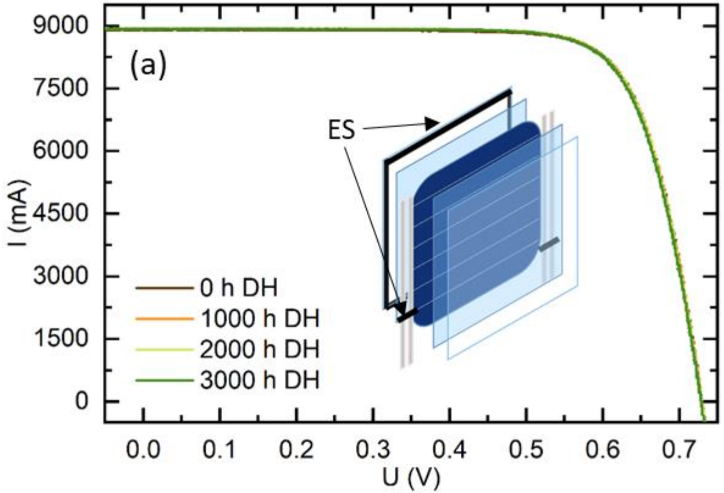
I_{SC}: short-circuit current
V_{OC}: open-circuit voltage
FF: fill factor

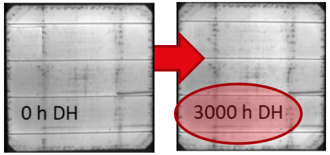
- SHJ: degradation driven by **losses in I_{SC}**, followed by V_{OC} and FF.
- Degradation starts at the edges and spreads over the whole area as the test is extended.

The role of water……

➤SHJ + EVA + **ES**







- In presence of an edge seal (ES), no **degradation observed**.
- Water is needed to trigger degradation.

Ruling out contributions….

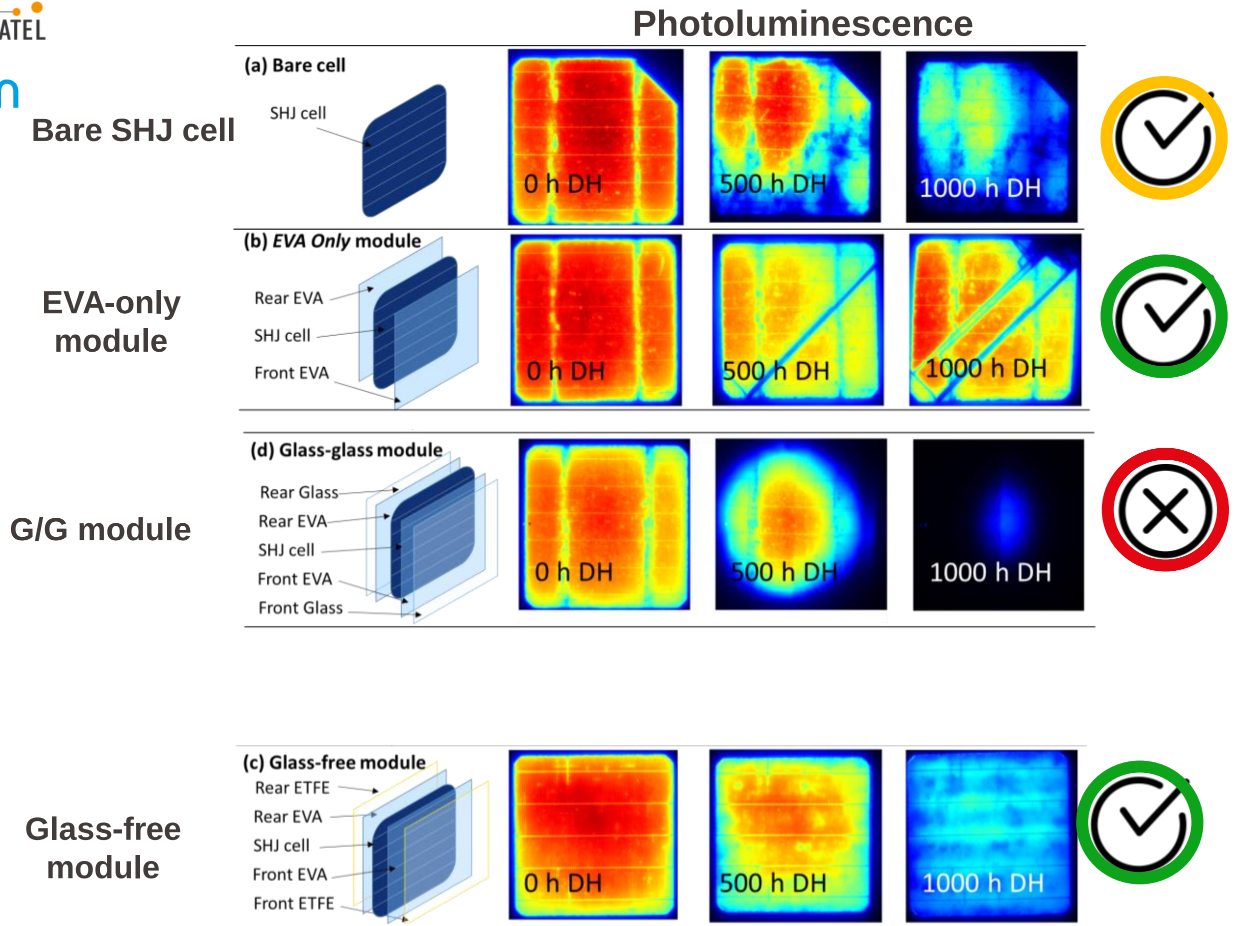
For the investigates SHJ solar cells/modules:

- Formation of Si-OH bonds (FTIR) due to diffusion of H_2O molecules on wafers, but no major contribution to degradation (see next slides).
- ECA-based interconnects are stable.
- EVA encapsulant is stable.
- Glass covers are stable, but…

ITO: indium tin oxide

The role of glass...

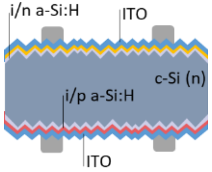
Arriaga-Arruti et al., PiP 2023
Gnocchi et al., Cell Rep. 2023

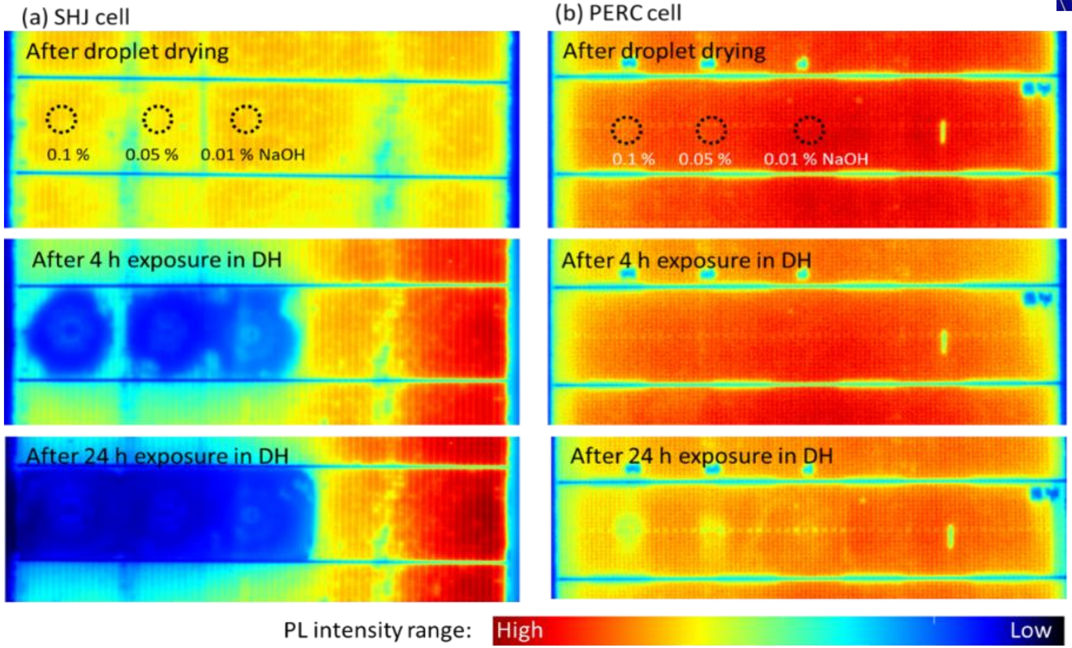


- Water is needed to trigger degradation in SHJ.
- Glass is needed too!!!

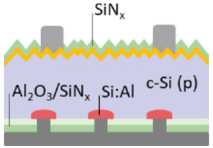
Droplet tests (NaOH, NaCl)

SHJ





PERC

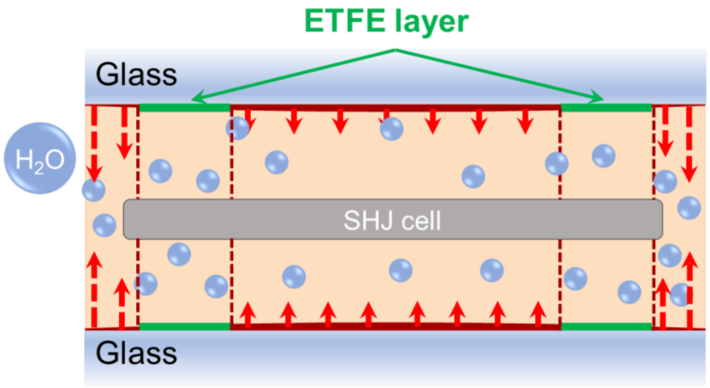


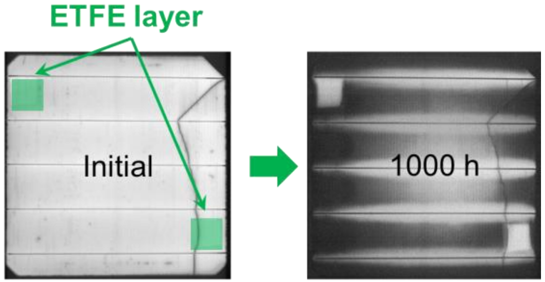
- Droplet tests confirm high sensitivity to NaOH for SHJ
- Lower sensitivity to NaCl (SHJ)
- PERC cells are very stable

  >> **degradation mechanism is specific to SHJ cells**

The role of glass (2)…where does Na/NaOH come from?

ETFE inserts as barrier to Na+/NaOH diffusion to confirm hypothesis.





Electroluminescence

A barrier between the glass covers and EVA prevents degradation in DH.

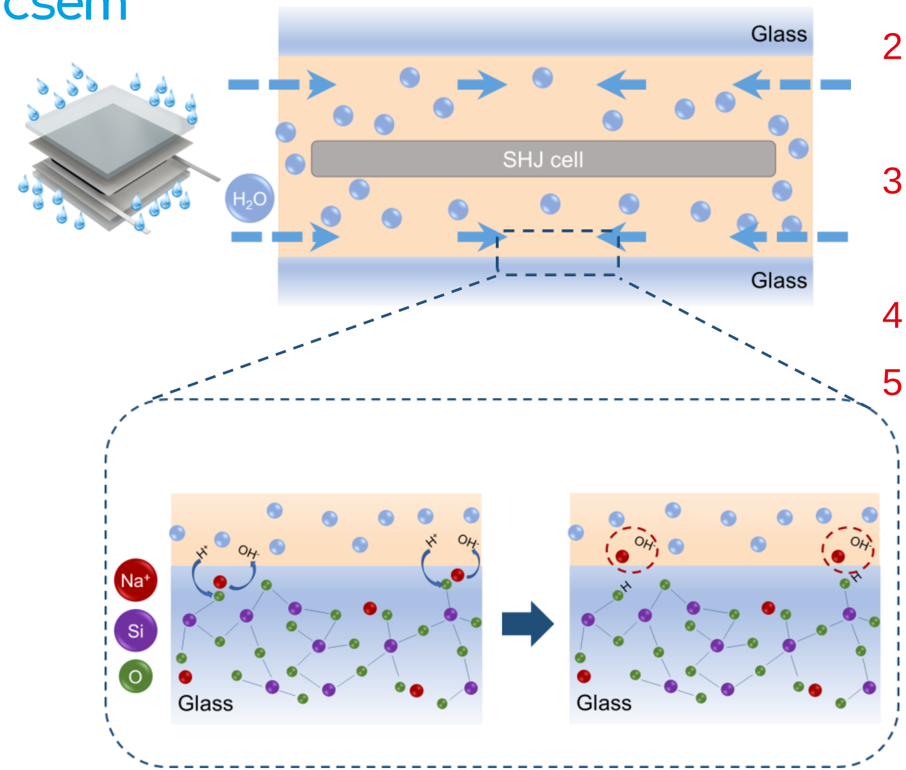
Glass is root cause of degradation mechanism

ETFE: ethylen-tetrafluorethylen-copolymer

Moisture-induced degradation model of SHJ

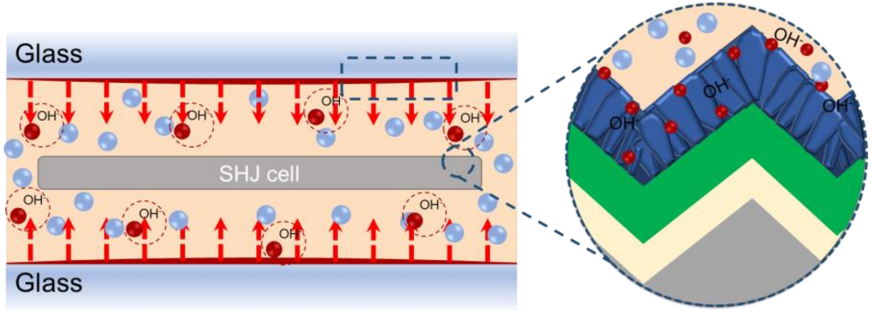
Arriaga-Arruti et al., PiP 2023

Gnocchi et al., Cell Rep. 2023

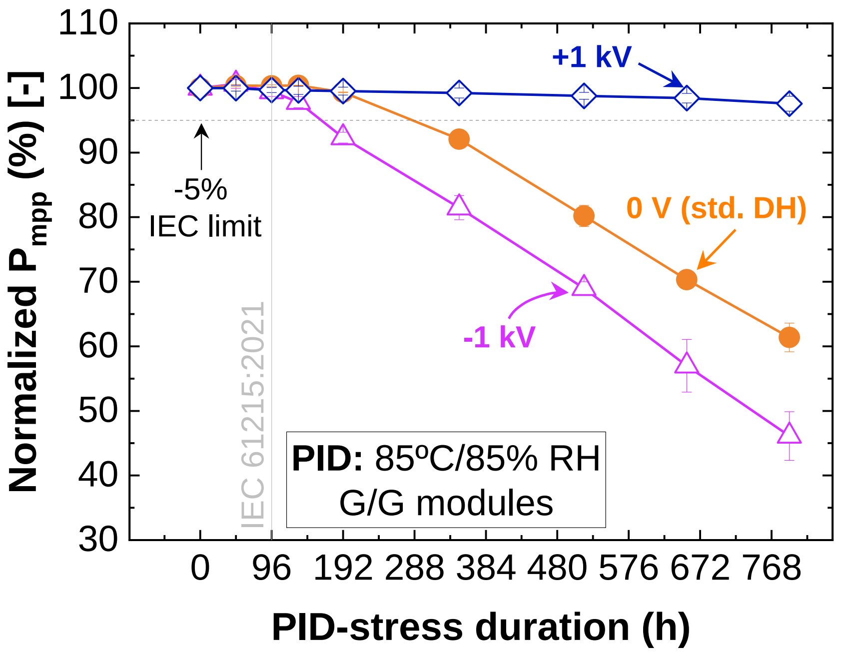


Guiheneuf et al. CorrEngSciTech 2017

1. EVA promotes moisture ingress in the laminate.
2. Corrosion of glass surface and creation of NaOH molecules.
3. NaOH molecules (and Na+) diffuse through the encapsulant & towards the solar cell.
4. NaOH & Na+ diffuse through the TCO.
5. Loss of passivation properties at Si/a-Si:H interface.

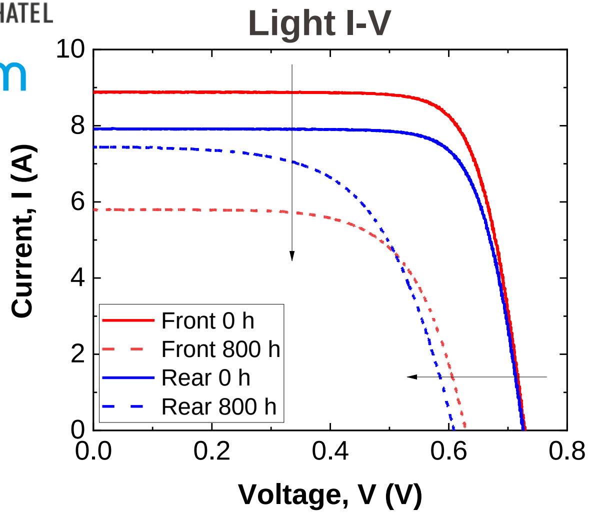


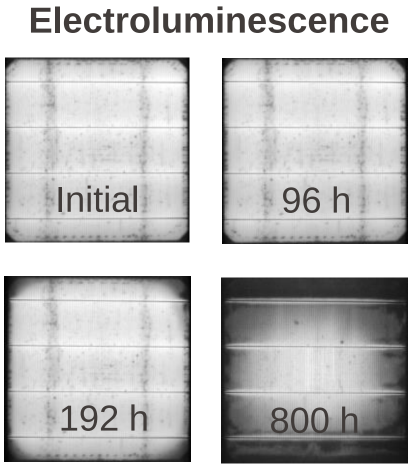
The Role of Voltage Bias in Degradation

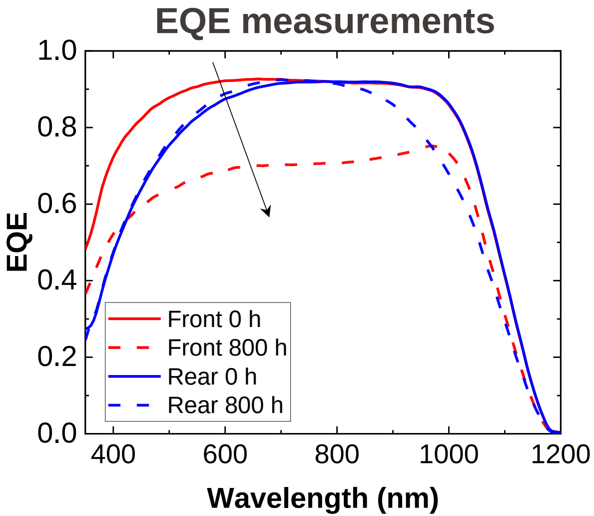


- Negative PID and DH show similar degradation kinetics.
- Negative bias enhances degradation caused by moisture ingress.
- Positive bias prevents degradation, consistent with our model.

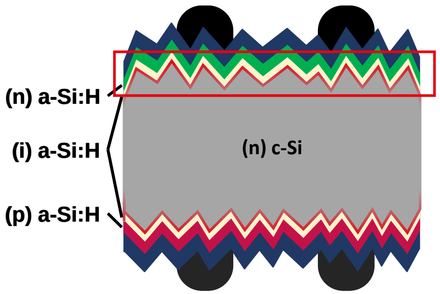
PID Mechanism in SHJ Solar Cells







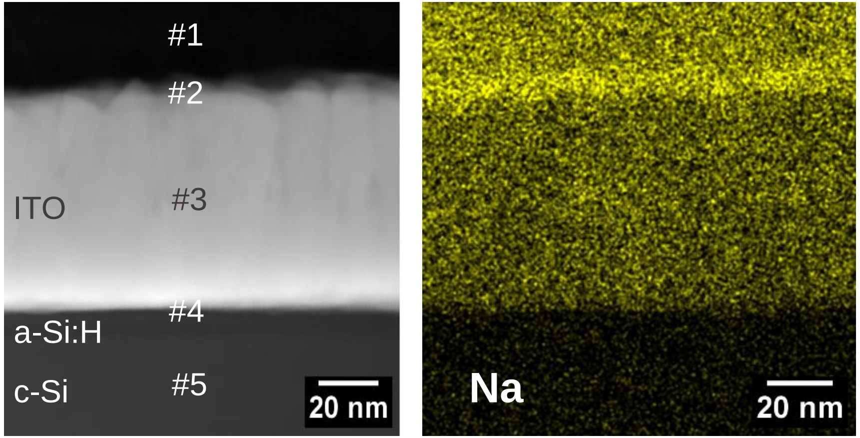
- Higher I_{SC} losses at front side.
- Degradation starts at the edges.
- **Same mechanism as DH laminates.**
- Increased front-surface recombination.
- Simulations indicate that recombination is due to increased defects at the a-Si:H/c-Si interface.



Microscopic analysis

- **DH-degraded samples:** no presence of Na (below detectability limit).
- **PID-neg**: presence of Na (barely noticeable) at the ITO/a-Si:H interface → increased **recombination centers** that can cause **losses in passivation** and **hinder charge carrier collection**.

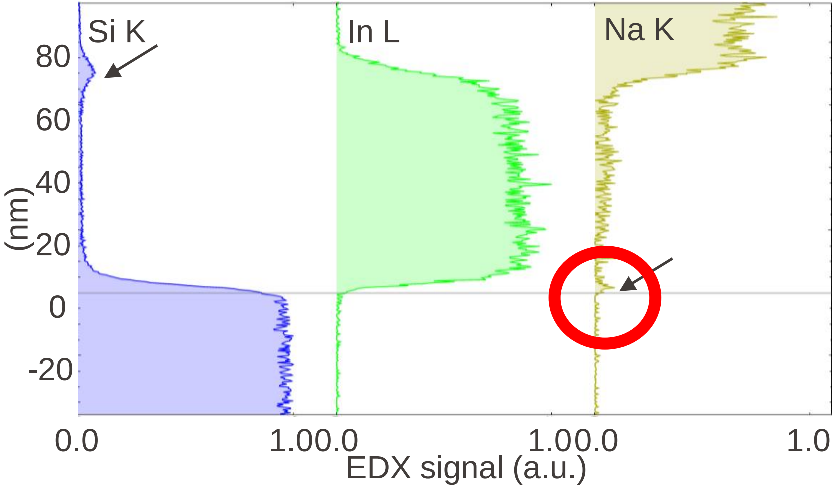
PID (-) degraded sample



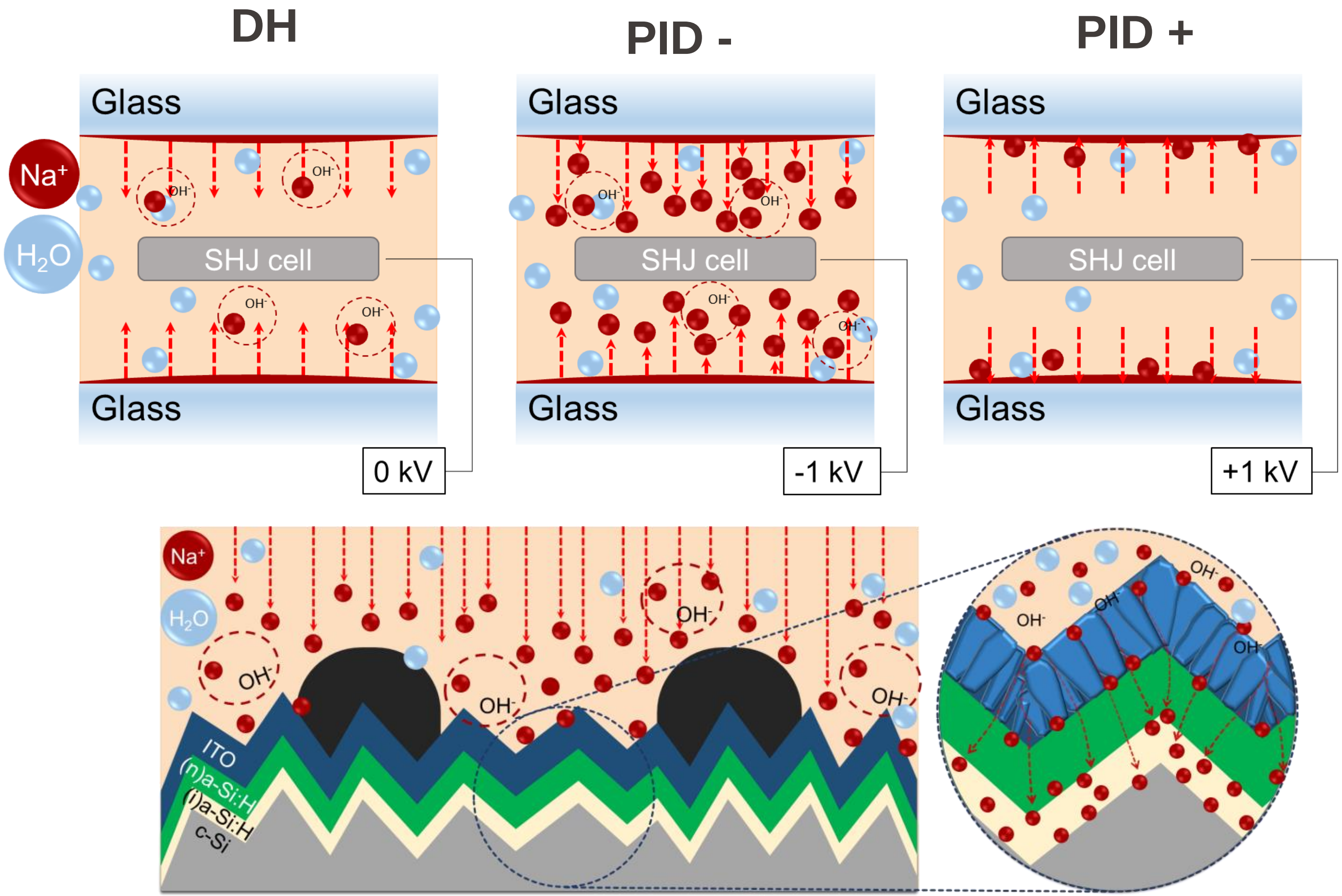
STEM

EDX signal (a.u.)

PID (-) degraded sample



PID Mechanism: Microscopic Model



Mitigation Strategies at Module & Cell Level

MODULE LEVEL

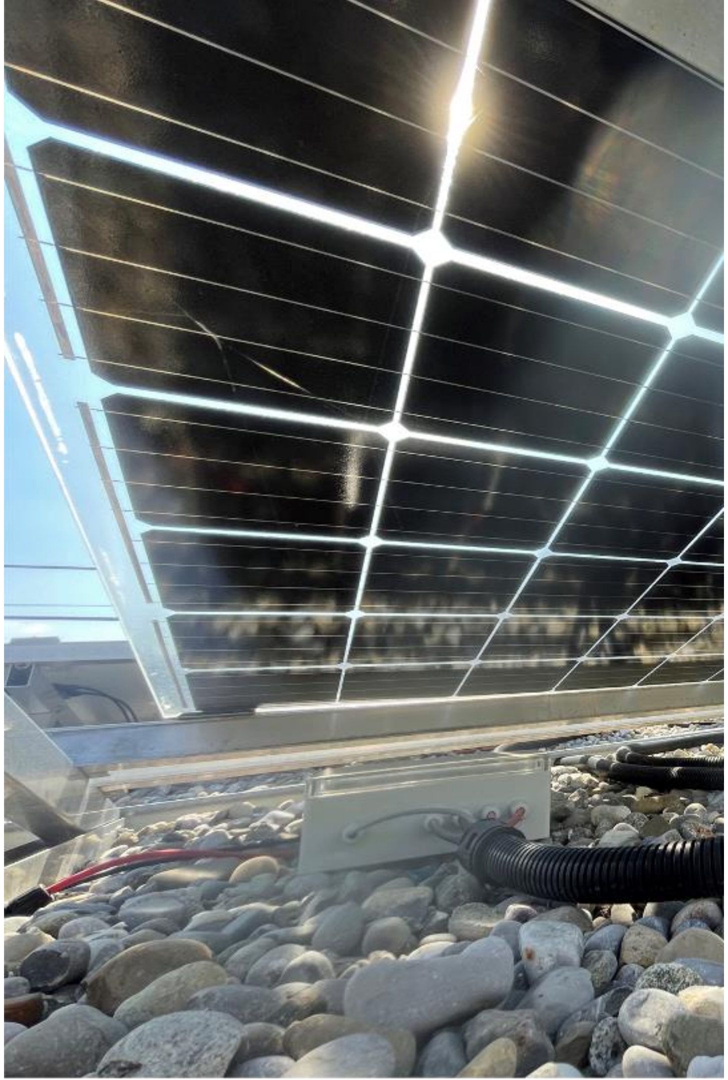
1. Use of encapsulants with high-volume resistivity and low-WVTR.
2. Reduction of water ingress: e.g. use of edge sealants.

CELL LEVEL

1. Quality (thickness, homogeneity, low grain-boundary density, absence of voids/crack) of TCO layers is critical.
2. Use of capping layers (AlOx, SiNx,….)

>> O.Arriaga-Arruti ieee-PVSC 2024,

>> Liu et al. Joule 2020, Adachi et al. SolEnMatSolCell 2017, Park et al. Microel. Engin. 2019, Li et al. PiP 2023



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Alessandro Virtuani

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Sensitivity to UV of SHJ Cells/modules

Two **different mechanism** reported in the literature:

- Defect generation at a-Si:H/c-Si interface (impacts **FF** & $\mathbf{V_{oc}}$)
- Loss of transparency of TCOs (impacts **Isc**)

Mitigation strategies:

- Switch from front to rear emitter solar cells (Sanyo: ~2009)
- Use of encapsulants with high UV cutoffs (even up 400-420 nm)

>>> see next talk from Archana Sinha on UV-ID.

TCO: transparent conductive oxyde

Conclusions

1. Long-term degradation rates found in the literature higher for SHJ (-0.8%/y) than for conventional c-Si (-05 %/y).
2. We proposed a microscopical model to explain the extreme sensitivity of SHJ cells/modules to water (and PID).
3. Glass is a key ingredient, acting as a Na reservoir.
4. This failure mode is specific to the SHJ technology (not PERC, Al-Bsf, …).
5. We discuss mitigation strategies at solar cell and module level.
6. A quick look at the sensitivity of SHJ to UV (UV-ID).

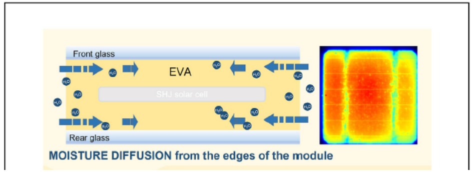
Want to learn more?

Cell Reports
Physical Science

CellPress
OPEN ACCESS

Article

A comprehensive physical model for the sensitivity of silicon heterojunction photovoltaic modules to water ingress



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Highlights

Study stability of encapsulation of G-G SHJ modules using EVA

REVIEW

PROGRESS IN PHOTOVOLTAICS WILEY

Long-term performance and reliability of silicon heterojunction solar modules

Olatz Arriaga Arruti[1] | Alessandro Virtuani[1,2] | Christophe Ballif[1,2]

RESEARCH ARTICLE

PROGRESS IN PHOTOVOLTAICS WILEY

Potential-induced degradation in bifacial silicon heterojunction solar modules: Insights and mitigation strategies

Olatz Arriaga Arruti[1,2] | Luca Gnocchi[1] | Quentin Jeangros[2] | Christophe Ballif[1,2] | Alessandro Virtuani[1,2]

Moisture sensitivity of SHJ:

- Adachi et al. SolEnMatSolCell 2017, Park et al. Microel. Engin. 2019, Li et al. PiP 2023, Sen et al. SolEnMatSolCell 2023…..

PID in SHJ:

- Yamaguchi et al. SolEnMatSolCel 2020, ….

UV-ID in SHJ:

- Sinha et al. PiP 2022, Lelievre et al. SolEnMatSolCel 2022, Pinochet et al. PiP 2023, Taguchi et al. SHJ Workshop 2023-2014…

Acknowledgments

- All PV-lab staff at CSEM and EPFL
- @CSEM: Lison Marthey, Jonathan Champliaud, Matthieu Despeisse, Loann Baum, ….
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Thank you!

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