Extended Reliability of Silicon Heterojunction Solar Modules

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12th SOPHIA PV-Module Reliability Workshop

July 1st, 2022

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Outline

1. Introduction

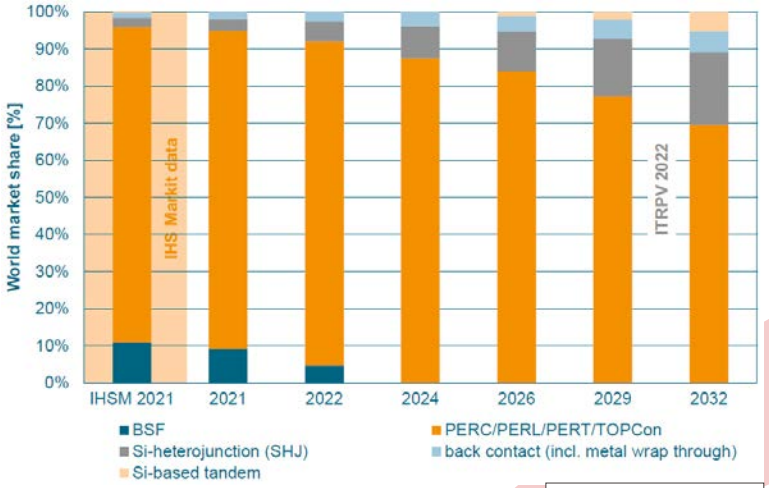
2. Reliability and Long-term Performance of c-Si PV Modules

3. Field Performance of Si Heterojunction Modules

4. Indoor Accelerated Stress Testing on Si Heterojunction Technology

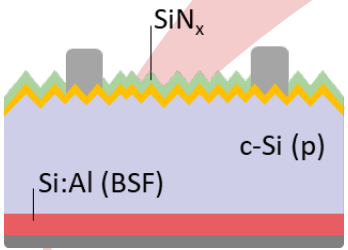
5. Conclusions

Introduction – Evolution on solar cell technology



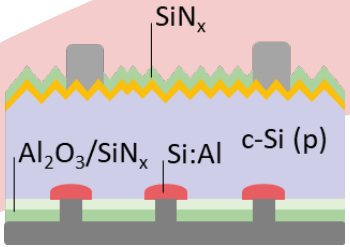
ITRPV (2022)

Al-BSF



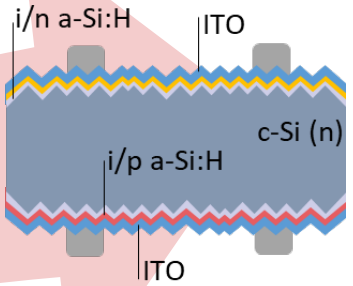
Mainstream c-Si technology until 2014…

PERC



Today's mainstream c-Si technology (**≈80% market share**)

SHJ



Easy to process **bifacial devices** with few process steps (**low cost** with **high efficiency**)

Key technology to restart the PV production in EU

3 GW/year

01 April 2022

Enel Green Power signs grant agreement with the EU for solar panel Gigafactory in Italy

NEWS

Meyer Burger optimising production expansion to 1.4GW in Germany to cater for European demand

By Jonathan Tourino Jacobo

April 29, 2022

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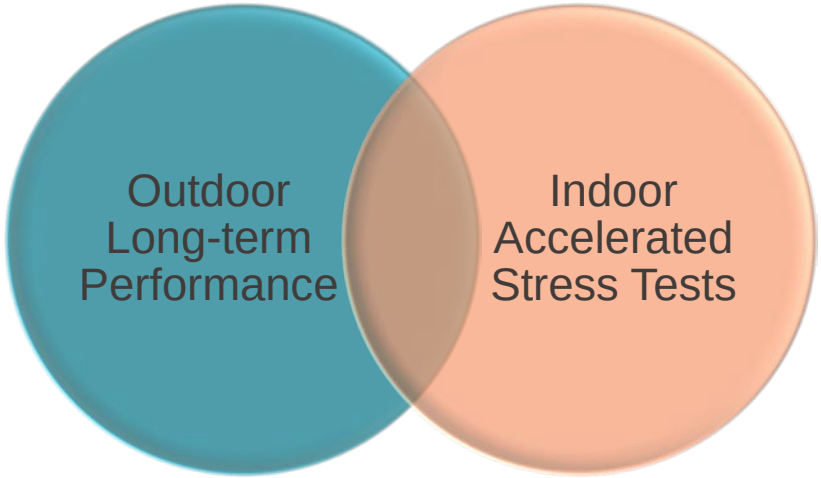
Outdoor Performance vs Indoor Tests

Outdoor Long-Term Performance

- **Commercial technologies** installed in the field.
- Long time-series (ideally over 10-15 years).
- Variety of climatic and operating conditions.



Indoor Accelerated Stress Tests

- Technologies in **development**.
- **No direct correlation** to potential duration in the field.
- Detection of **weak points** ⟶ reliable modules at the manufacturing process.
- No consideration of particular climate or operating conditions.

Novel high efficiency technologies can be more sensitive to degradation

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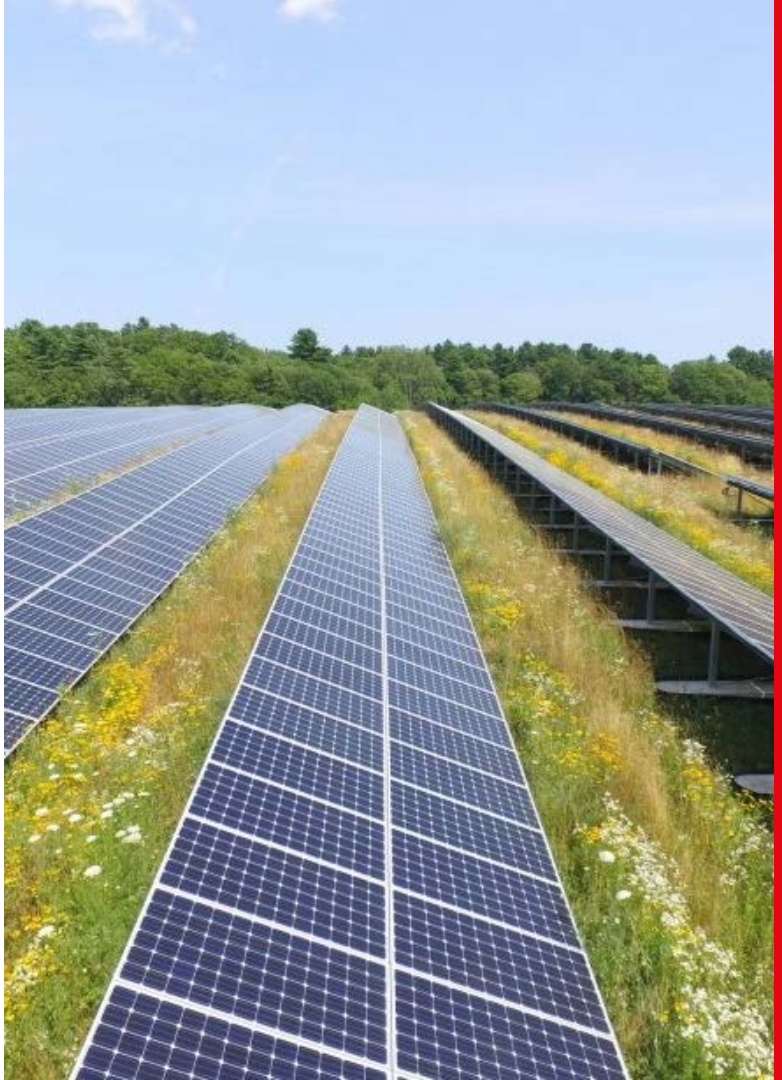

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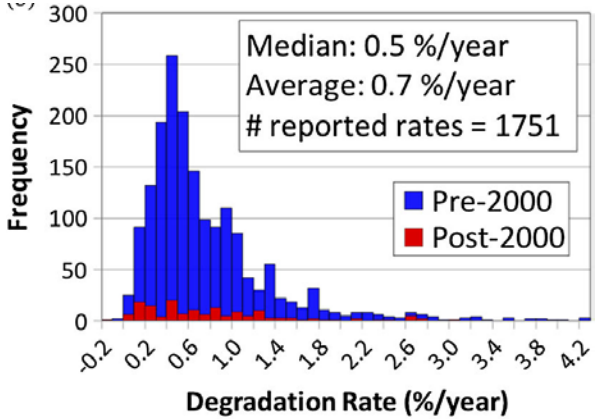
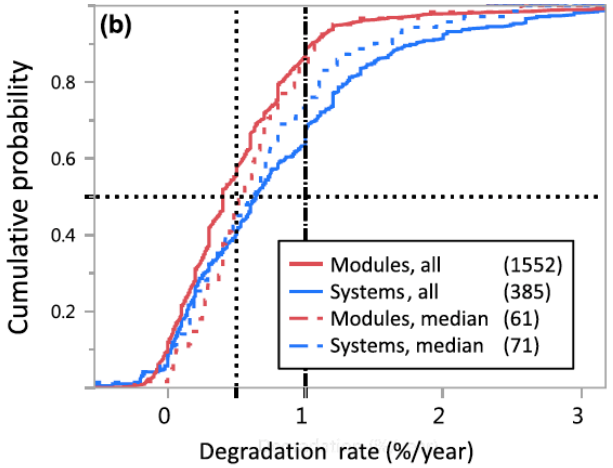
Reliability and Long-term Performance of c-Si PV Modules



D. Jordan, S.R. Kurtz , Prog. Photovolt: Res. Appl. (2011)



D. Jordan et al., Prog. Photovolt: Res. Appl.(2016)

- **Deviations** in initial measurements vs nameplate rating + uncertainties in outdoor measurements.
- Necessary to **identify non-linearities** ⟶ often linear degradation rates considered.
- Main degradation mode ⟶ **encapsulant discoloration**.
- **Hot** climate & **rooftop** mounting ⟶ **higher degradation rates**.

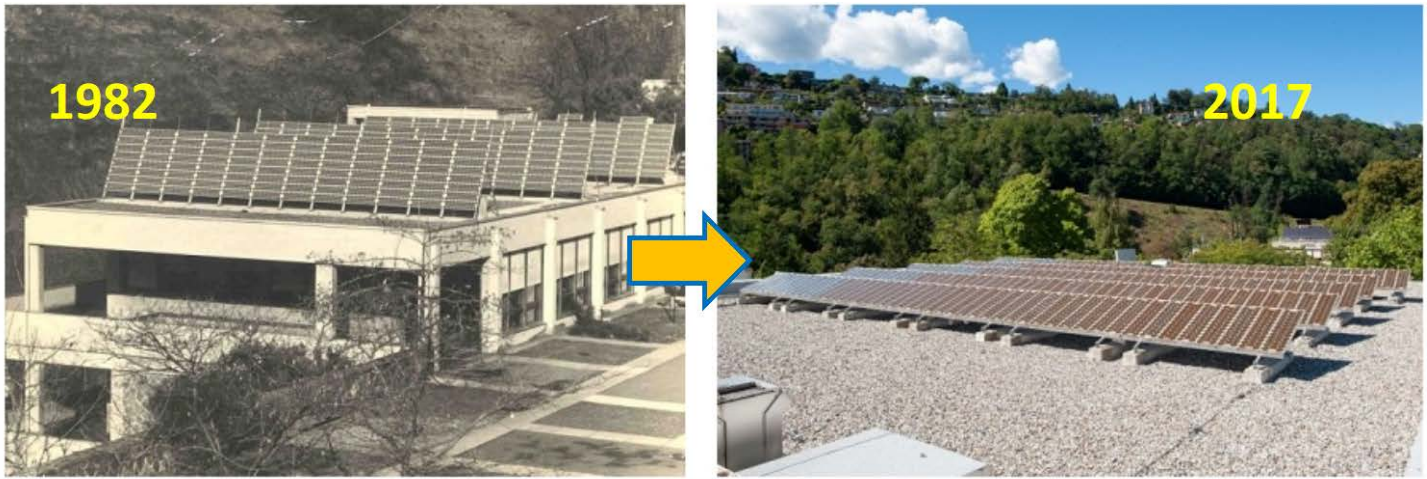
Example of a 35-year-old PV System

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]



70% of modules experience a degradation of ≤ 20% and would still be covered by a 35-yrs-long warranty set at 80% of initial power.

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Literature Review: Surveyed Works (some)

IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 8, NO. 1, JANUARY 2018 177

Silicon Heterojunction System Field Performance

Dirk C. Jordan, Chris Deline, Steve Johnston, Steve R. Rummel, Bill Sekulic, Peter Hacke, Sarah R. Kurtz, Kristopher O. Davis, Eric John Schneller, Xingshu Sun, Muhammad A. Alam, and Ronald A. Sinton

Analysis of Photovoltaic Performance Loss Rates of Six Module Types in Five Geographical Locations

Philip Ingenhoven, Giorgio Belluardo, George Makrides, George E. Georghiou, Paul Rodden, Lyndon Frearson, Bert Herteleer, Dario Bertani, and David Moser

Degradation analysis of photovoltaic modules under tropical climatic conditions and its impacts on LCOE

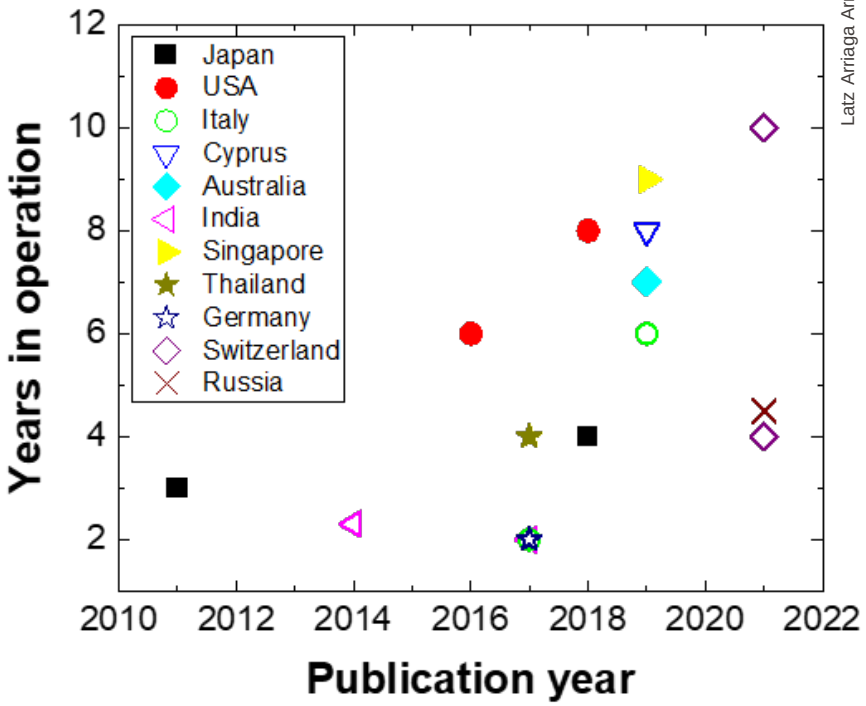
Amornrat Limmanee [a,*], Sasiwimon Songtrai [a], Nuttakarn Udomdachanut [a], Songpakit Kaewniyompanit [b], Yukinobu Sato [c], Masaki Nakaishi [c], Songkiate Kittisontirak [a], Kobsak Sriprapha [a], Yukitaka Sakamoto [c]

Performance stability of photovoltaic modules in different climates

Markus Schweiger[1,2]*, Johanna Bonilla[1], Werner Herrmann[1], Andreas Gerber[2] and Uwe Rau[2]

Methodology

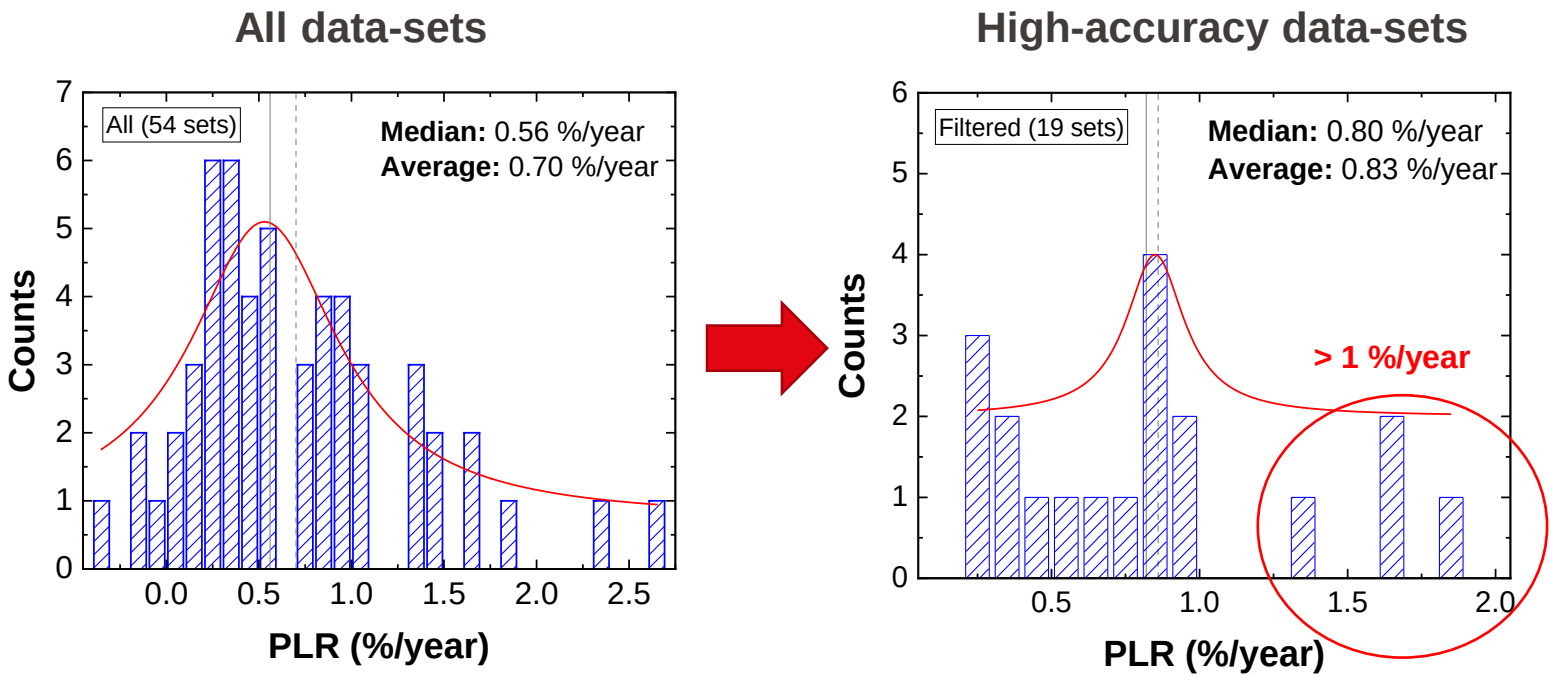
- **54 data-sets from 14 publications**
- Variety of climates (temperate, tropics, arid…).
- **Performance Loss Rates** (PLR) [%/year] considering a **linear degradation**.
- Filtering of high-accuracy data-sets.
- Study of **main failure modes**.
  - From the survey.
  - From indoor accelerated ageing tests.



Caveats of this meta-analysis

- **Sanyo/Panasonic** technology ⟶ changed over the years.
  - **G/BS** module configuration ⟶ G/Al-BS at some point.
    - Currently ⟶ **POE/EVA encapsulation scheme**.
  - Front-emitter technology ⟶ **changed to rear-emitter in 2009**.
- **Limited statistics** and **temporal horizon** (max. 10-15 years).

Performance Loss Rates (PLR)



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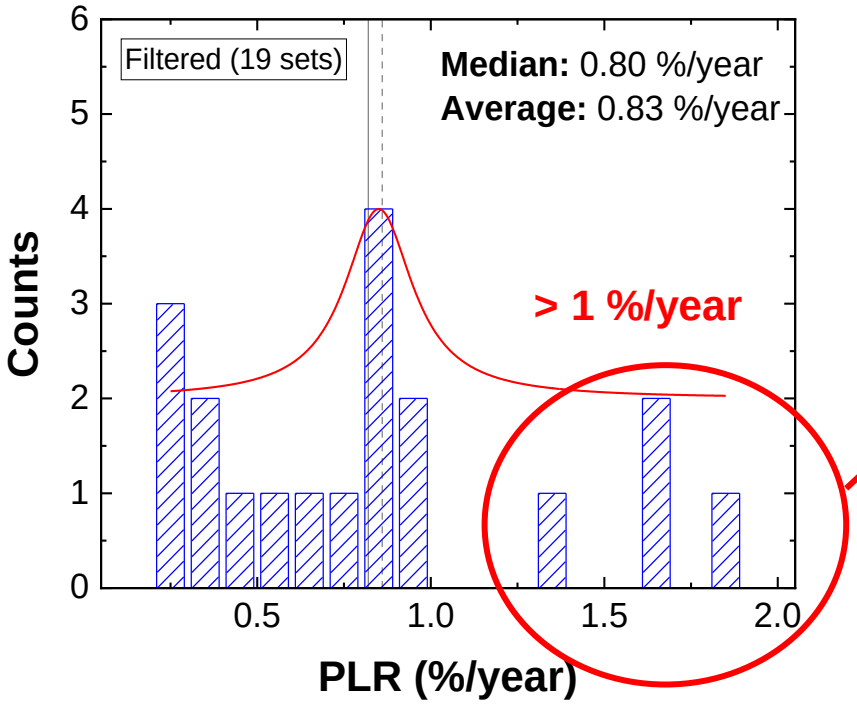
High-accuracy data-sets – Failure modes

Not a clear climate dependence trend



Main failure modes

- Often not studied.
- Loss in V_{oc} (several climates).
- **Encapsulant browning** ⟶ not particular to the SHJ technology.

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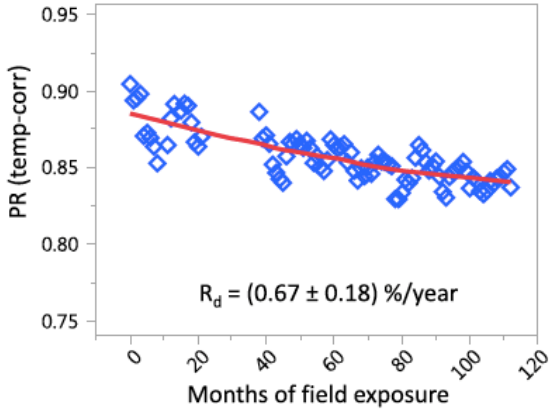
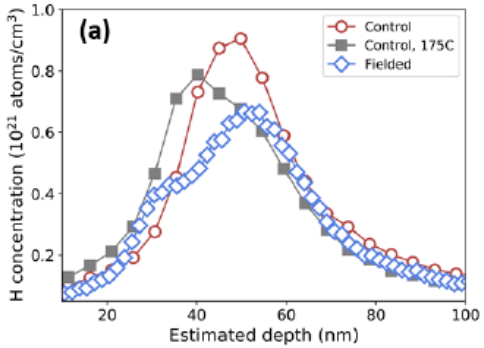
Failure modes – Loss in V_{oc}

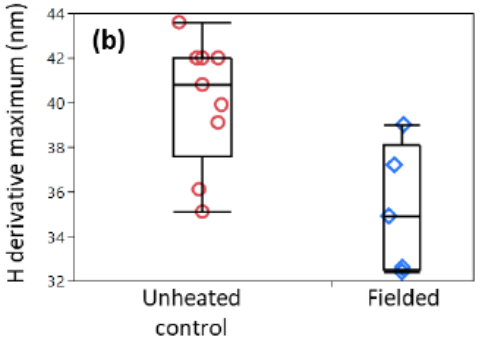
Silicon Heterojunction System Field Performance

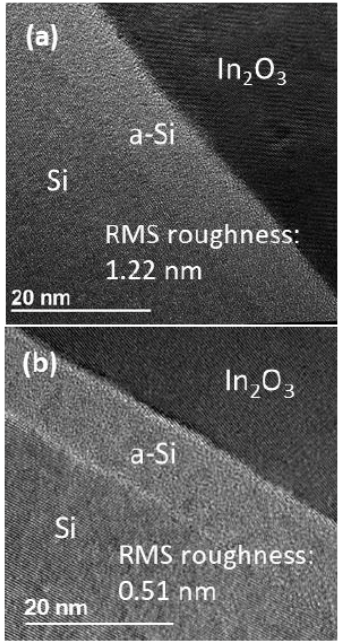
Dirk C. Jordan, Chris Deline, Steve Johnston, Steve R. Rummel, Bill Sekulic, Peter Hacke, Sarah R. Kurtz, Kristopher O. Davis, Eric John Schneller, Xingshu Sun, Muhammad A. Alam, and Ronald A. Sinton



- **Non-linear** degradation.
- **Thin front (p) a-Si:H** ⟶ lack of stability when exposed to light.







D. Jordan et al.,, IEEE PVSC (2020)

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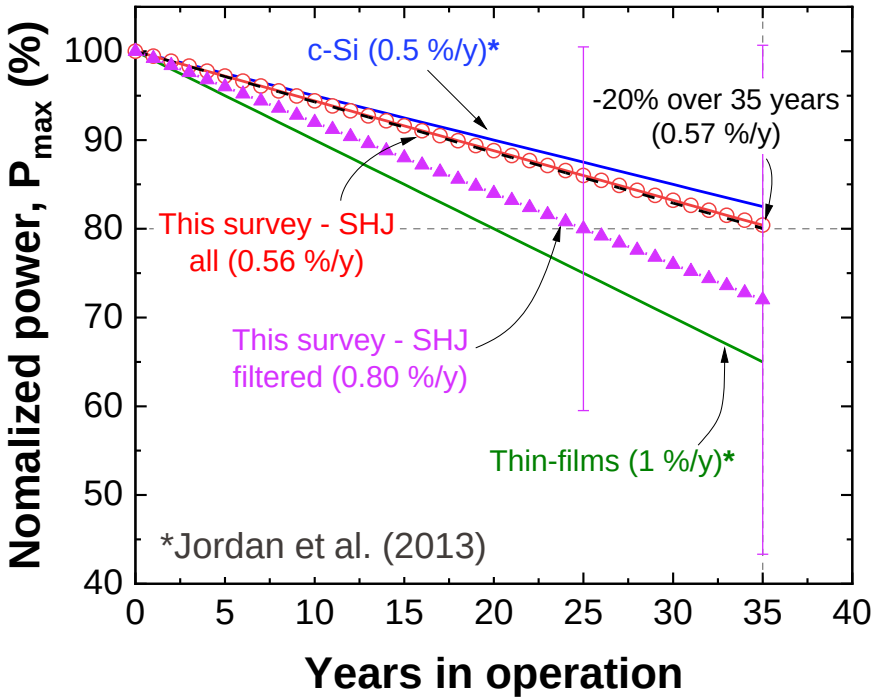
How do we ensure the 35+ years of operation of SHJ modules?



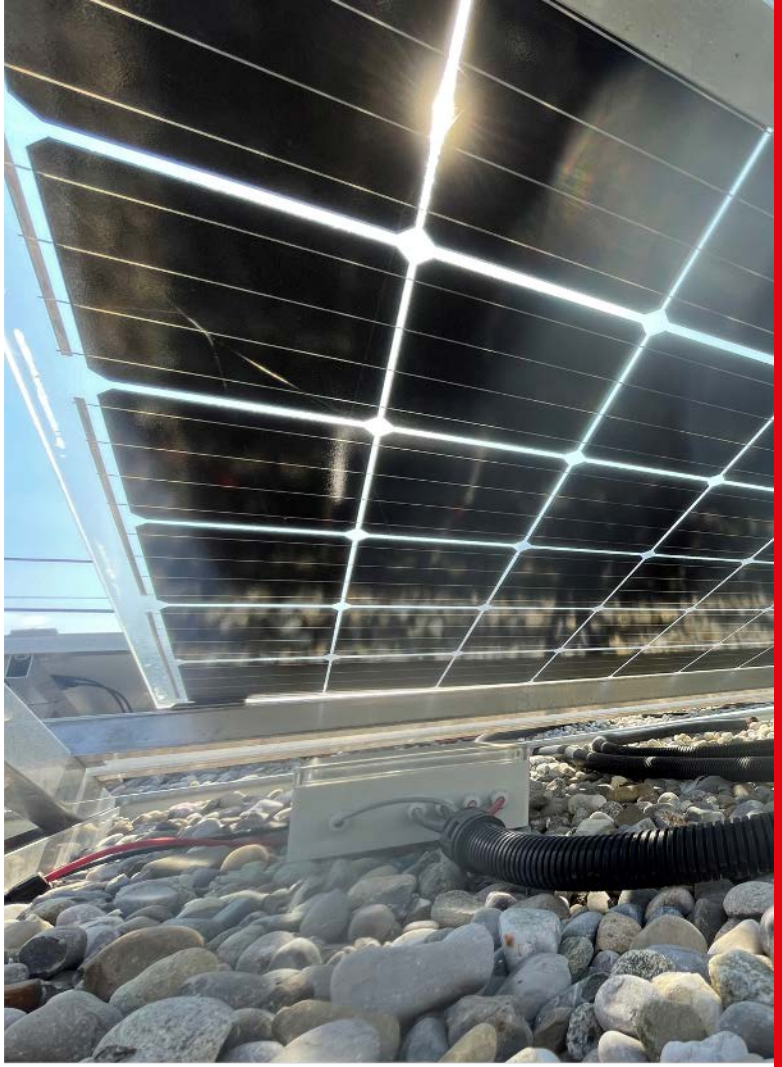
Main issues of SHJ technology

Sensitivity to:

1. Moisture ingress
2. PID
3. UV exposure

Solutions:

- Use of **high volume resistivity encapsulants** (ionomer, PO).
- Prevent moisture ingress by using an **edge sealant**.
- Using encapsulants with **UV cut-off** or a cut-off **no lower than 353 nm**.



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Extended DH test (2000 hrs)

RH=85%, T=85°C

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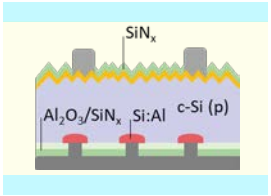
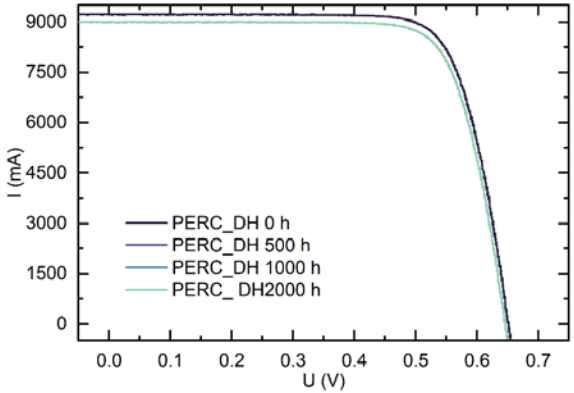
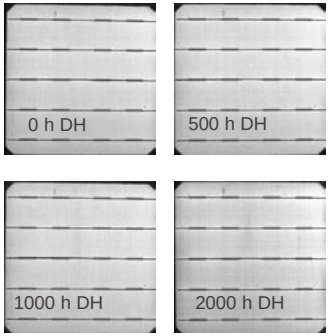
- PERC



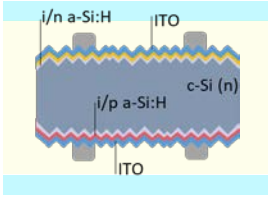
I-V curves

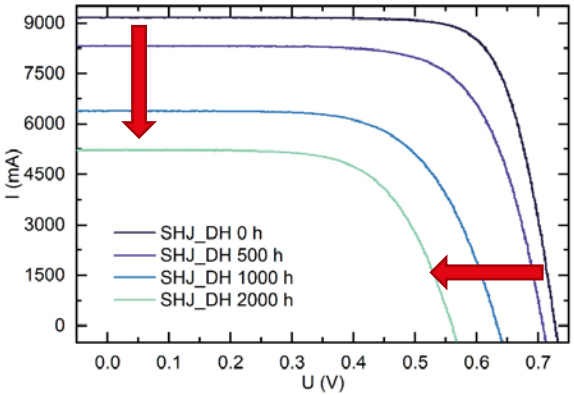


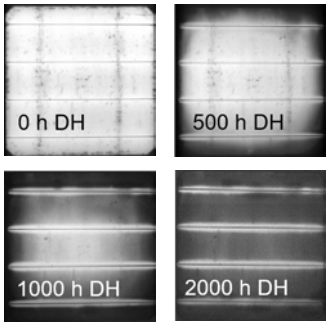
Electroluminescence images



- SHJ







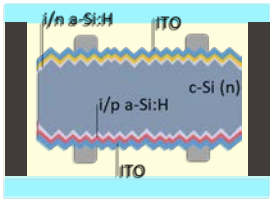
G-G SHJ: results during extended DH test

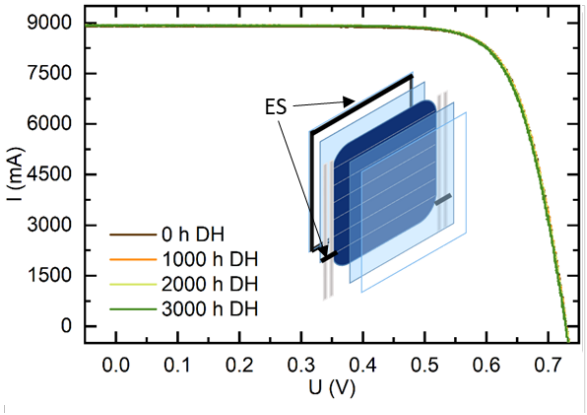
RH=85%, T=85°C

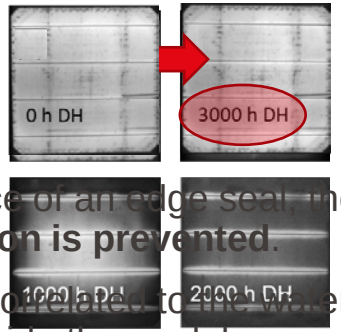
I-V curves

Electroluminescence images

- SHJ + ES





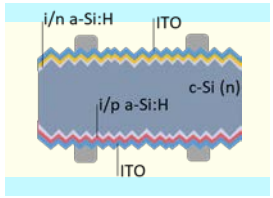


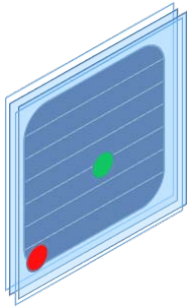
- In presence of an edge seal, the **degradation is prevented**.
- It can be correlated to the water ingress inside the module.

Water ingress and EVA properties

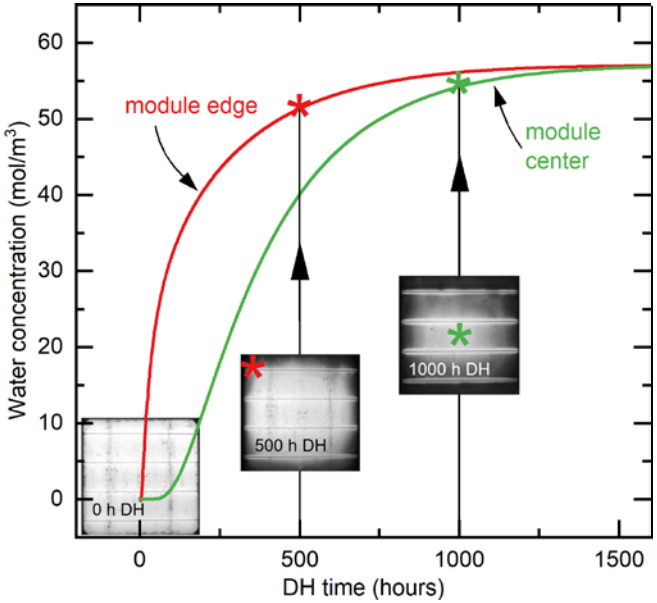
RH=85%, T=85°C

- SHJ

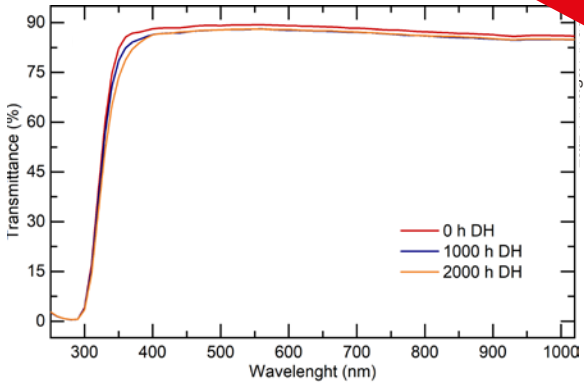




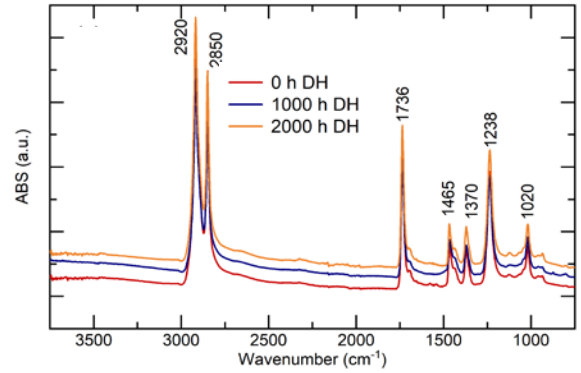
Moisture diffusion model



EVA properties



UV-Vis spectras



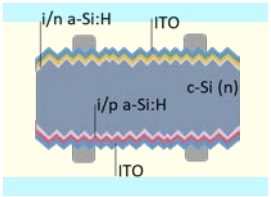
FTIR-ATR spectras

- The kenitics of the moisture diffusion and module degradation are in agreement.
- The EVA shows a good stability.

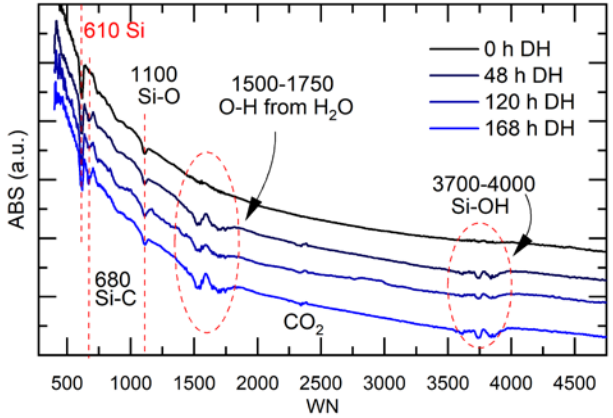
Direct effect of the moisture on the cell

RH=85%, T=85°C

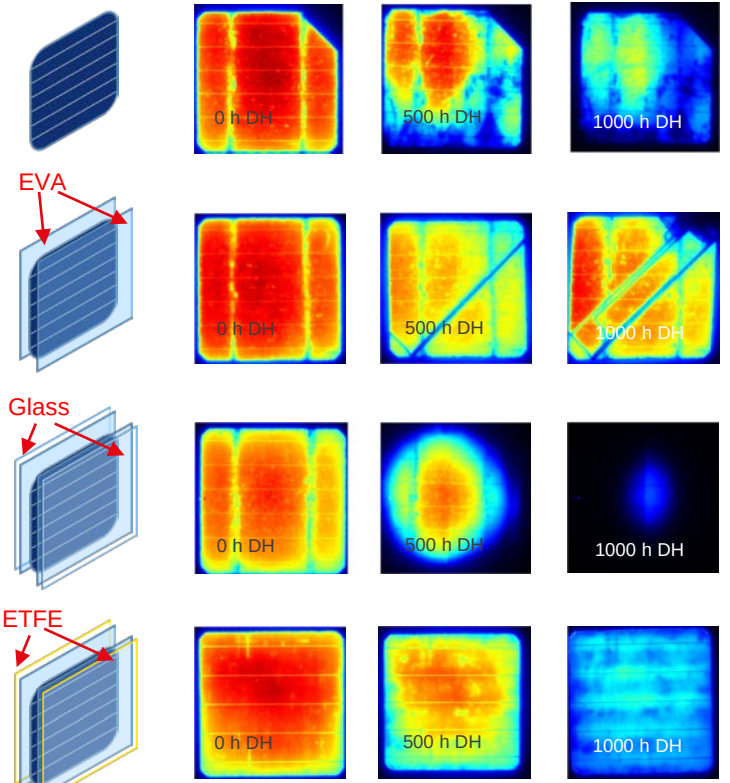
- SHJ



FTIR spectras



Photoluminescence image



- Water only is not enought to explain the degradation mechanism.
- The presence of the glass seams to be the key point for the SHJ degradation.

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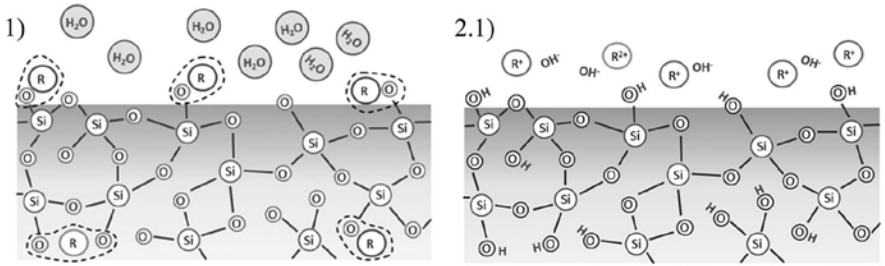
Glass corrosion and the role of sodium

- Potential induced degradation (PID)

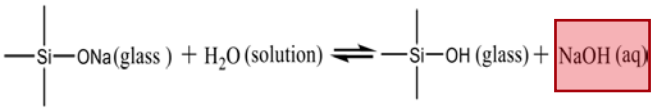
- Na^+ are driven by an electric field from the glass towards the cell

E. Annigoni, PVDays (2018)

- Damp Heat aging test



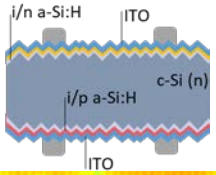
- The corrosion of the glass (i.e. leaching mechanism) produces Na^+ in DH conditions.

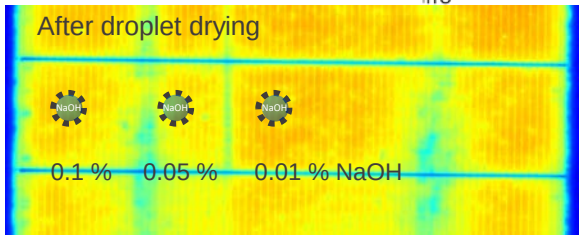


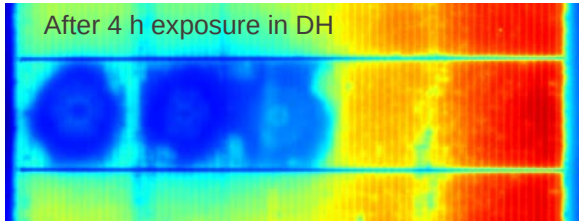
Guiheneuf, Vincent, et al. Corrosion Engineering, Science and Technology 52.3 (2017): 170-177.

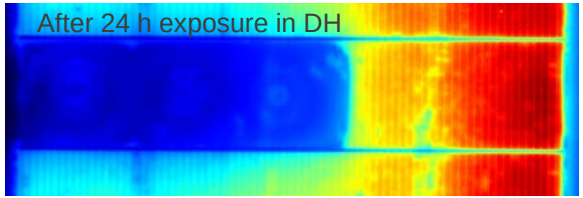
NaOH Droplet test

SHJ cell type

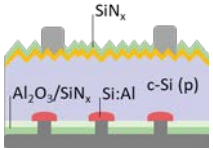


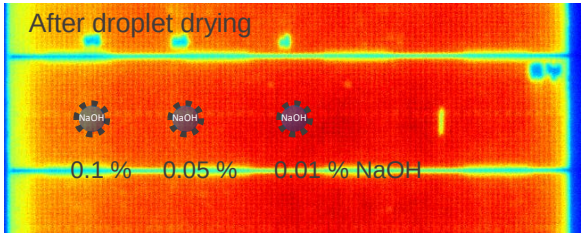


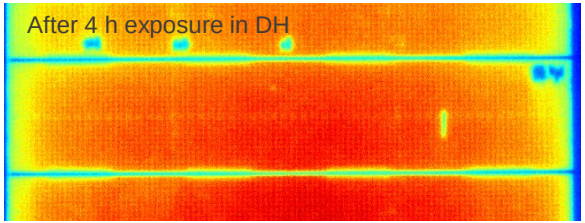


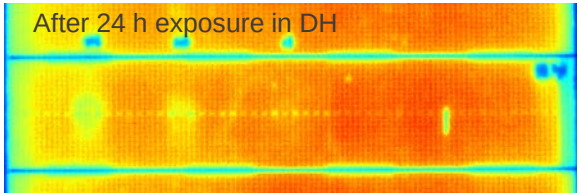


PERC cell type









PL intensity: High Low

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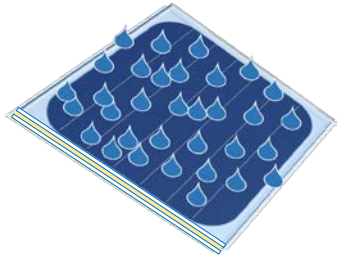
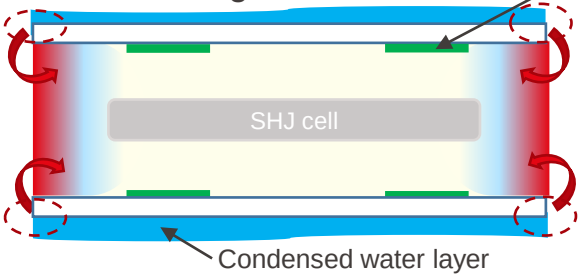
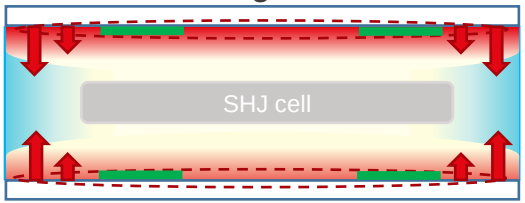
Where does the NaOH come from?

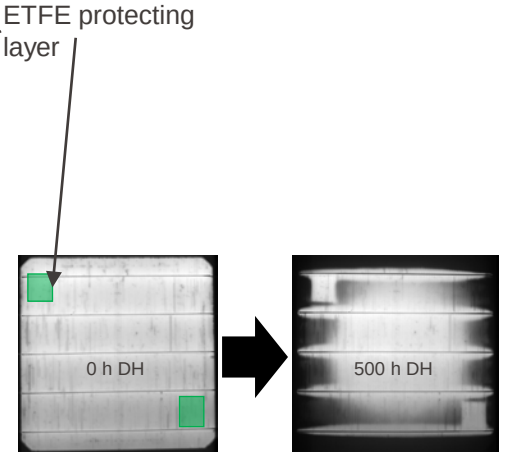


1. NaOH source along the external edges of the module



2. NaOH source at the inner surface of the glass





EL images

The presence of a protecting layer prevents the cell degradation!

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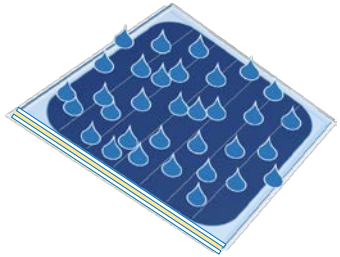
Where does the NaOH come from?



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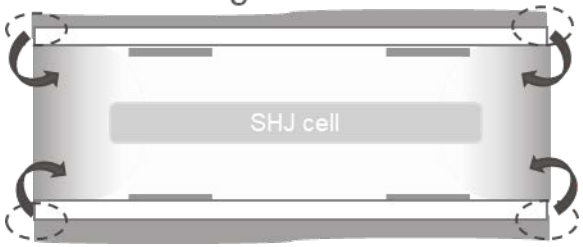
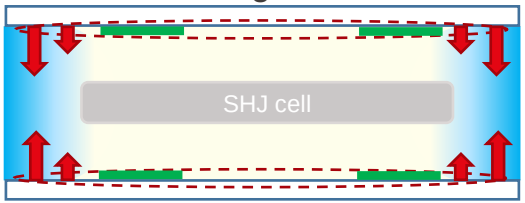
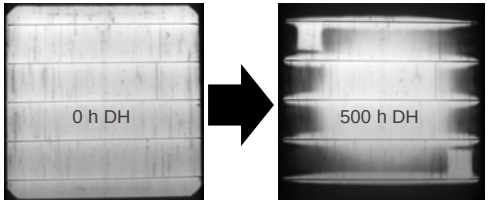


2. NaOH source at the inner surface of the glass





EL images

The presence of a protecting layer prevents the cell degradation!

- The corrosion of the glass occurs at the inner surface of front and rear glass plates.

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Microscopical model

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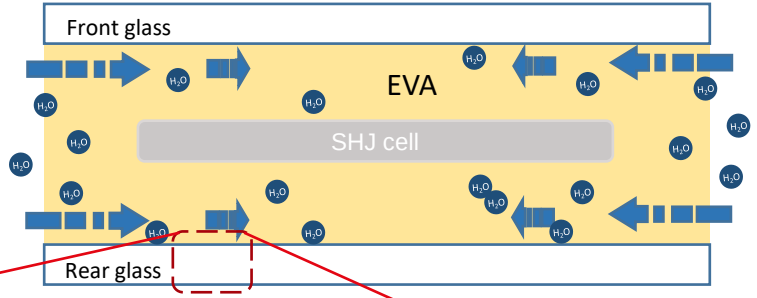
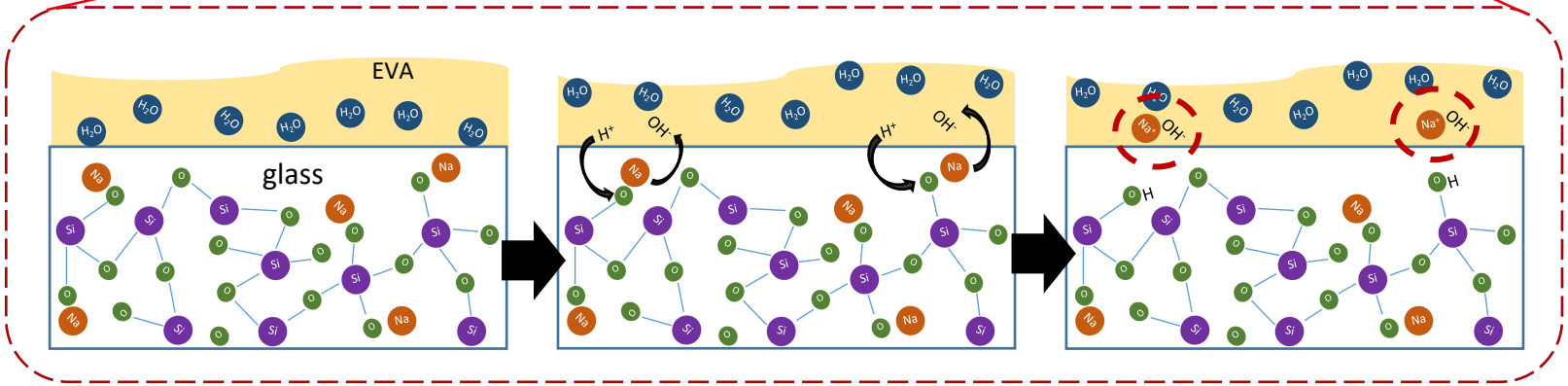
1) Water diffusion through the EVA



2) Ion exchange at the EVA-glass interface → Na+ are released in the EVA



Microscopical model

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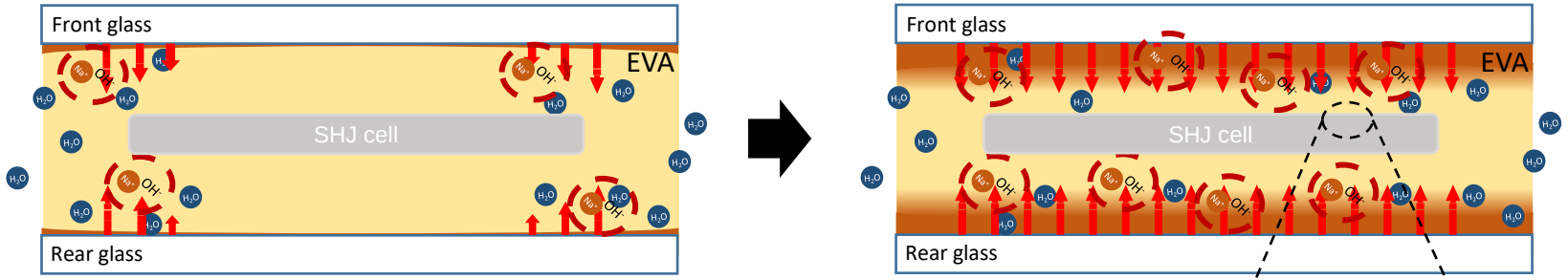
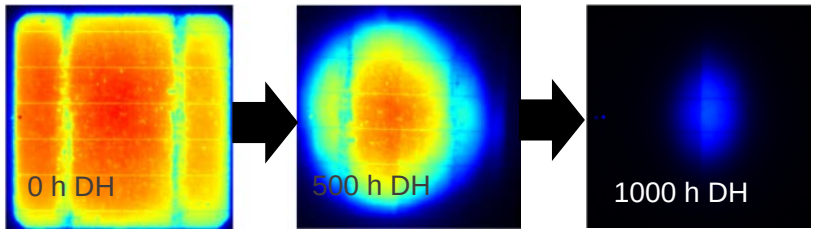
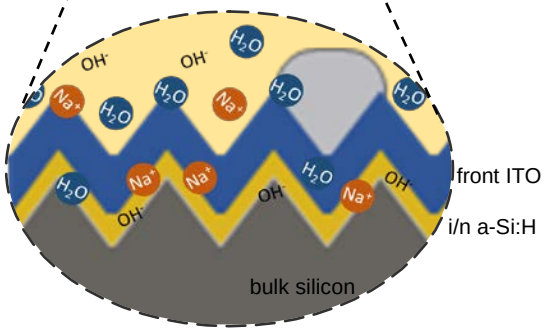
3) Gradual diffusion of Na+ towards the cell



4) Na+ cross the ITO and degrade the passivation properties of the SHJ cell





Mitigation strategies

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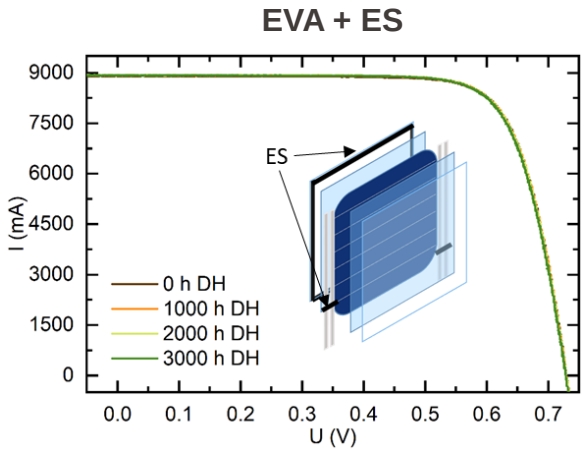
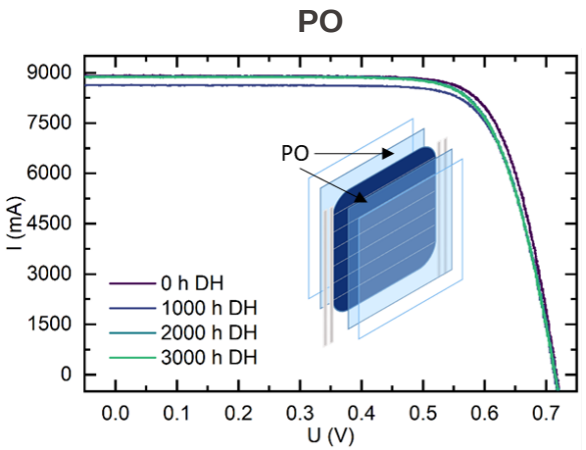




Further strategies to be investigated:

- Deposition of a SiNx capping layer on top of the ITO;
- Deposition of a *Na-barrier* layer on the inner surface of the glass (to prevent also the PID..)
- Others…

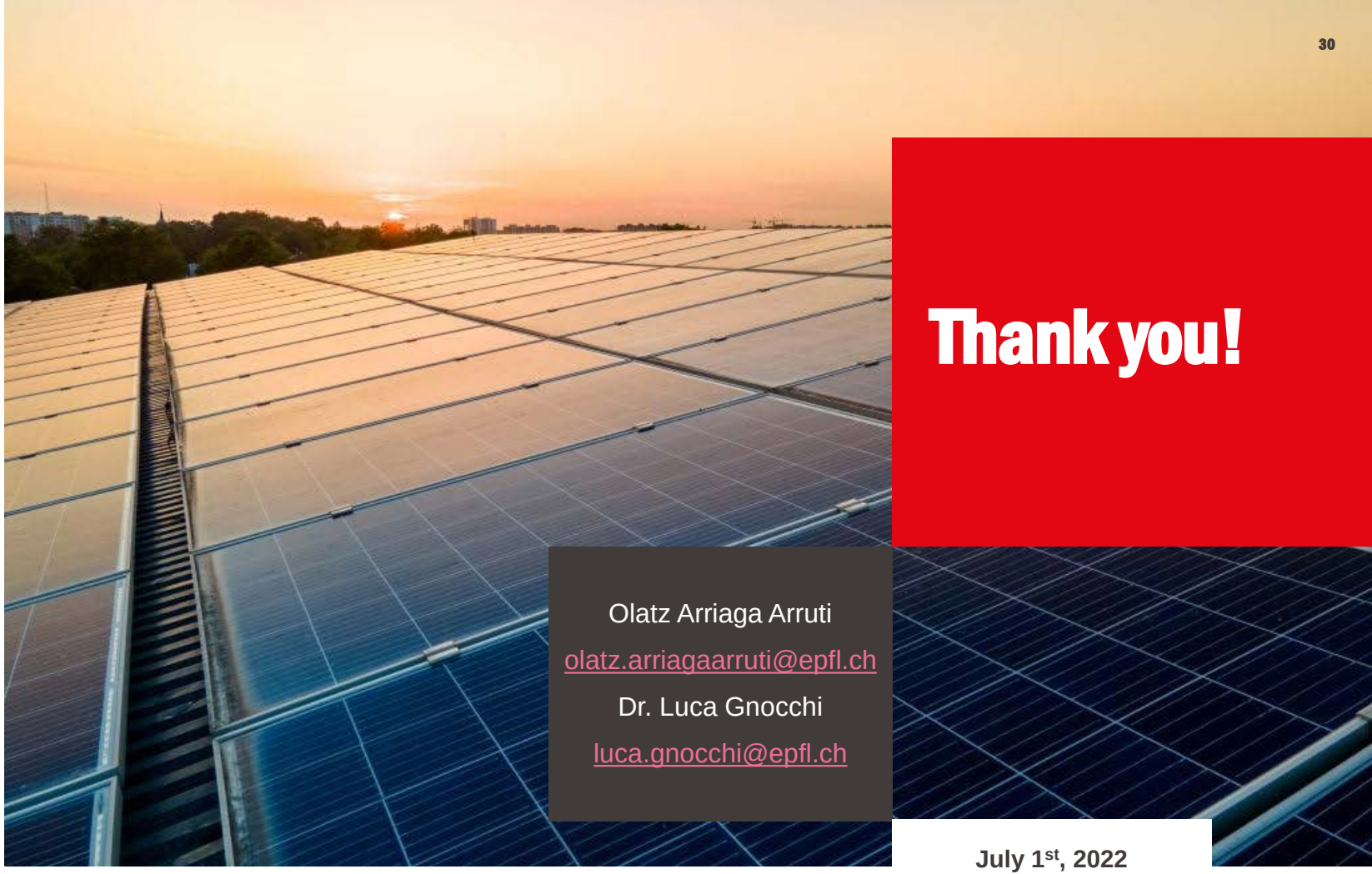
Outline

1. Introduction
2. Reliability and Long-term Performance of c-Si PV Modules
3. Field Performance of Si Heterojunction Modules
4. Indoor Accelerated Stress Testing on Si Heterojunction Technology
5. Conclusions

Conclusions

- **Literature review on long-term performance of SHJ modules**:
  - **PLR** values of **0.56 %/year** for all data-sets and 0.80 %/year for high-accuracy.
  - Main failure modes: loss in $\mathbf{V_{OC}}$ and **encapsulant discoloration**.
  - Could achieve lifetimes of 35+ years if encapsulated with a reliable BOM.

- **Indoor Accelerated Stress Tests:**
  - Sensitivity of SHJ cells & modules to **moisture ingress**, high voltages (**PID**) and **UV** exposure.
  - The use of an **edge sealant** is recommended to **reduce water ingress**: a dry EVA has proven to better withstand prolonged UV exposure and to mitigate SHJ DH and potential induced degradation (PID).



Thank you!

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