UV Induced Degradation in N-Type Modules:

Metastability, Stabilization and Mitigation

PV CellTech

Oct 7-8, 2025

Archana Sinha, Jean-Nicolas Jaubert, Todd Karin (Kiwa PVEL)
Dana B. Kern (NREL)

Kiwa PVEL

*creating trust, **driving progress***

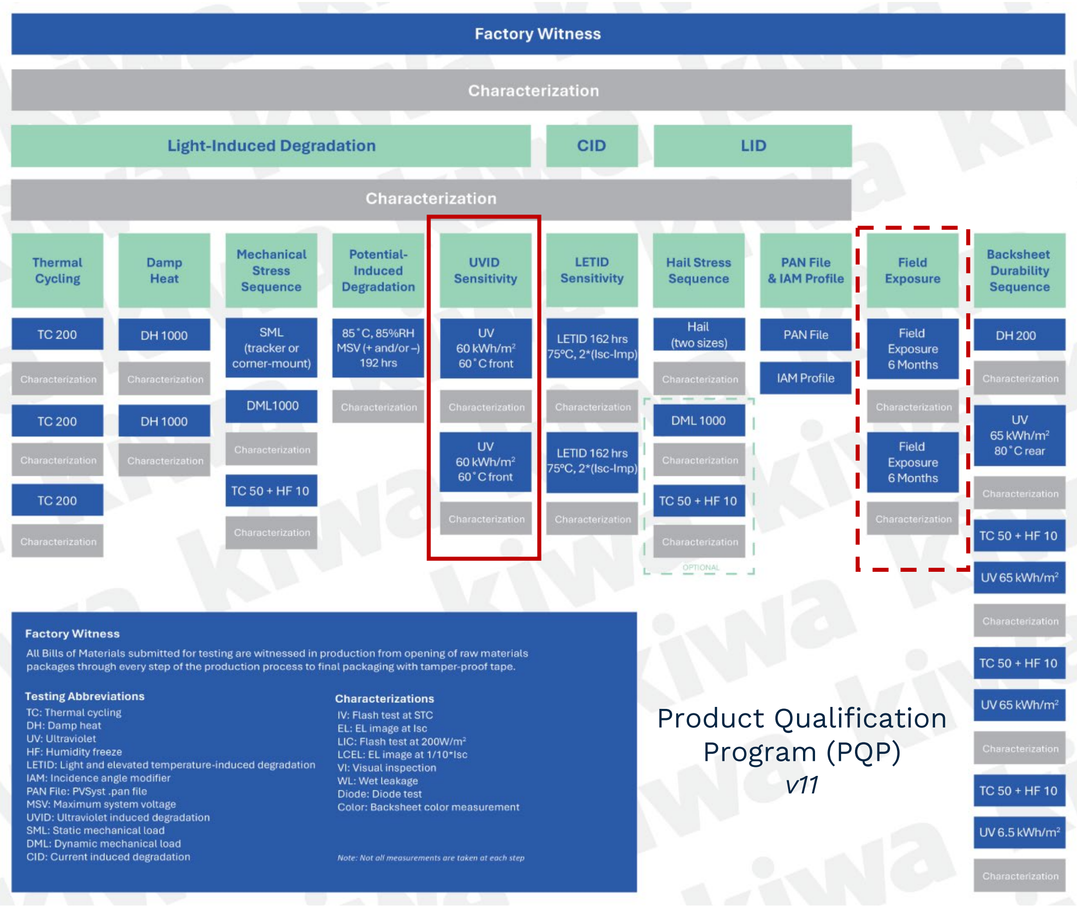
About Kiwa PVEL

- Independent lab for PV Module **Performance and Reliability Testing.**
- Headquarter test lab at Napa, US and a sister company at Suzhou, China.
- PQP test sequences updated every 2 yrs. PQP*v12* will be released by the end of this year.
- Releases PV Module Scorecard every yr. 11th ed released on June 4, 2025.

2025 PV Module
Reliability Scorecard

Executive Summary

Welcome to the 11th Edition of Kiwa PVEL's PV Module Reliability Scorecard, ***featuring the latest insights in module reliability*** and ***performance and this year's list of Top Performers.***



Factory Witness

Characterization

Light-Induced Degradation | CID | LID

Characterization

Thermal Cycling	Damp Heat	Mechanical Stress Sequence	Potential-Induced Degradation	UVID Sensitivity	LETID Sensitivity	Hail Stress Sequence	PAN File & IAM Profile	Field Exposure	Backsheet Durability Sequence
TC 200	DH 1000	SML (tracker or corner-mount)	85 °C, 85%RH MSV (+ and/or –) 192 hrs	UV 60 kWh/m^2 60 °C front	LETID 162 hrs 75°C, 2*(Isc-Imp)	Hail (two sizes)	PAN File	Field Exposure 6 Months	DH 200
Characterization	Characterization	DML1000	Characterization	Characterization	Characterization	Characterization	IAM Profile	Characterization	Characterization
TC 200	DH 1000	Characterization		UV 60 kWh/m^2 60 °C front	LETID 162 hrs 75°C, 2*(Isc-Imp)	DML 1000		Field Exposure 6 Months	UV 65 kWh/m^2 80 °C rear
Characterization	Characterization	TC 50 + HF 10		Characterization	Characterization	Characterization		Characterization	Characterization
TC 200		Characterization				TC 50 + HF 10			TC 50 + HF 10
Characterization						Characterization			UV 65 kWh/m^2
						OPTIONAL			Characterization
									TC 50 + HF 10
									UV 65 kWh/m^2
									Characterization
									TC 50 + HF 10
									UV 6.5 kWh/m^2
									Characterization

Factory Witness

All Bills of Materials submitted for testing are witnessed in production from opening of raw materials packages through every step of the production process to final packaging with tamper-proof tape.

Testing Abbreviations

TC: Thermal cycling
DH: Damp heat
UV: Ultraviolet
HF: Humidity freeze
LETID: Light and elevated temperature-induced degradation
IAM: Incidence angle modifier
PAN File: PVSyst .pan file
MSV: Maximum system voltage
UVID: Ultraviolet induced degradation
SML: Static mechanical load
DML: Dynamic mechanical load
CID: Current induced degradation

Characterizations

IV: Flash test at STC
EL: EL image at Isc
LIC: Flash test at 200W/m^2
LCEL: EL image at 1/10*Isc
VI: Visual inspection
WL: Wet leakage
Diode: Diode test
Color: Backsheet color measurement

Note: Not all measurements are taken at each step

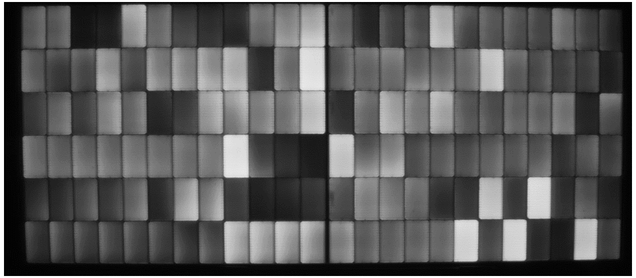
Product Qualification Program (PQP)
v11

UVID - PV Industry’s Concern

- UVID affects all module types - **TOPCon**, HJT and PERC.
- Higher vulnerability due to increased cell sensitivity to UV radiation (280-360 nm).
- Degradation occurs at cell level and directly impact the system performance, reliability and warranty.

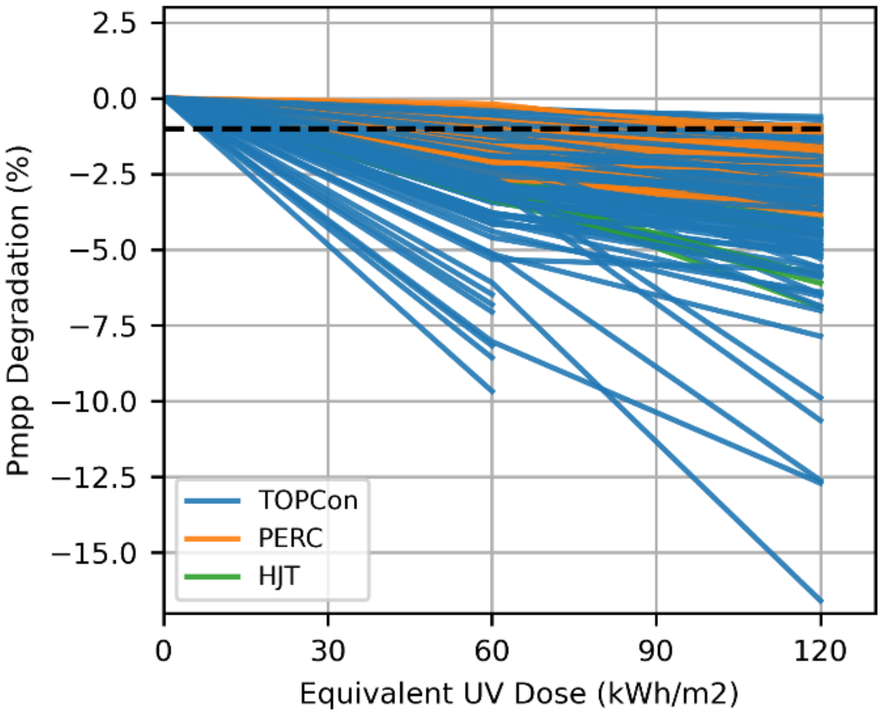
UVID 120 kWh/m^2
(Metal halide lamp exposure)

Pmpp deg -16.6%



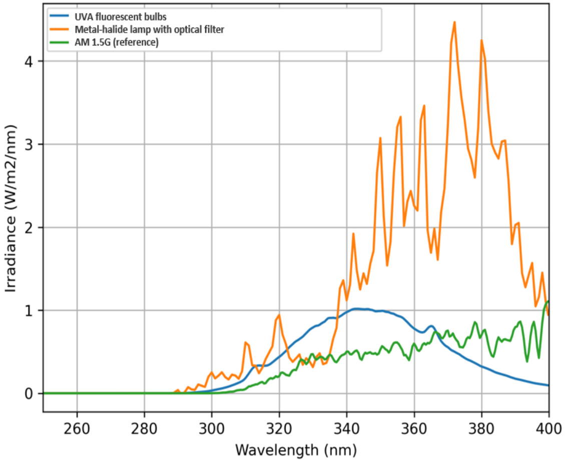
Checkerboard pattern in EL image

Kiwa PVEL’s UVID testing



Kiwa PVEL’s UVID Testing

- UV Testing with **front-side exposure,** 60°C, short-circuit condition.
- UV exposure dose of **120 kWh/m²** of UV (280-400 nm) **when using metal-halide lamps** or 53 kWh/m² when using UV fluorescent lamps.



UVID Sensitivity

UV 60 kWh/m²
60°C front

Characterization

UV 60 kWh/m²
60°C front

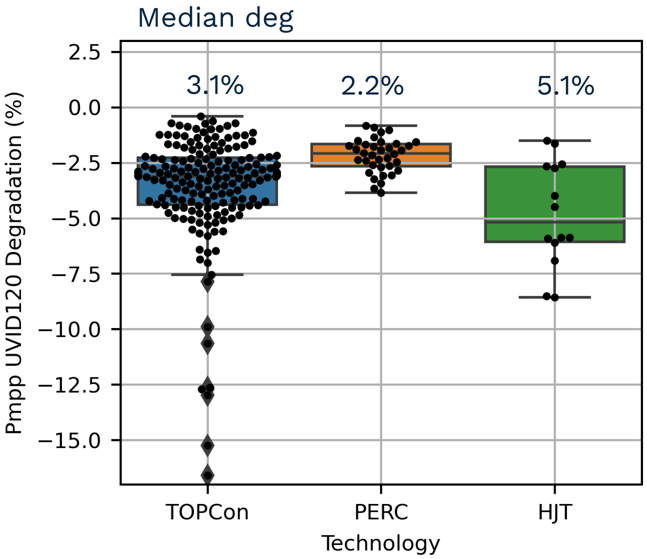
Characterization

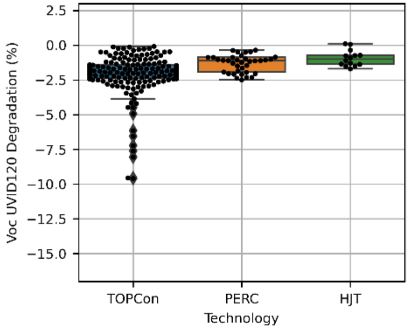
Metal-halide lamps (China)

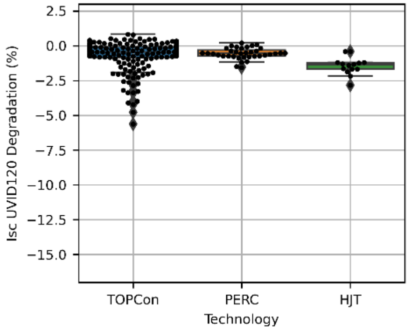
UVF-345 nm lamps (US)

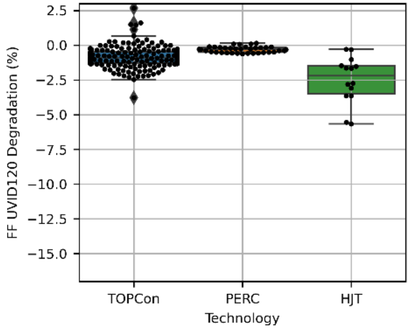
UVID Test Results

- Largest “public” dataset:
  - Total **380 modules** (190 BOMs) evaluated.
  - 77% TOPCon modules.
- Degradation mechanisms varies by cell type
- **TOPCon:** 0.6-16.6% deg
  - **Voc most affected** → cell ARC or passivation degradation
  - Greater Isc & FF losses in few BOMs
- **HJT:** 1.5-8.5% deg (limited)
  - **Isc and FF losses are significant** → front TCO/a-Si interface degradation
  - Voc is fairly stable
- PERC: lower deg







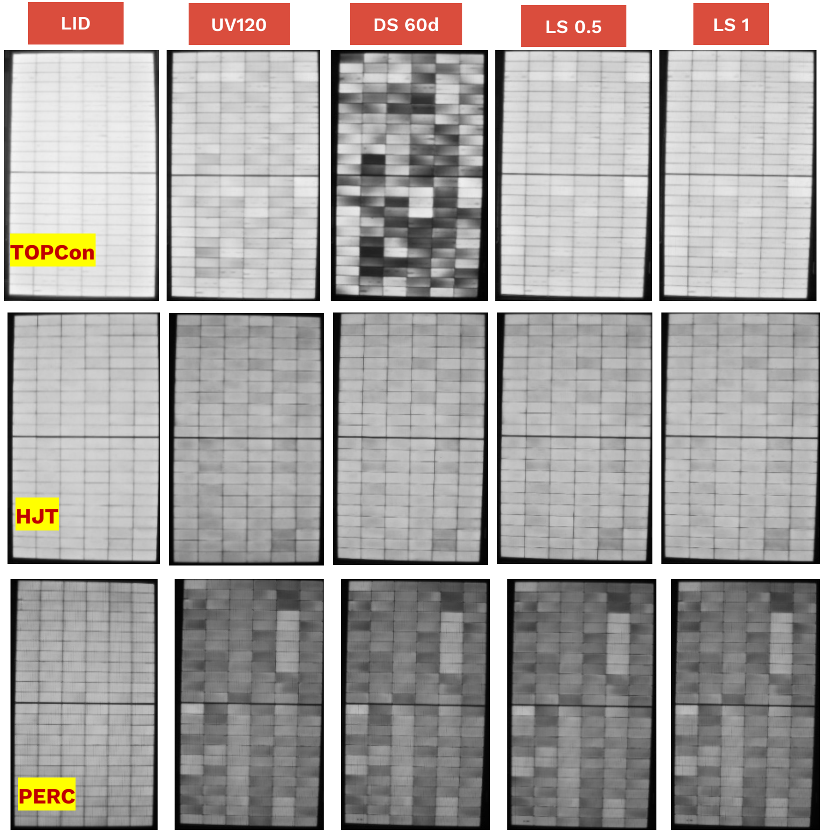


Dark Storage Metastability & Stabilization

- UVID-sensitive modules suffer from dark storage (DS) degradation (metastability).
  - Longer the dark storage period, greater is the power degradation.

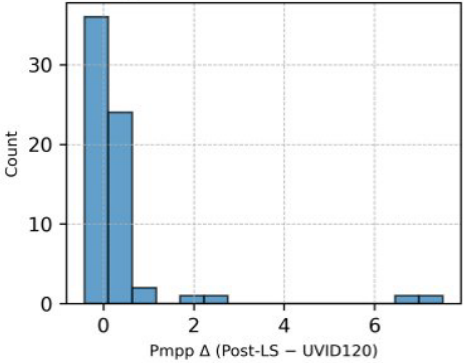
- **DS degradation is partially/fully recoverable under full spectrum light soak (LS).**
  - TOPCon - Fast and effective recovery.
  - HJT - Obvious recovery but at slower rate.
  - PERC - No obvious degradation or recovery.

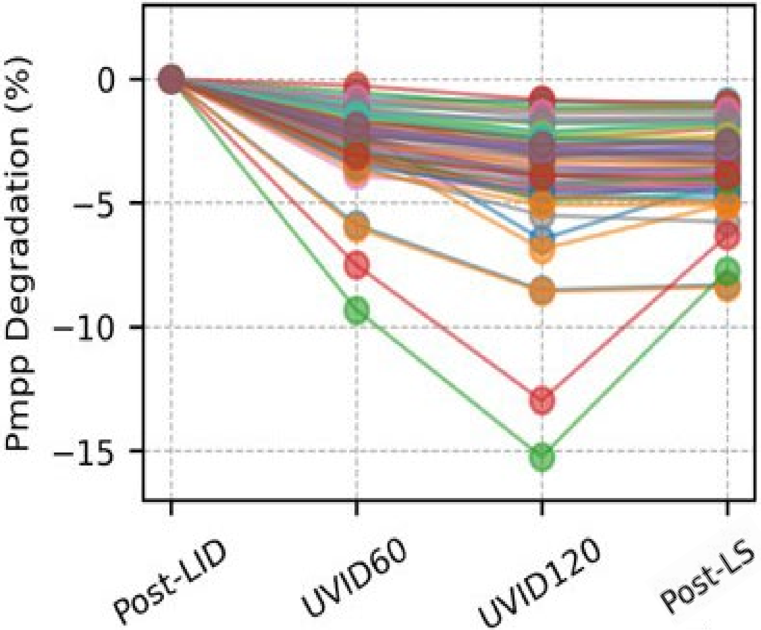
	LID	UVID120	Dark Storage (60 days)	LS 0.5kWh/m^2	LS 1kWh/m^2
Bad TOPCon	0.40%	-5.60%	-12.30%	-5.70%	-5.60%
Good TOPCon	-0.10%	-1.40%	-2.60%	-2.40%	-2.30%
HJT	0.10%	-4.50%	-6.30%	-6.00%	-5.50%
Bad PERC	0.00%	-3.00%	-3.80%	-3.80%	-3.70%
Good PERC	0.00%	-1.90%	-2.30%	-2.40%	-2.30%



Light Soak Stabilization

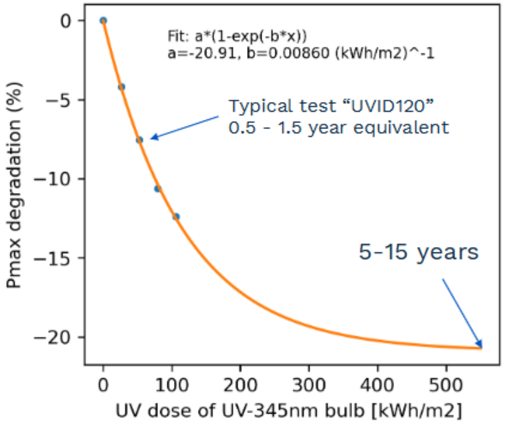
- Characterization window to flash UVID modules is controlled **within 48 hours after test completion**.
- Kiwa PVEL implemented LS stabilization step post-UVID120 (<1 kWh/m^2 of light exposure) in 2025.
- Many test samples not affected by LS (change is <0.4%), but some are very affected.
- Light soak is crucial to get accurate results on UVID-sensitive test samples.

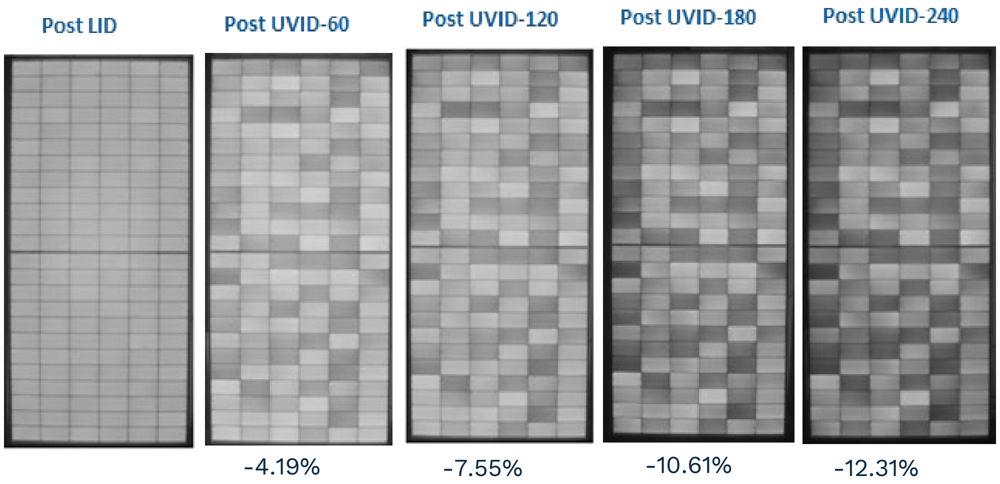




Extended UVID Testing

- Industrial TOPCon module with high UV sensitivity.
- Extrapolated using exponential fit.
- Saturation occurs after 400 kWh/m² of UV-345nm lamps.
- Kiwa PVEL will likely introduce extended UVID testing in PQP v12 [optional].



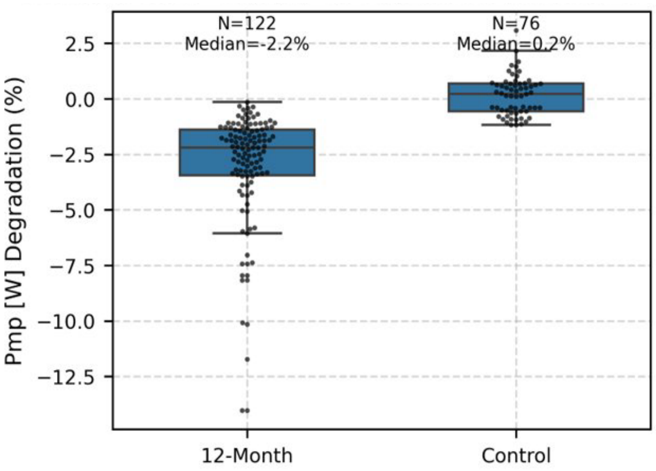


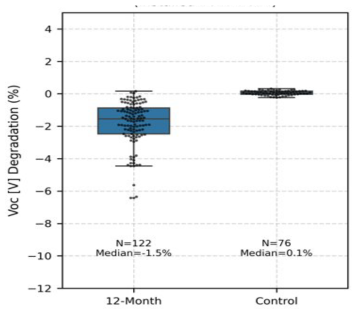
Field Degradation (TOPCon only)

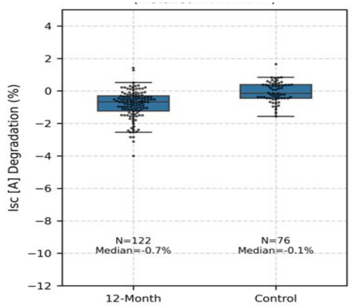
- 1-year field exposure (FE) in Davis, CA. Modules installed in 2023-2024 under MPP.

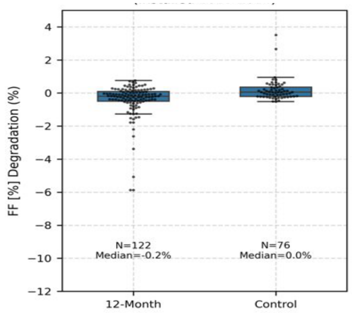
- Significant degradation (**median of 2.2%)** in fielded modules.
  - **Mainly due to UVID**. Pmp degradation is driven by Voc and Isc losses, while FF is generally stable.
  - UVID checkerboard pattern in FE modules.
  - Combined LID and LETID Pmpp loss <1%.
  - Control modules exhibited stable performance.

- Most modules do not meet a <1.0% degradation warranty in the first year.



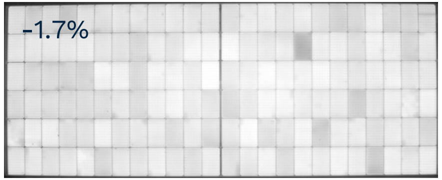


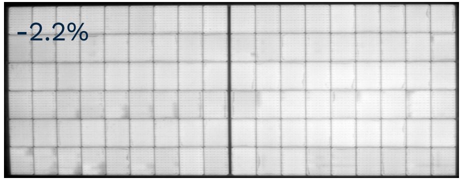


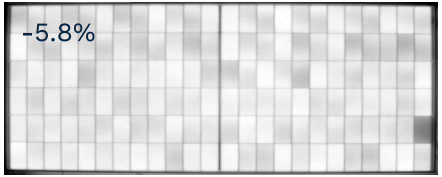


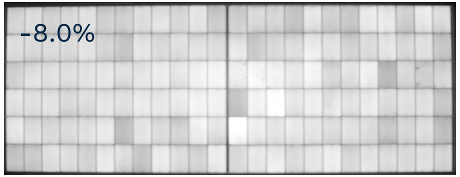
Correlation of UVID and Field Exposure

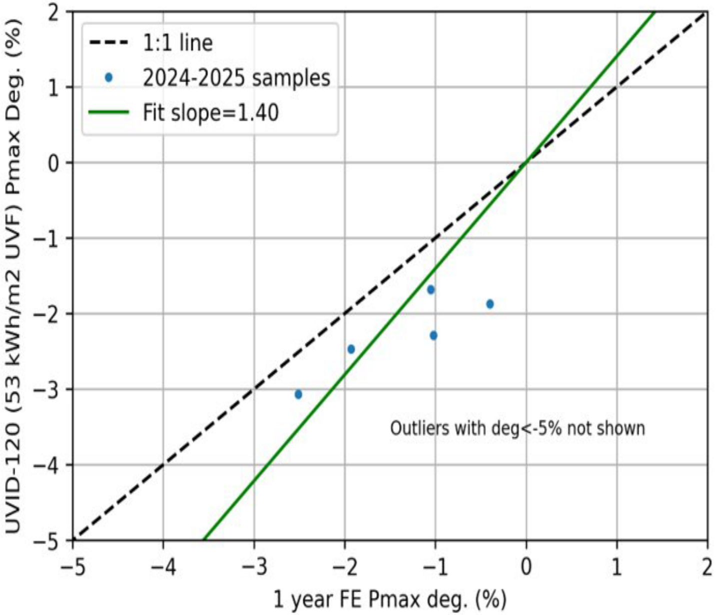
- Average of 2 modules data from UVID120 test (53 kWh/m^2 of UVF-345nm) and 1-yr field exposure in Davis CA.
- Observed higher degradation in UVID testing as compared to field. Possibly due to
  - Short-circuit condition in UV chamber
  - Full-spectrum light stabilization in outdoor field
- UVID signature is clearly visible in EL images of several FE modules, post 1-yr exposure.









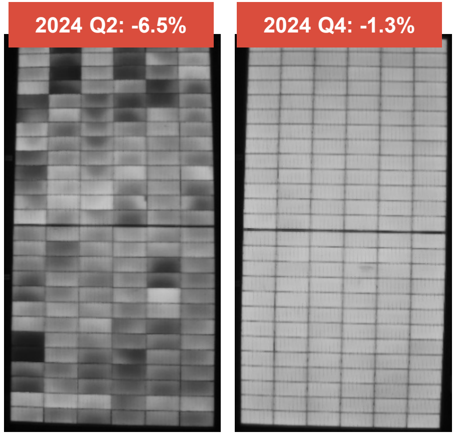


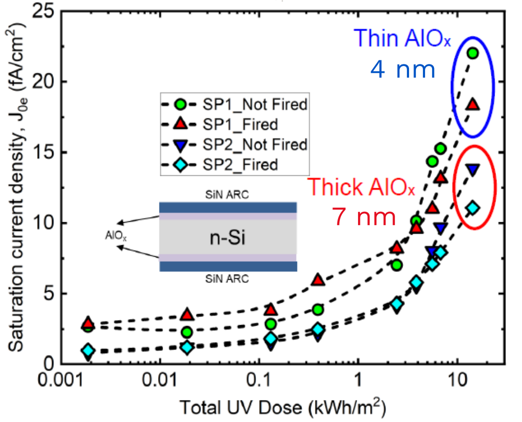
UVID Mitigation at Cell Level

- Cell design/process improvements
  - **Front cell ARC/passivation layer process controls (**AlOx thickness, passivation and ARC stack uniformity, refractive index and quality of passivation layer, etc.**)**

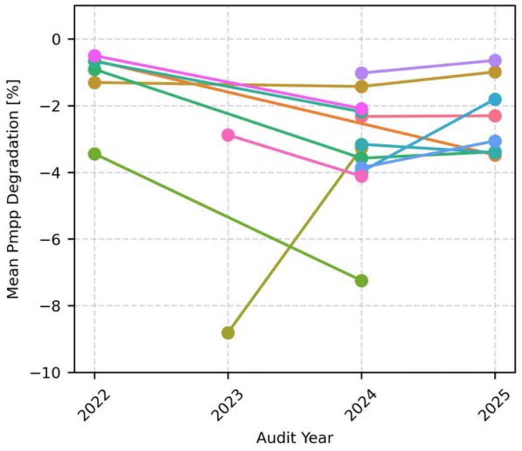
- Example: A TOPCon project tested in 2024 Q2, was retested in 2024 Q4 with same BOM.
  - Original samples: deg 6.5% (average), strong checkerboard pattern.
  - Retest samples: deg 1.3% (average), no EL defects.

- Many cell suppliers have improved their production quality processes, resulting in lower degradation in UVID testing 2025 from 2024.





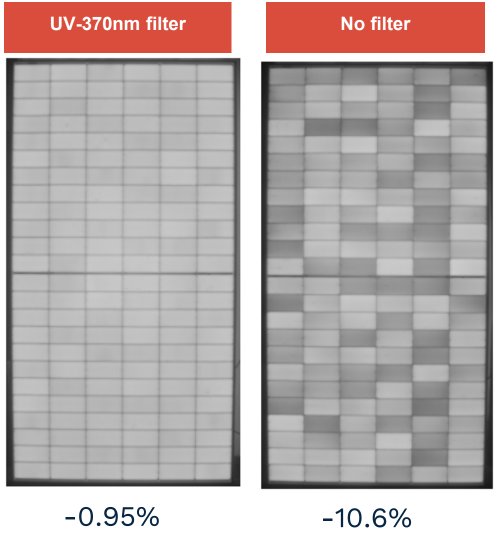
Source: Bram Hoex, UNSW, 2025.

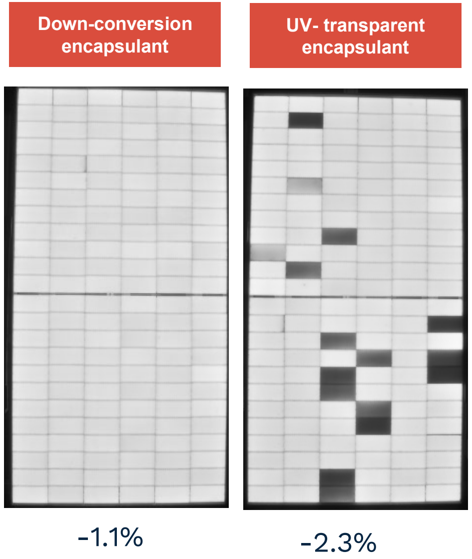


Note: Each line is an individual cell supplier.

UVID Mitigation at Module Level

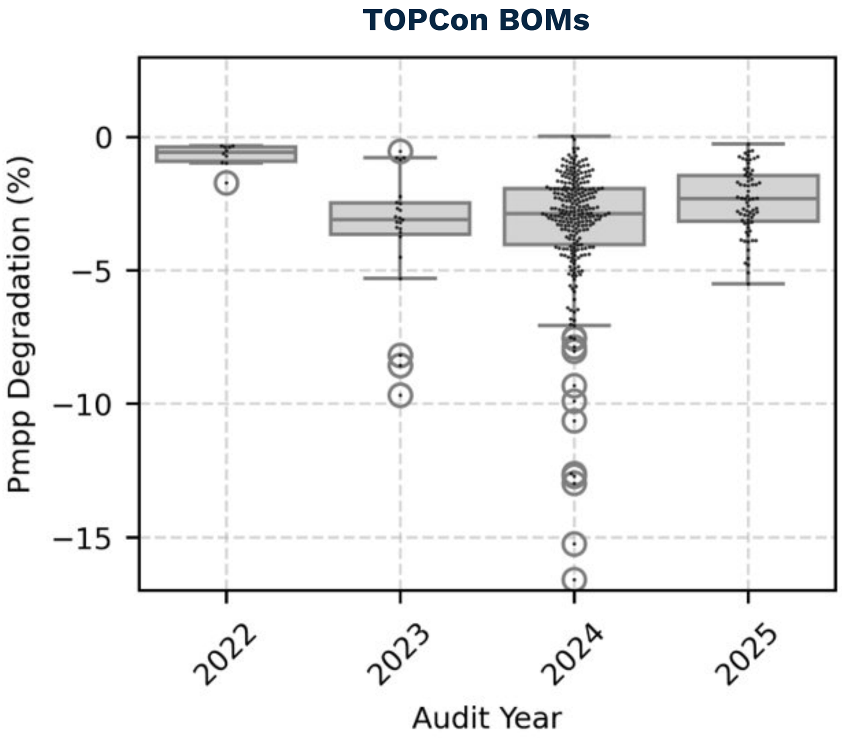
- **Encapsulant Additives and UV cut-off wavelength are critical** for UVID.
- Cut-off wavelength of front encapsulant varies in the range of 220-380 nm.
  - **Higher degradation below 350nm cut-off**.
  - UVID extent can be lowered when tailoring the encapsulant cut-off band.
- **UV down-conversion encapsulants.**
  - Currently used in HJT module designs.
  - UVID effects can be mitigated.
  - Other reliability issues may trigger, need to be tested.





Key Takeaways

- UVID is a **reliability concern for n-type** modules, as confirmed in the field.
- Test modules must be flashed within 48 hours to accurately measure the power degradation.
- **A short light soak under full spectrum** (indoors or outdoors) can stabilize the modules from dark storage metastability.
- Front cell **ARC/passivation layer process controls** and appropriate **encapsulant additives** can help in solving the UVID problem.
- UVID stability has improved as cell manufacturers learned how to mitigate UVID by using better or thicker AlOx.
- Many recent modules exhibited **power loss <3%**.



Note: some big outliers are partially a result of dark metastability.

Thank you!

Funding provided by the Durable Module Materials Consortium 2 (DuraMAT 2), an Energy Materials Network Consortium funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office agreement number 38259. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

creating trust, ***driving progress***

Contact us:
Kiwa PVEL
pvel@kiwa.com
www.kiwa.com/pvel