New Cells, New Issues: Stress Tests For N-Type PV Module Designs

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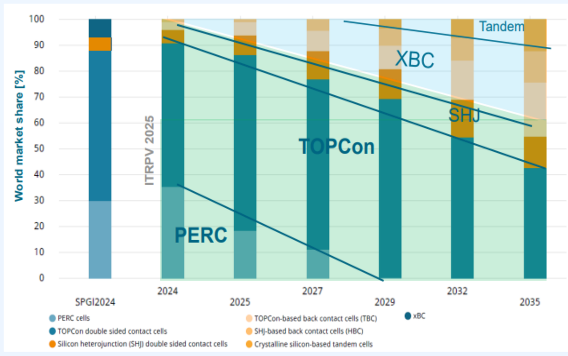
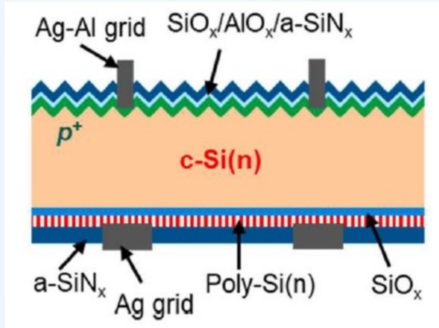
INTRODUCTION

- n-type cell technologies (primarily TOPCon) replaced p-type PERC as c-Si workhorse.
- Growth is driven by higher efficiency, improved bifaciality, and better resilience to LID and LETID.
- These cell types are found susceptible to
  - *UV induced degradation (UVID)* - passivation loss
  - *Potential induced degradation (PID)* – shunting, polarization, contact corrosion, delamination
- Checkerboard patten observed in module EL images at several plant sites – **field reliability problem**.
- Higher risk for module performance and warranty, as the first year of degradation may exceed 2%.





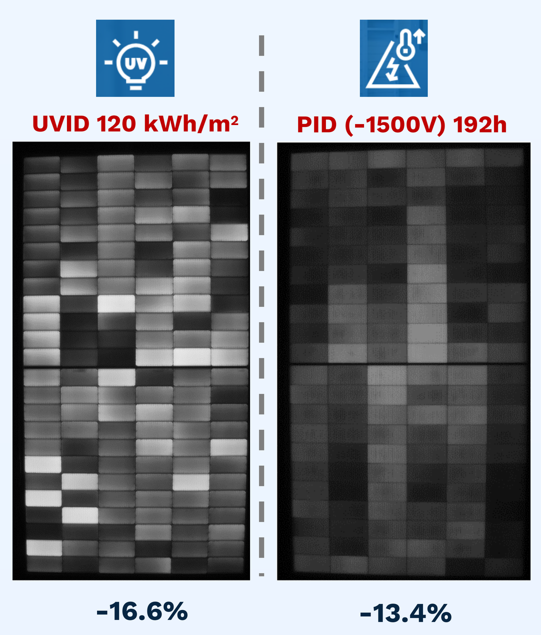
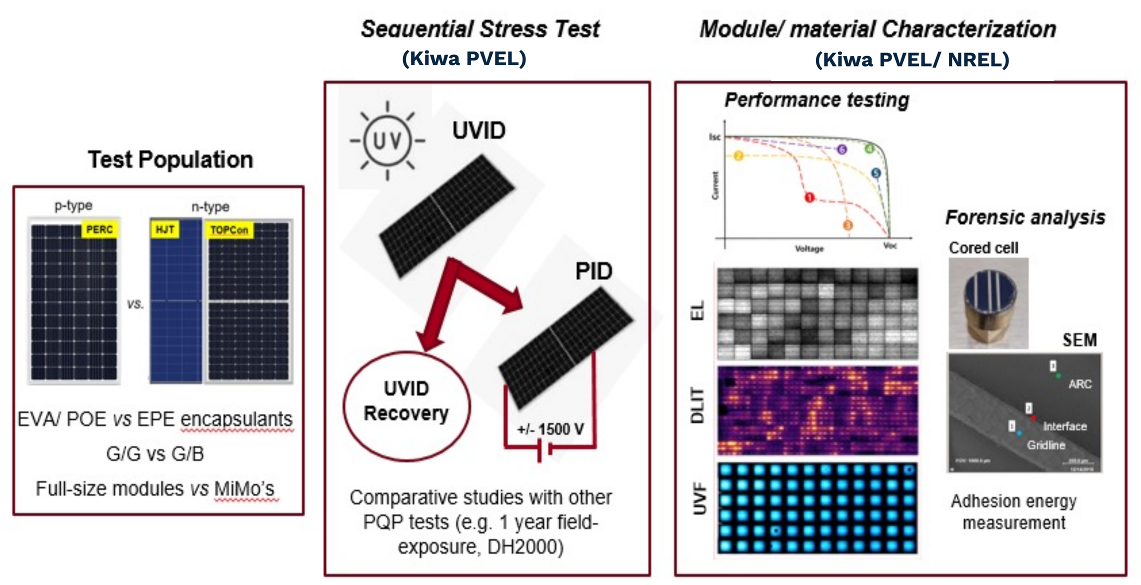


Image: Kiwa PVEL's PQP testing results

PROJECT GOALS

- Benchmark state-of-the-art reliability for n-type cells and new encapsulants against UVID and PID of industrial full-size modules.
- Understand the root-cause mechanisms behind UVID and PID.
- Develop UVID recovery techniques.
- Correlate accelerated stress tests with field-exposure and other tests (DH2000, LETID).
- Deposit test results in the DuraMAT DataHub.

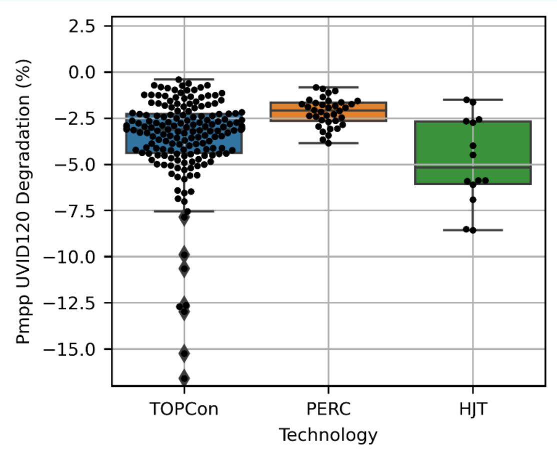


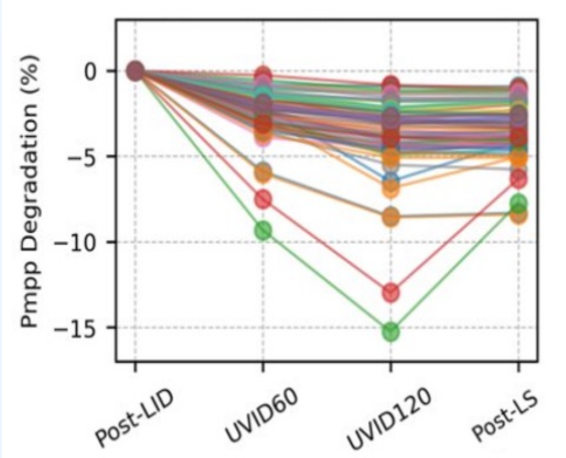
CORE OBJECTIVES

- Disruptive Acceleration Science
- Fielded Module Forensics

RESULTS: ACCELERATED UVID TESTING

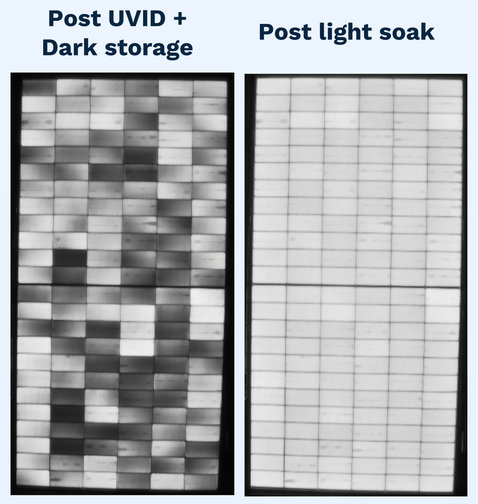
- Largest "public" dataset:
  - 380 modules (190 BOMs) -- 77% TOPCon
- Different cell types & BOMs have different UV sensitivity
  - TOPCon: -0.6% to -16.6% (passivation loss → Voc loss)
  - HJT: -1.5 to -8.5% (TCO degradation → Isc & FF losses)
  - PERC: <-3% (relatively stable)
- UVID-sensitive modules suffer from dark storage degradation (metastability) with pronounced checkerboard pattern.
- DS degradation is partially/fully recoverable under full spectrum light soak (LS).
  - TOPCon - Fast and effective recovery.
  - HJT - Obvious recovery but at slower rate.





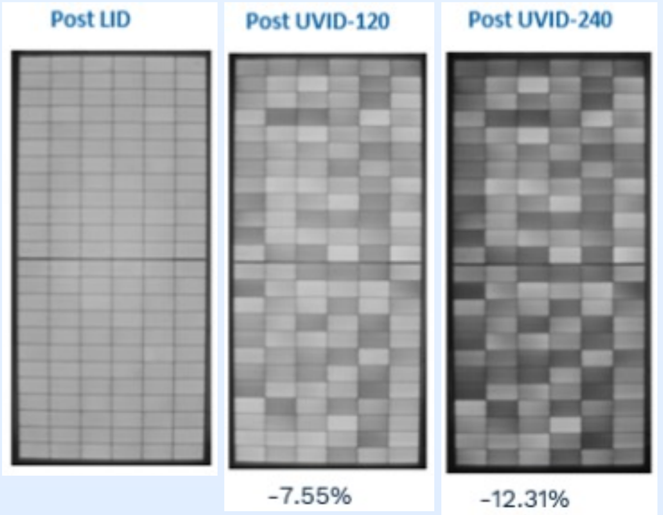
Light soak stabilization:

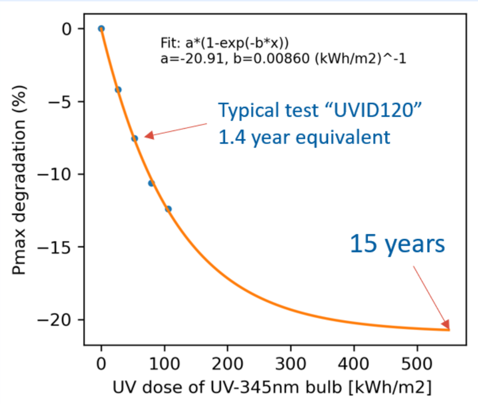
- Modules flashed within 48h after test completion.
- If not, modules subjected to a full-spectrum light soak of 1 kWh/m²
- Light soak under open-circuit.
- Module flashed within 4h after removing from light soaking.



Extended UVID testing:

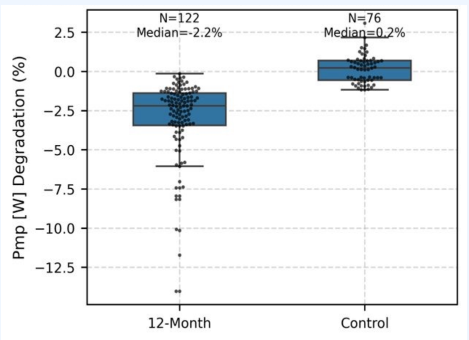
- Industrial TOPCon with high UV sensitivity
- Extrapolated using exponential fit.
- Saturation occurs after approx. 15-yr of field aging (550 kWh/m² of UV-345nm bulbs)
- Module that loses 7.5% after UVID120 expected to saturate at 21% power degradation.

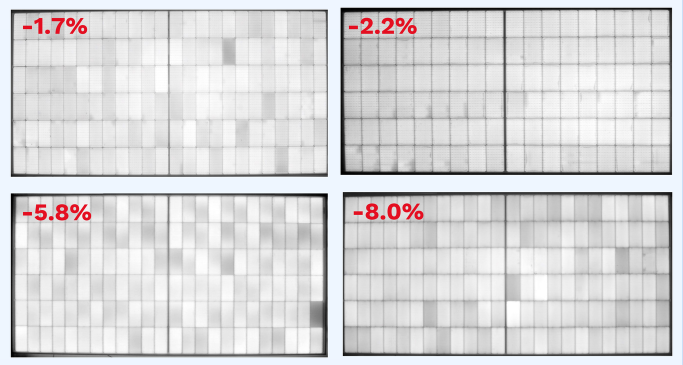




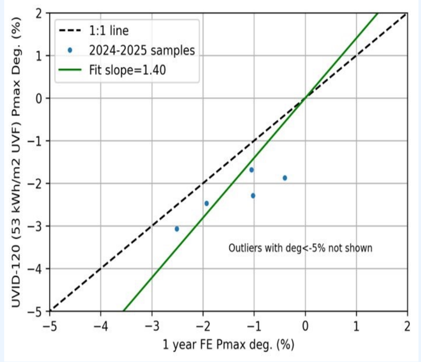
OUTDOOR TESTING

- 1-yr field exposure in Davis, CA. TOPCon modules installed in 2023-2025 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 fielded modules.
  - Combined LID and LETID Pmp loss <-1%.
- Control modules exhibited stable performance.



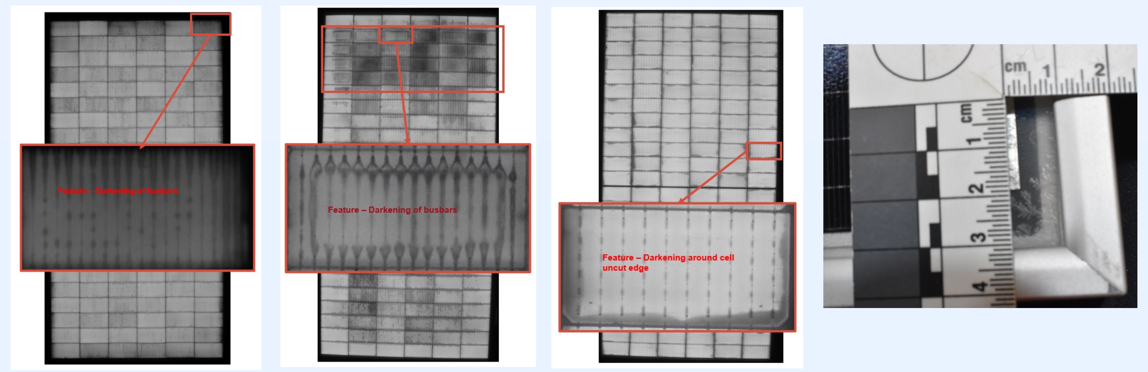


- Higher degradation in UVID chamber testing as compared to outdoor field.
  - Short-circuit condition in UV chamber.
  - Full-spectrum light stabilization in outdoor field.



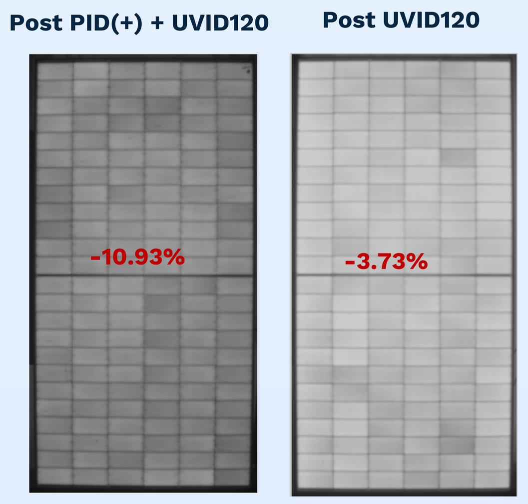
ACCELERATED PID TESTING

- PID modules exhibited significant power loss under negative bias compared to positive bias.
- EL images displayed different degradation features.



PID + UVID SEQUENTIAL TESTING

- UVID120 testing on PID stressed modules (+1500V, 192h) showed strong power degradation.
  - Driven by Voc and FF losses.
- Standalone UVID test showed lower degradation.
- PID+ might have caused some changes in passivation layer that resulted increased UVID sensitivity.

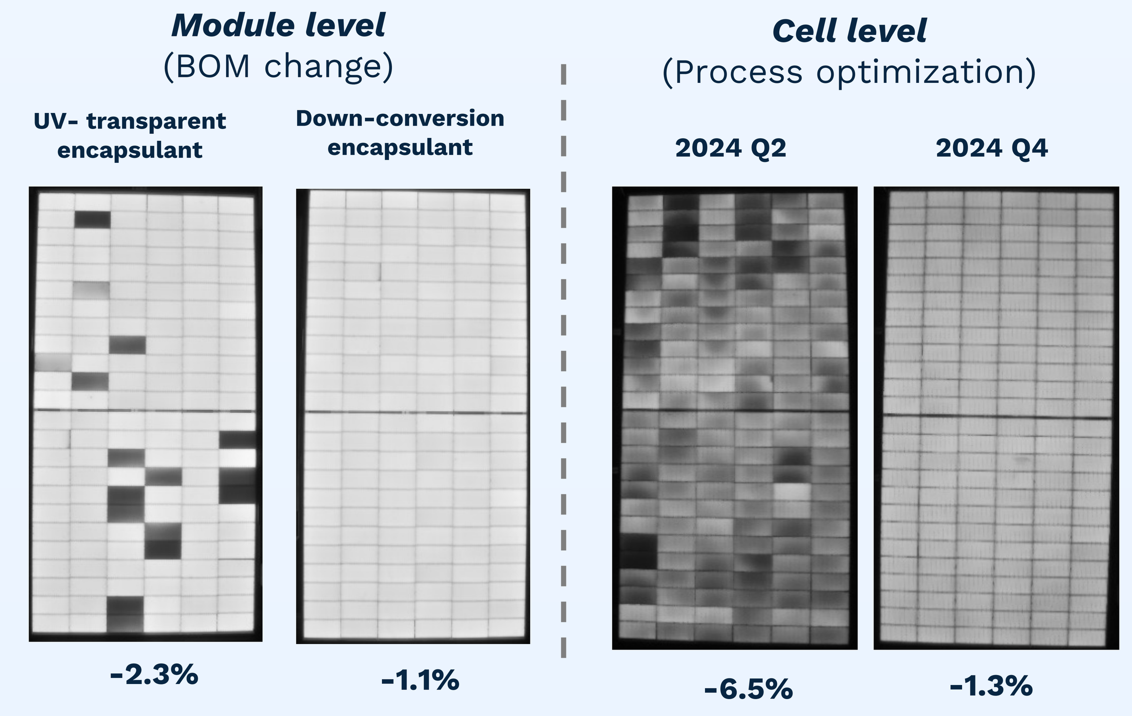


Step#	Pmp%	Voc%	Isc%	FF%
Post PID+	-1.06	0.31	-0.68	-0.69
UVID60#1	-7.90	-3.91	-1.43	-2.77
UVID60#2	-10.93	-6.86	-1.66	-2.74

Step#	Pmp%	Voc%	Isc%	FF%
UVID60#1	-0.76	-0.84	0.60	-0.52
UVID60#2	-3.73	-2.32	-0.15	-1.29

UVID or PID MITIGATION

- ***Material choices (BOM):***
  - ***For UVID,*** Use UV-stable encapsulants with strong stabilizers package (UV-blocking or UV down-conversion).
  - ***For PID,*** Use encapsulants with better moisture barrier and sodium blocking; low-sodium glass.
- ***Cell and interface engineering:*** Optimize the tunnel oxide and poly-Si or AlOx layers (for TOPCon). Optimize the TCO layer (for HJT).
- ***Process control and testing rigor:*** Maintain better quality and more testing.
- Industry adoption is very limited as these solutions will affect cost, efficiency & production turnaround.



SUMMARY & FUTURE WORK

- Few TOPCon and HJT BOMs exhibited higher susceptibility to UVID as evidenced by both lab and field test data.
- Growing concerns exist regarding their metastability behavior in the dark. Light soak stabilization method has been standardized.
- Perform forensic analysis of UVID samples using coring and advanced characterization. (*ongoing*)
- UVB testing on mini-modules for studying the long-term degradation, which is expected to provide faster test results than UVA testing.
- Perform combined/sequential stress testing on more test samples to understand coupling mechanism and its impact on bankability.

ACKNOWLEDGMENT

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