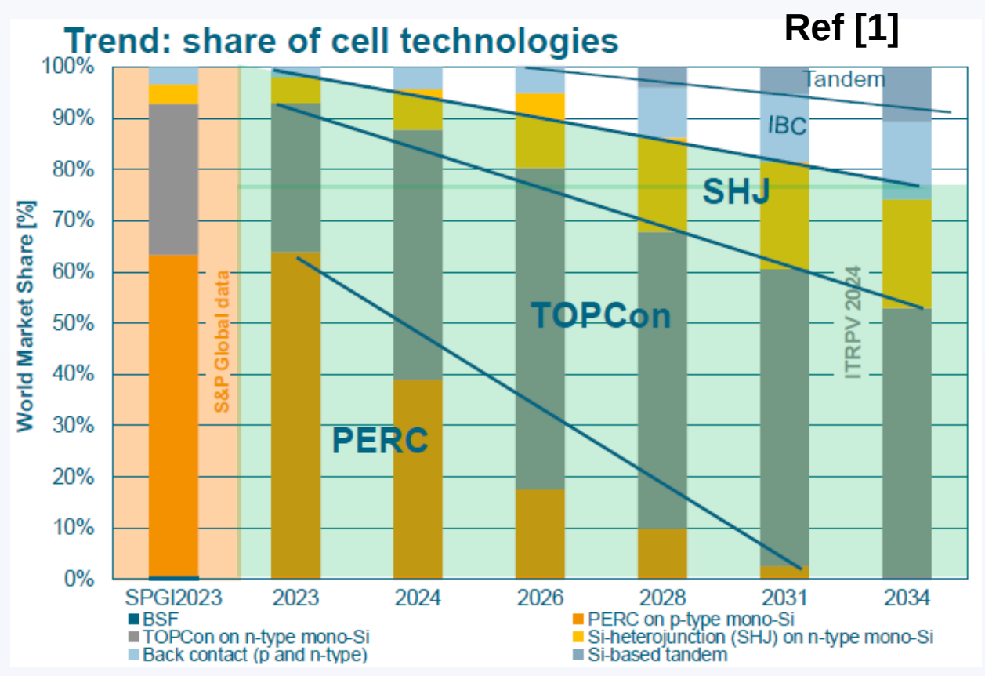
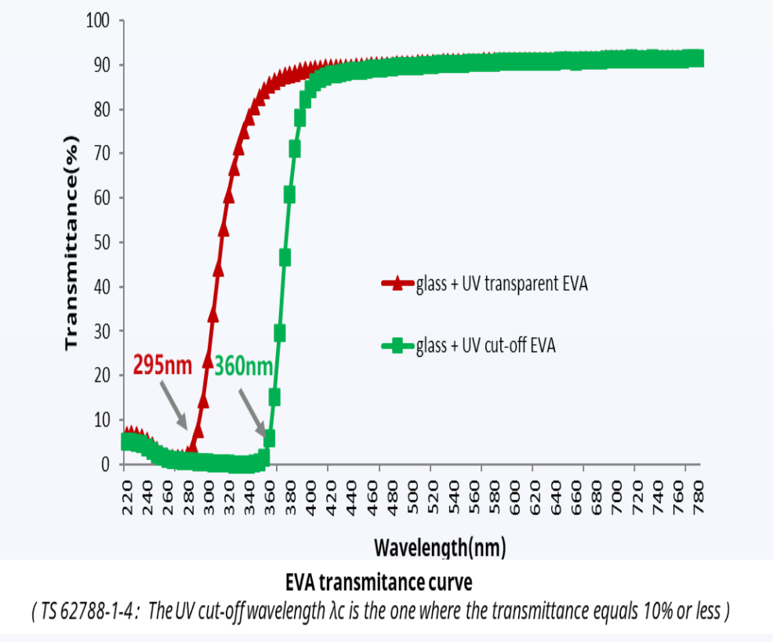
UV-Induced Degradation Susceptibility of Industrial N-Type Silicon High-Efficiency PV Modules

Archana Sinha*, Jean-Nicolas Jaubert, Todd Karin
Kiwa PVEL | Napa, CA 94558, USA
Contact: Archana.Sinha@pvel.com

INTRODUCTION

- New cell technologies such as TOPCon and HJT are witnessing rapid adoption worldwide and are marketed with improved first year (1%) and annual degradation rates (<0.4%).

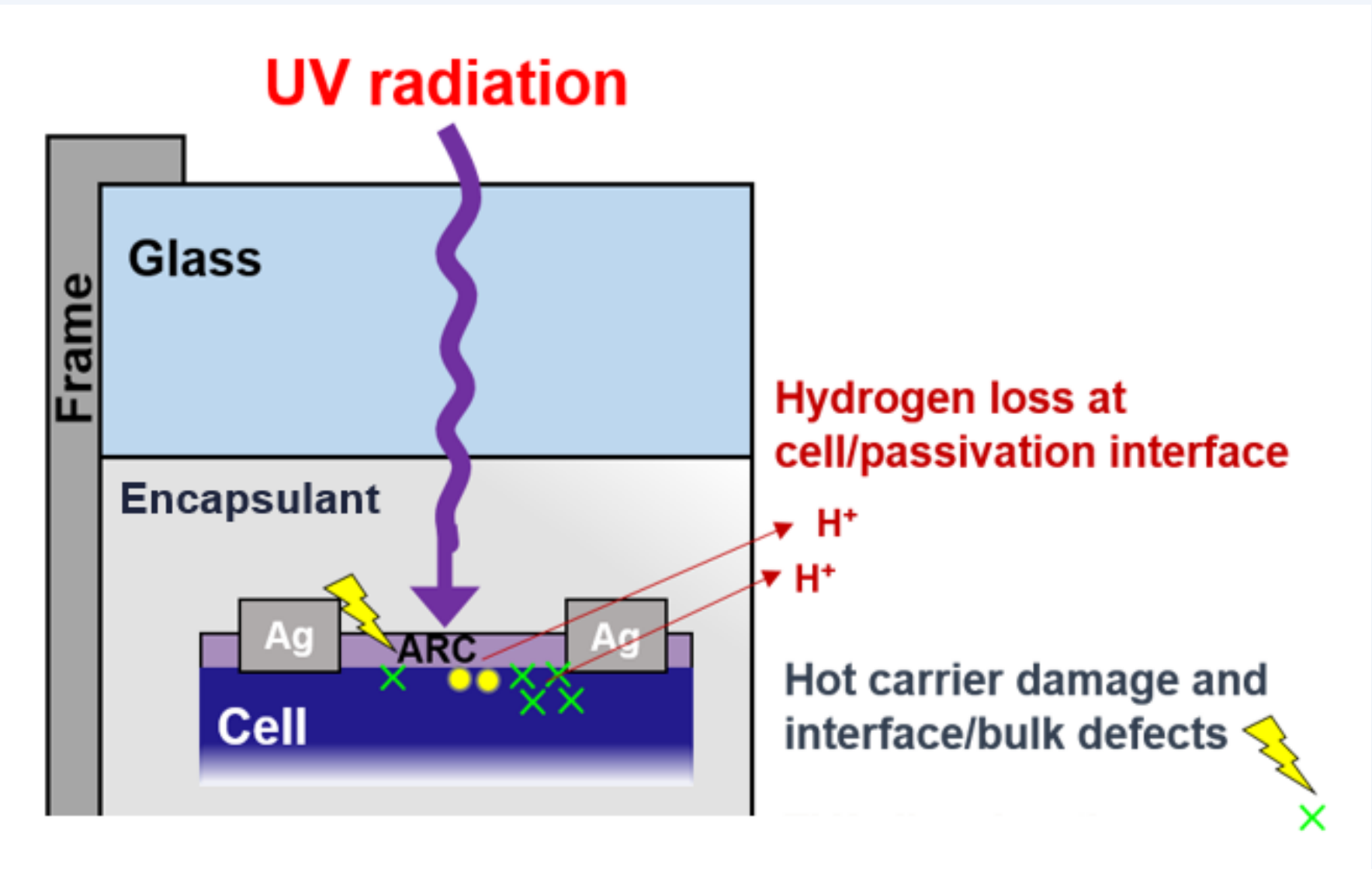




EVA transmitance curve
(TS 62788-1-4 : The UV cut-off wavelength λc is the one where the transmittance equals 10% or less)

- Both technologies found to be vulnerable to ultraviolet light-induced degradation (UVID) due to increased cell sensitivity to UV radiation
  - UV-transparent encapsulants
  - Improved emitter doping profiles and ARC SixNy layer (density, thickness)
- Manufacturers in their quest for high-efficiency may play dangerously with ARC layer structure.
- Power degradation observed >5%.
  - Significantly compromise the module performance, longevity and warranty.

PROPOSED DEGRADATION MECHANISMS



UVID mechanism is different from other light-induced degradation modes (BO-LID and LETID).

1) Recombination at SixNy/Si Interface [2]

UV photon energy >3.5 eV (λc<360 nm) breaks Si-H bonds (Eb: 3.34-3.5 eV) at SixNy/Si interface, deteriorates passivation quality by creating dangling bonds that increases emitter saturation current and decreases the carrier lifetime.

2) Recombination in Si bulk [3]

UV causes the injection of carriers that change the charge states (and mobility) of impurities during the transfer process and then combined to create a defect center in the bulk.

3) Hot-carrier Effect [4, 5]

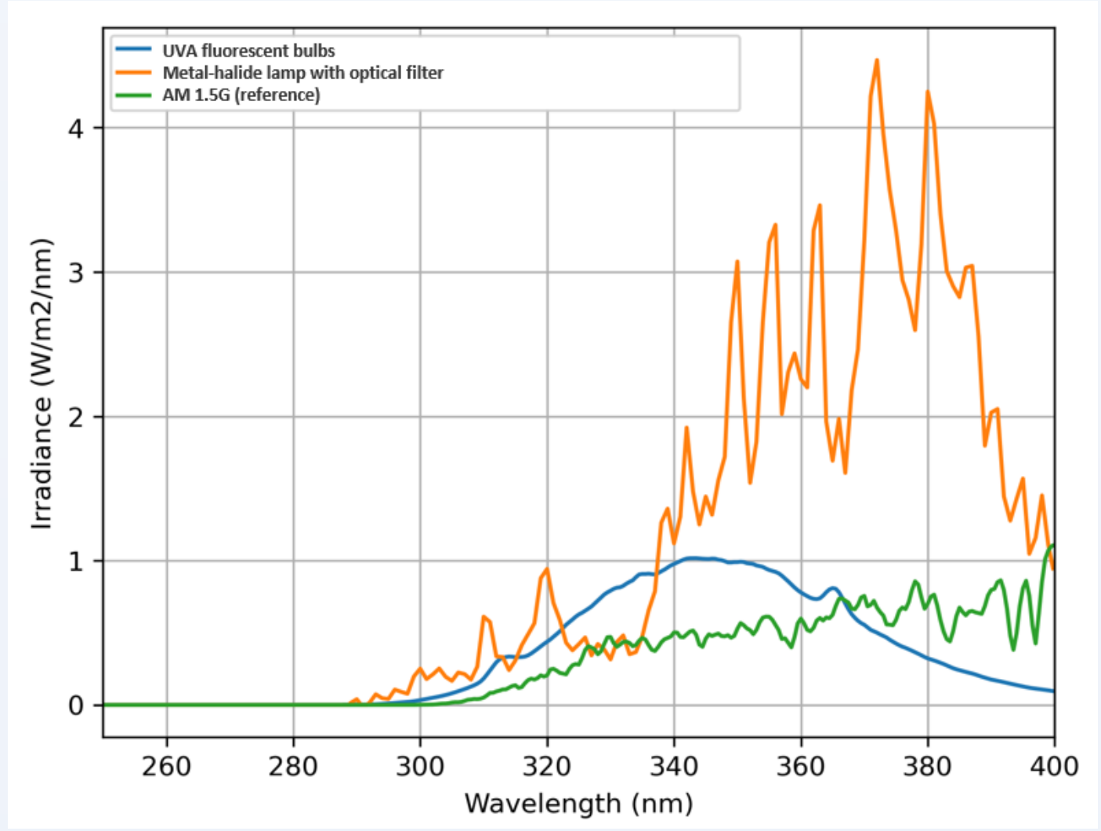
Generation of hot electrons (extremely mobile, sufficiently high KE) that surpass interfacial potential barrier, allowing them to damage the passivation layer and increase the interface state density.

OBJECTIVE

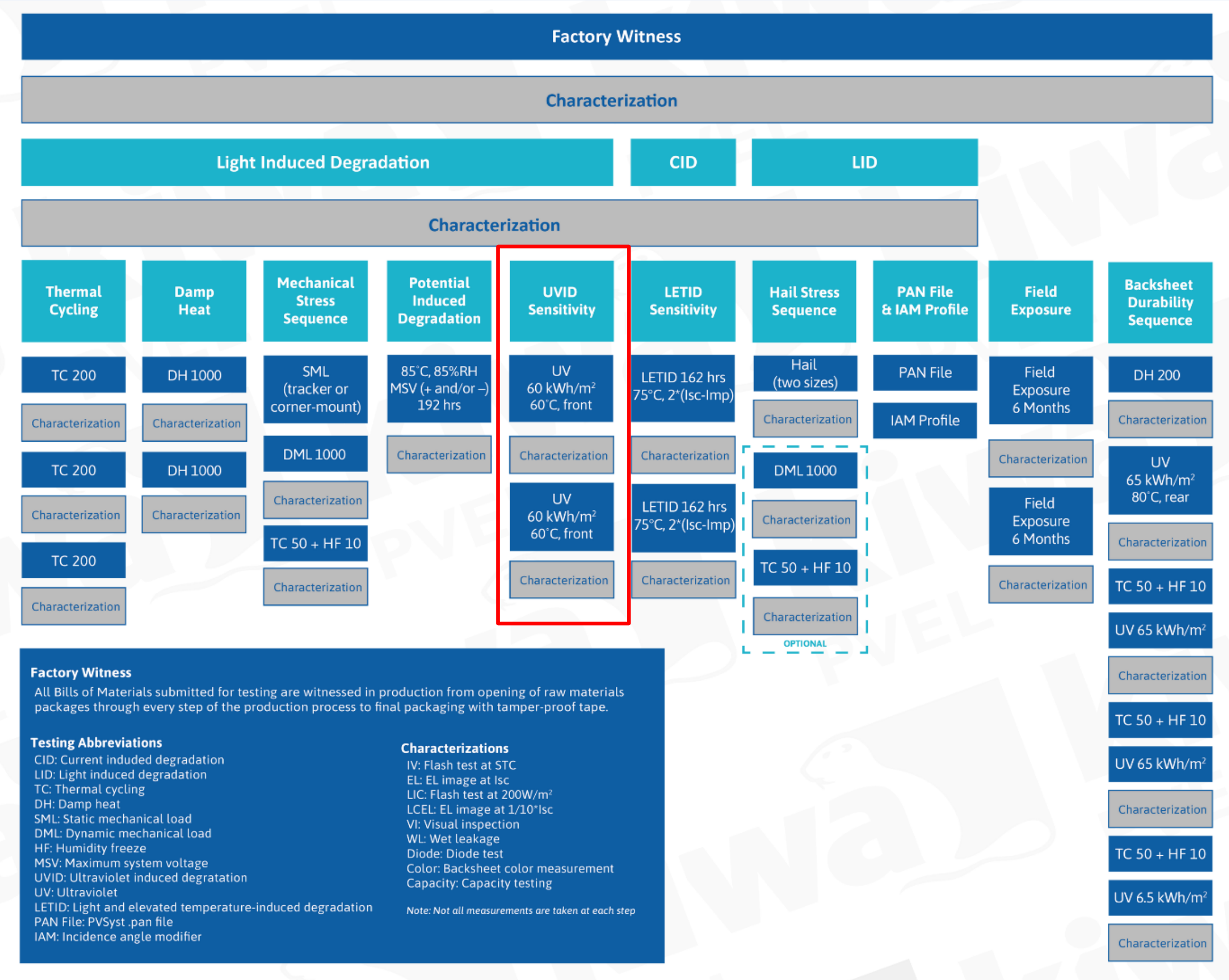
To investigate UVID susceptibility of modern, industrial-size Si PV modules, including n-type (TOPCon and HJT) and p-type PERC technologies.

EXPERIMENT

- Tested various commercial n-type and p-type modules in accordance with Kiwa PVEL's UVID test sequence, 2 modules per BOM.
- Modules preconditioned outdoor for 40 kWh/m^2 for LID stabilization.
- Subjected to UVID test: front-side module exposure to 120 kWh/m^2 of UV (280-400 nm) at 60^{o}C under short-circuit condition.
- Total UV dose is equivalent to 1-2 year of outdoor exposure, depending on location.
- Characterization include visual inspection, I-V at STC and low irradiance, high & low-current EL.
- UVID test setup complies with IEC61215: 2021 MQT10 requirements. The UV chambers in PI China and Napa, USA use metal-halide lamps with UV filters and UV fluorescent bulbs, resp. The UVB ratio falls within 3-10% range.



KIWA PVEL'S PQP (PRODUCT QUALIFICATION PROGRAM)



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

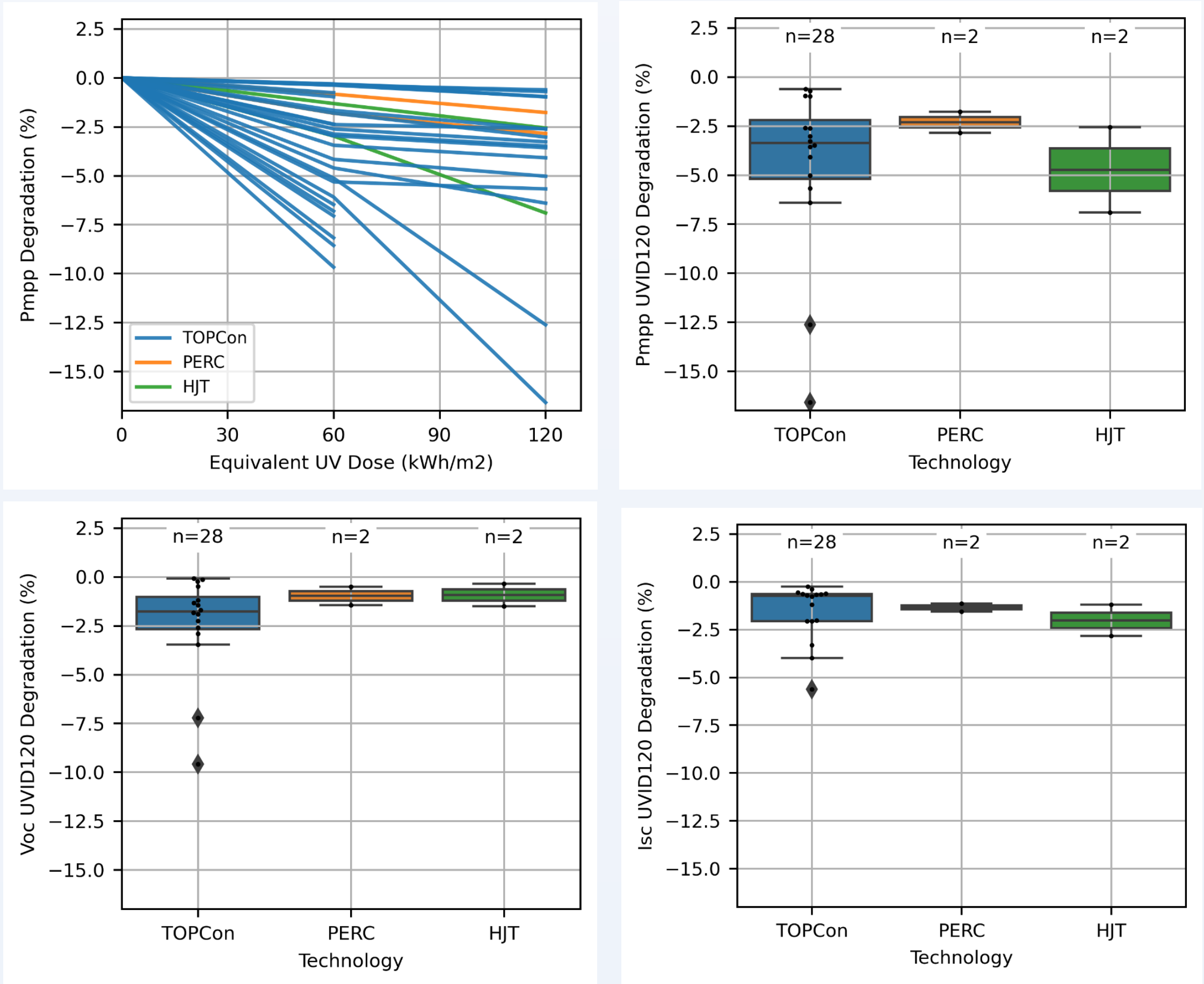
Characterizations
IV: Flash test at STC
EL: EL image at Isc
LIC: Flash test at 200W/m^2
LCEL: EL image at 1/10*Isc
VI: Visual inspection
WL: Wet leakage
Diode: Diode test
Color: Backsheet color measurement
Capacity: Capacity testing

Note: Not all measurements are taken at each step

KEY RESULTS

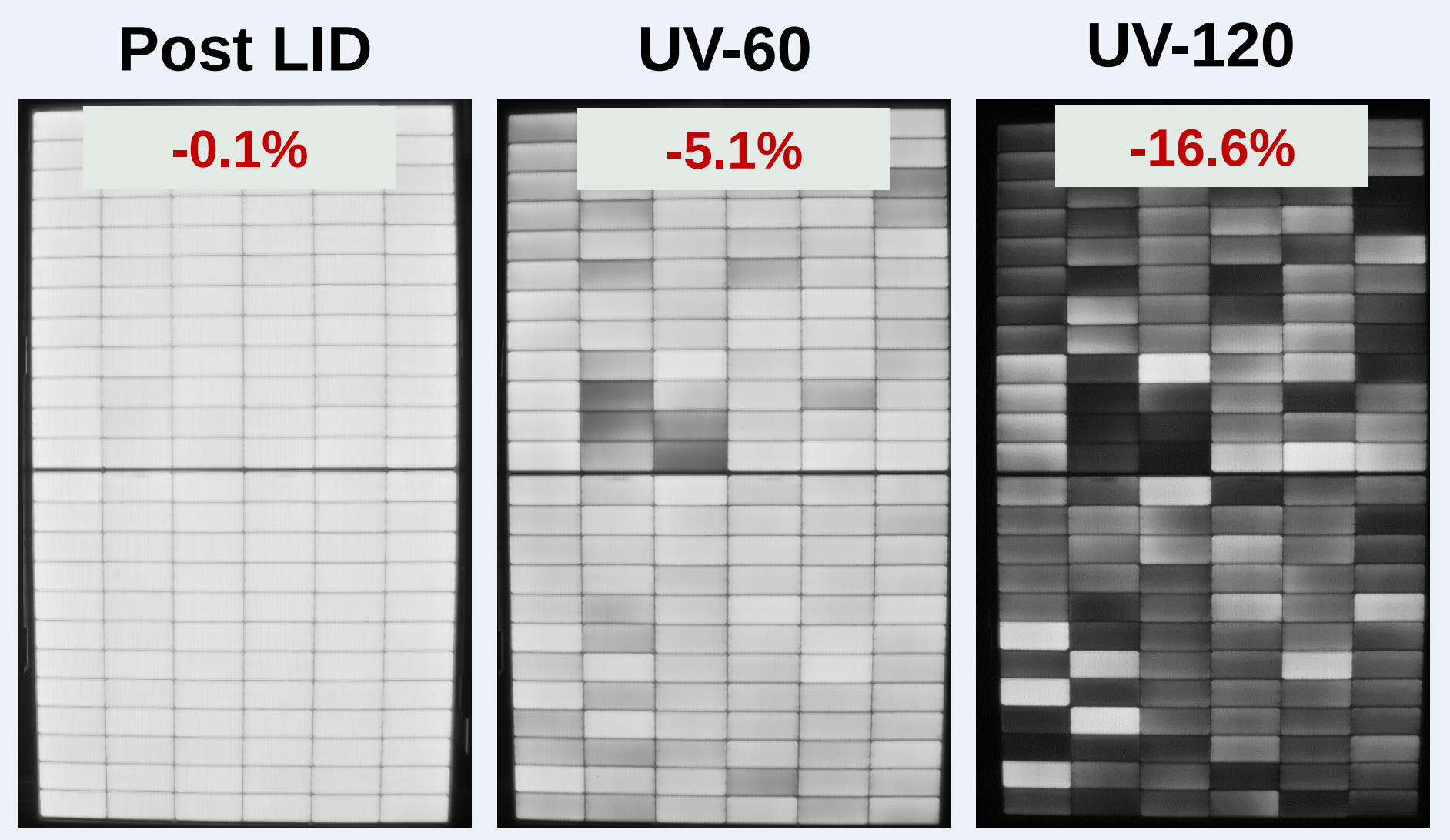
Power Degradation & Failures

- Wide spread of degradation, ranging from 0.6% to 16.6% power loss after UVID-120.
- More than 50% BOMs of TOPCon modules exhibited power degradation >5%/y. Other modules are UV-stable.
  - Retesting of highly-degraded TOPCon modules showed consistent degradation patterns in I-V.
- n-type HJT and p-type PERC modules showed moderate power degradation (2-7%) after UV-120, sample size was very limited.
- Voc is the most affected parameter (attributed to passivation loss), followed by Isc and FF.
  - Isc loss is minimal in good performing samples, hinting that different degradation mechanisms occuring concurrently.
- Factors affecting extent of UVID - cell architecture, BOM type, test condition, module electrical configuration, etc.



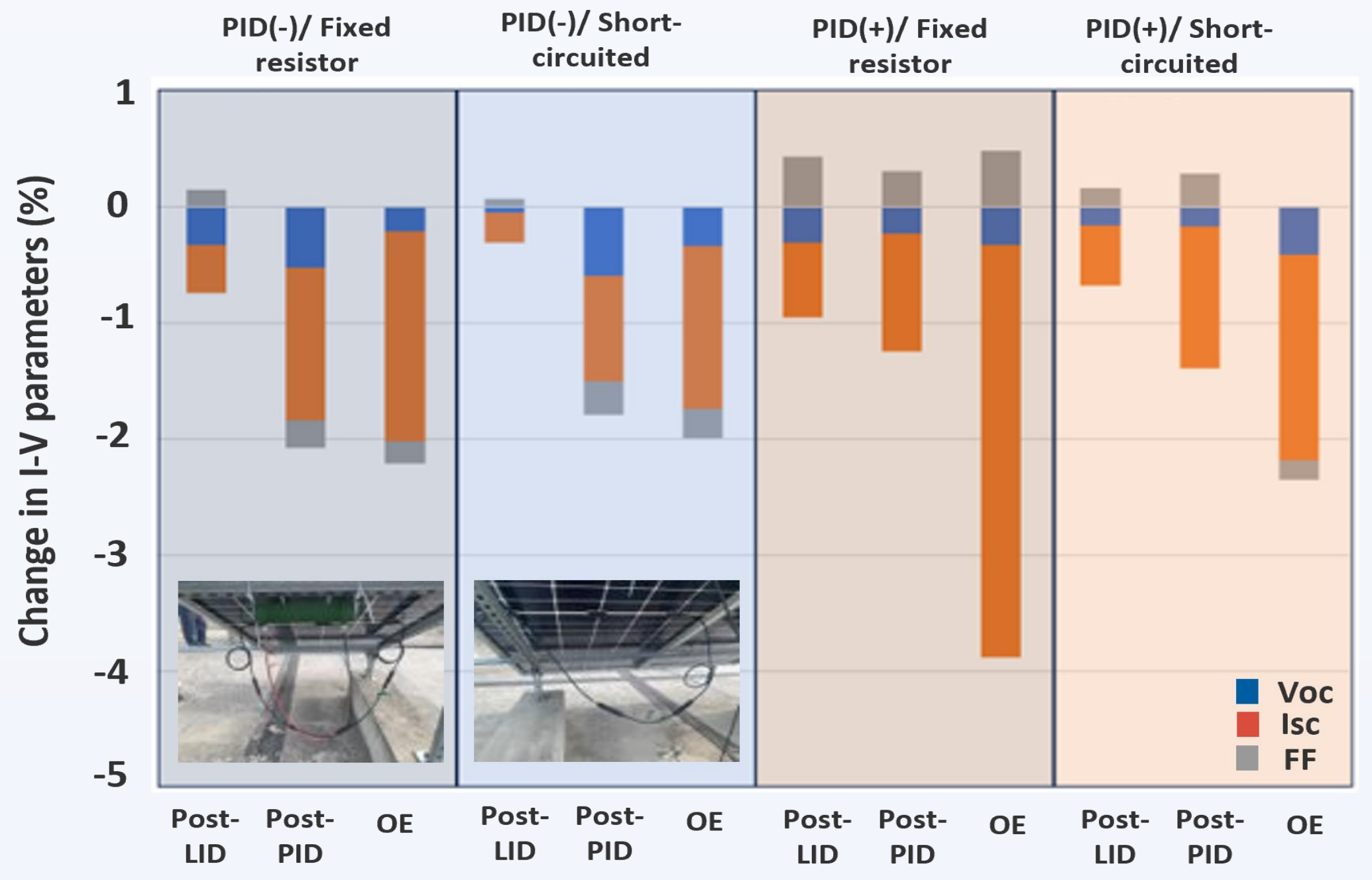
EL Characterization: Checkerboard Pattern

- Cells randomly affected, displaying a checkerboard pattern.
- Entire module EL signal weakened after UVID.
  - EL images of worst degraded sample are shown.



OUTDOOR EXPOSURE

- Placed 4 post-PID modules on rooftop, Suzhou, China - 2 under short-circuit, 2 under MPP (resistor load) for 1 month.
- All samples showed further Isc loss (~0.8%), independent from PID stress or load type.
- Additional Voc degradation also perceptible but less marked (~0.2%), hidden by Voc recovery observed on PID(-) samples.
- Module under SC exhibited new darkened cells, similar to that in UVID testing. Recovery of PID-p affected cell clearly visible on EL pictures.



SUMMARY

- Power loss after 120 kWh/m^2 of UVID ranged from 0.6% to 16.6%. UVID-stable TOPCon BOMs are possible, but some manufacturers need to take corrective measures.
- Initial results showed that HJT and PERC technologies are also susceptible to UVID.
- Degradation mechanisms behind UVID are not fully understood. Research is ongoing.
- Checkout ***Kiwa PVEL PV Module Reliability Scorecard 2024*** at www.scorecard.pvel.com
- New DuraMAT project awarded "***New Cells, New Issues***" (FY24 Open Call RFP).

REFERENCES

[1] ITRPV Report 2024; itrpv.vdmaa.org
[2] R. Witteck *et al.*, *physica status solidi (RRL)*, vol. 11, no. 8, p. 1700178, 2017.
[3] F. Ye *et al.*, *Solar Energy*, vol. 170, pp. 1009–1015, 2018.
[4] P. E. Gruenbaum, R. R. King, and R. M. Swanson, *J Appl Phys*, vol. 66, no. 12, pp. 6110–6114, 1989.
[5] A. Sinha *et al.*, *Prog in Photovolt.*, vol. 31, no. 1, pp. 36–51, 2023.