How to handle UVID for TOPCon and SHJ modules

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IEA PVPS Task 13: 15th SOPHIA PV-Module Reliability Workshop April 29, 2025

UVID Degradation of Modules

International Energy Agency
Photovoltaic Power Systems Programme

IEA PVPS TASK 13 - RELIABILITY AND PERFORMANCE OF PHOTOVOLTAIC SYSTEMS

Degradation and Failure Modes in New Photovoltaic Cell and Module Technologies

IEA PVPS Task 13, Report IEA-PVPS T13-30:2025, February 2025
ISBN 978-3-907281-71-0

Main Authors:
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The Technical Report is available for download from the IEA-PVPS website www.iea-pvps.org.

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Key Takeaway:
UV-Induced Degradation (UVID): This occurs in some PV modules but is manageable by using *UV-stable designs and encapsulation materials*. However, more research is needed to fully replicate laboratory tests to field conditions.

UVID Degradation of Modules

- <400 nm, interacts with materials and interfaces:
  - Passivation layers (a-Si:H, SiO_2, SiN_xH_y, Al_2O_3)
  - Crystalline Si
  - ITO (in Si heterojunctions)

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Guiheneuf 2017, DOI: 10.1016/j.solener.2017.08.044
Witteck 2017, DOI: 10.1109/PVSC.2017.8366019; DOI: 10.1002/pip.2861
Sinha 2022, DOI 10.1002/pip.3606
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- UV absorbers in encapsulants
  - Added to protect devices
  - Issues with browning
  - UV-transparent front materials are becoming more common
    - Increased initial performance
    - Avoid degradation of encapsulant
    - UVID of device is of increased concern

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TOPCon cells are not all the **“same”**

Key: Need to think of materials as unique due to manufacturing, stabilizers, processing

"What is a polyolefin? A critical overview of ethylene copolymers used as solar photovoltaic module encapsulants" Oreski et al. Submitted to Progress in Photovoltaics

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Fielded modules are the gold standard*

Fig. 1. View of 2 of the 5 modules after almost 10 years of field exposure. Some encapsulant discoloration is clearly visible. Photo credit: Dirk Jordan, NREL PIX 45038.

- Evidence of degradation in SHJs
- Nonlinear power loss: most degradation in the first two years
- V_{oc} loss dominates; recombination increased significantly
- Series resistance increased (extrinsic causes)
- Later publication saw similar effect in UVID lab-aged modules

***Multimodal degradations, long durations, technology can evolve faster than learnings**

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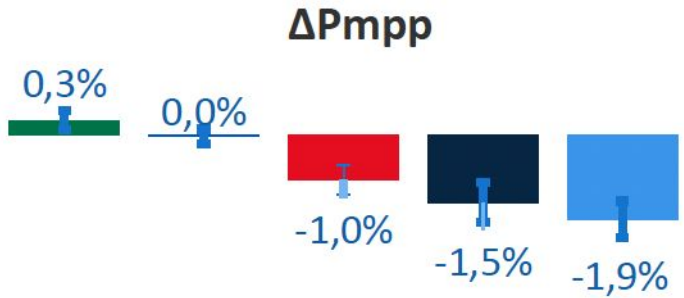
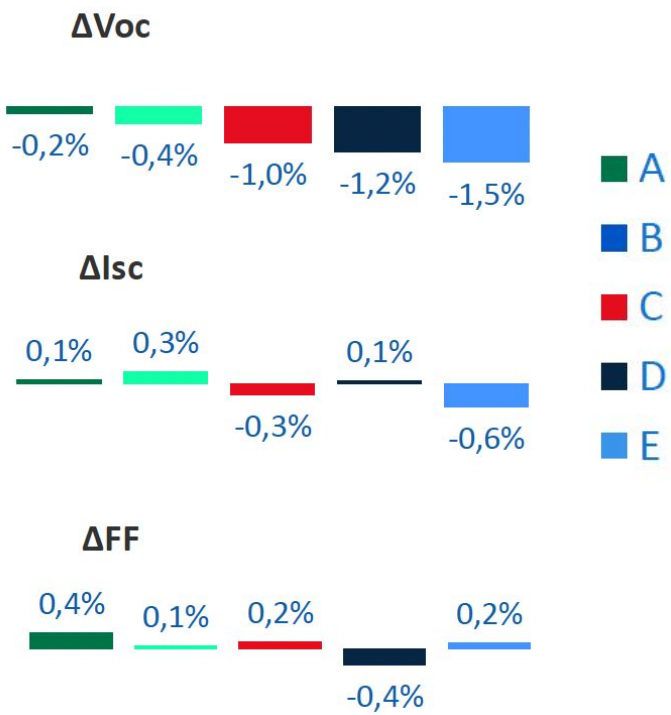
Jordan 2018, DOI: 10.1109/JPHOTOV.2017.2765680
Sinha 2022, DOI: 10.1002/pip.3606

Fielded modules show UVID of TOPCon





- Five module types (A-E)
- Degradation showed strong dependence on BOM composition
- EL images show checkerboard pattern
- Corresponds with laboratory aging tests
  - Degradation in field (-1.5% for C) < expected based on equivalent laboratory dose (-2.6%): measurement conditions

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S. Lust, S._R._Kuntamukkula, S._Friedrichs, L._Podlowski, “UV-Degradation von TOPCon-Solarmodulen im Labor und Feld,“ Proc. of 40. PV Symposium 12th March 2025, Bad Staffelstein, Germany, p.98-99

How do we study this: accelerated aging

Sources include: Xe arc lamps, metal halide lamps

Temperatures vary (45 - 70°C)

Device conditions (open vs. short circuit)

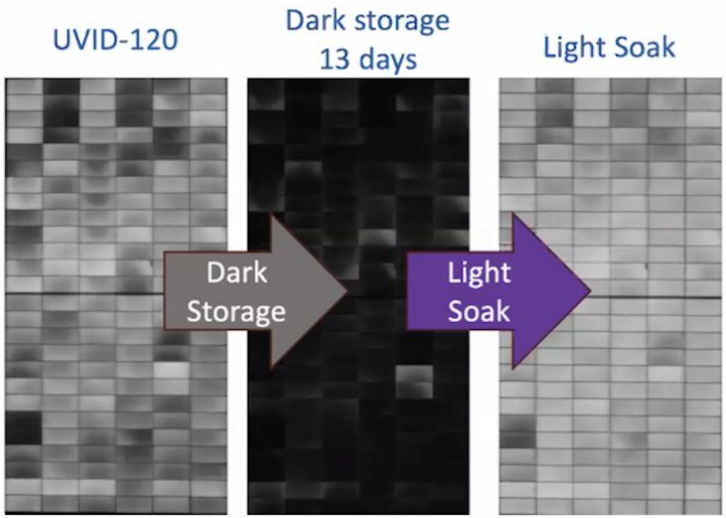
Bare vs. encapsulated, varied encapsulation

Dose varies

Definitions of “equivalent years of exposure”…vary

Cross validation is required

Degradation in the dark, recovery in the light



https://www.kiwa.com/us/en/kiwa/entities/pvel/news/access-the-pvrw-2025-presentations/

- Recent presentations (PVRW) shows that UV initiates metastabilty in dark storage conditions
- This should be taken into account in lab studies
  - Stabilization by full spectrum light soak, or 365 nm LEDs, or outdoor exposure
- Some recovery, not full recovery; variation within technologies

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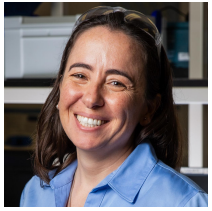
Recent results bridging materials and device studies



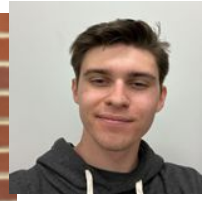



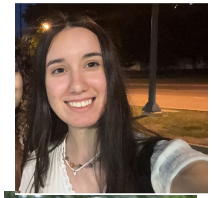
Postdocs

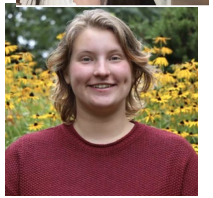

Undergraduates



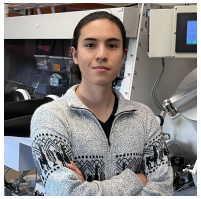








Graduate students

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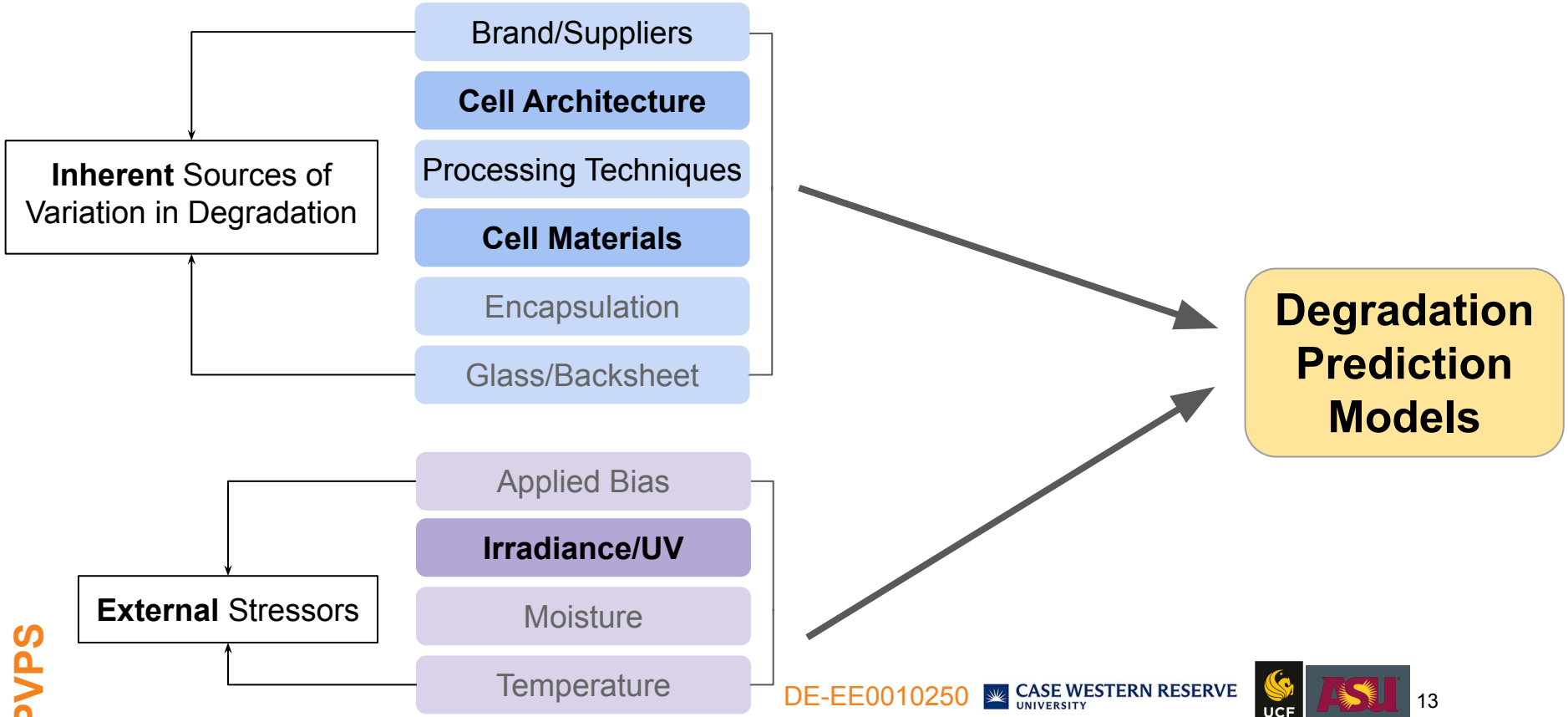
The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Deconvoluting Degradation



Experimental Setup

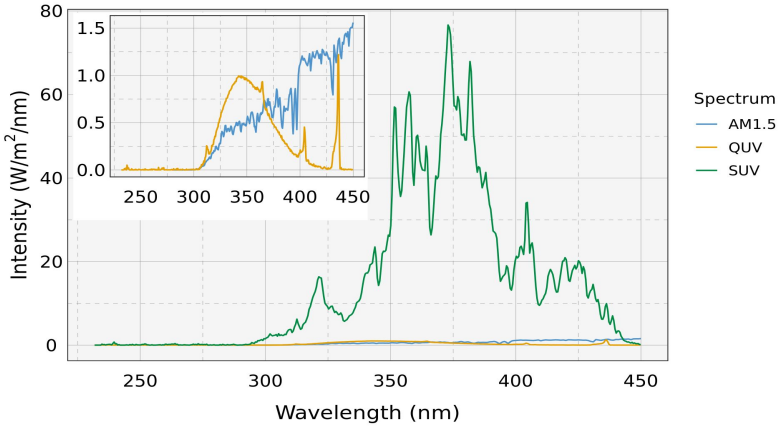
Samples:

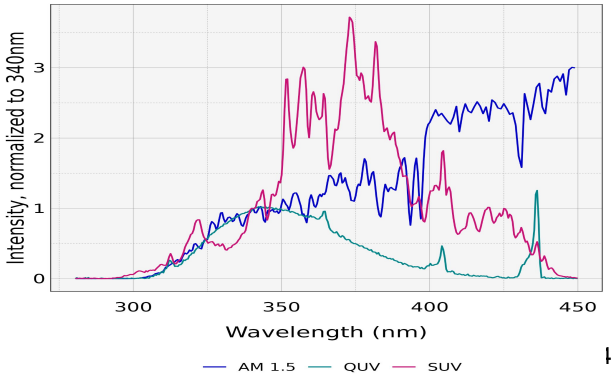
- Bifacial TOPCon
  - Full M10 cells - Multiple vendors
  - Laser-cut mini-cells (2.5 cm x 2.5 cm)

Exposure Conditions:

- SUV: High-Intensity 2.6 kW/m^2 between 300-400 nm
  - Total UV irradiance = 2574.6 W/m^2
  - Maximum UV dose = 1100 kWh/m^2 (418 h)
  - Metal oxide lamp, EYE Super UV Tester (SUV-W161)

- QUV: “Low-Intensity” 1.55 W/m^2/nm at 340 nm
  - Total UV irradiance = 69.3 W/m^2
  - Maximum UV dose = 190 kWh/m^2 (~3600 h)
  - Fluorescent lamp





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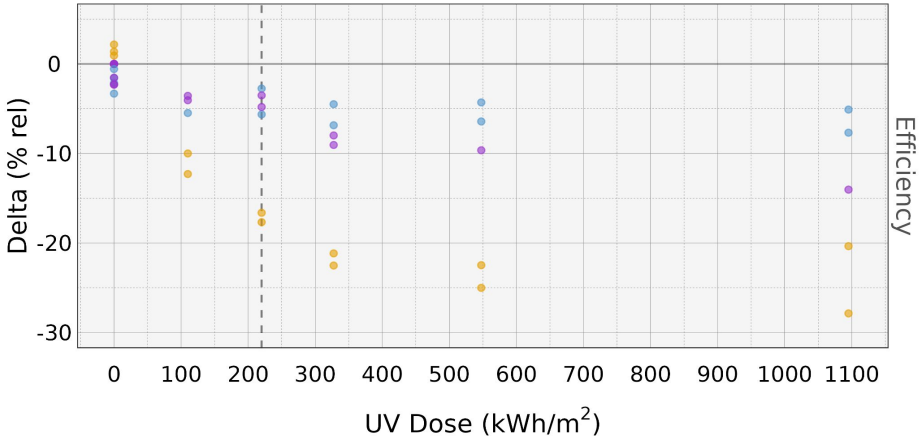
UCF ASU

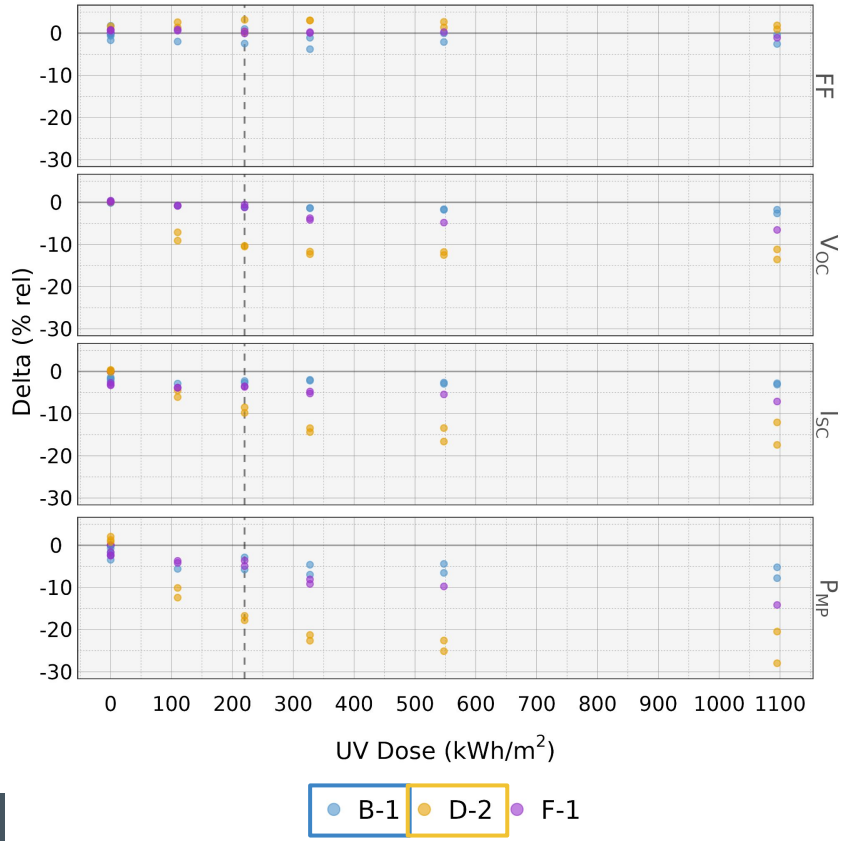
Illuminated I-V Curves of TOPCon devices

Difference in degradation between three vendors:

- **B-1** has least degradation (<8%rel)
- **D-2** showed significant degradation (>20%rel)
- FF remained stable throughout all manufacturers

Major losses in V_{OC} and I_{SC}





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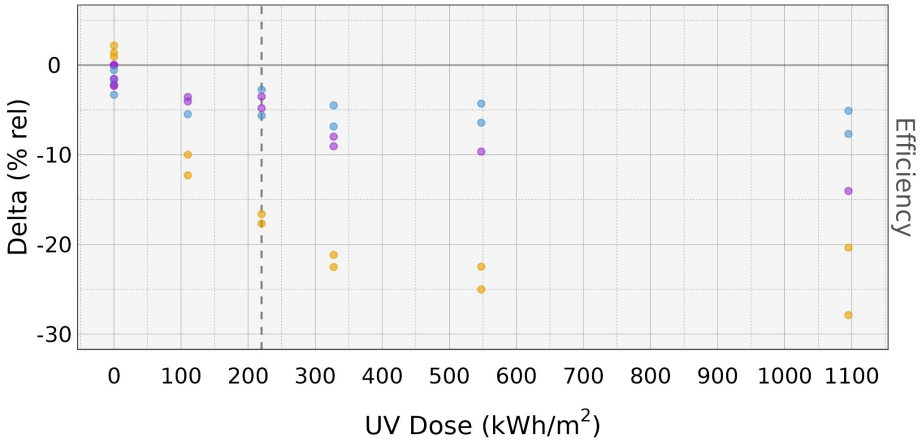
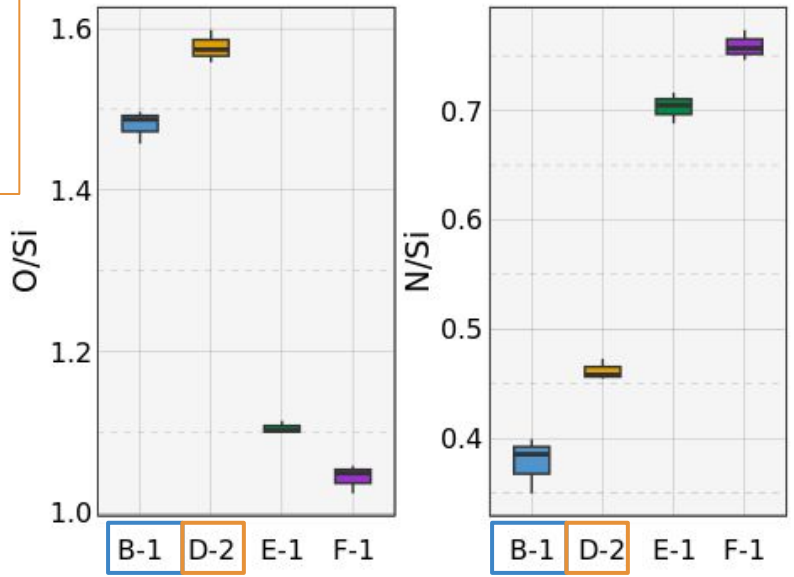
Illuminated I-V Curves of TOPCon devices

Difference in degradation between three vendors:

- XPS: **B-1** and **D-2** have similar compositions of the *surface* of the passivation layer
- What about the bulk and the interface?





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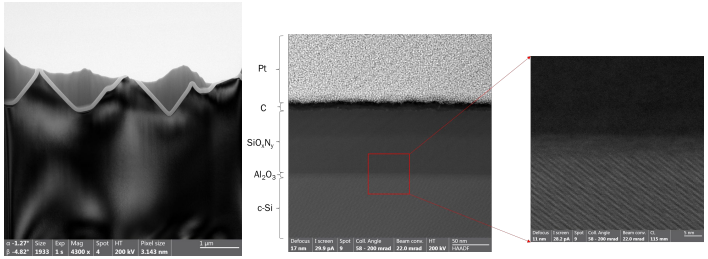
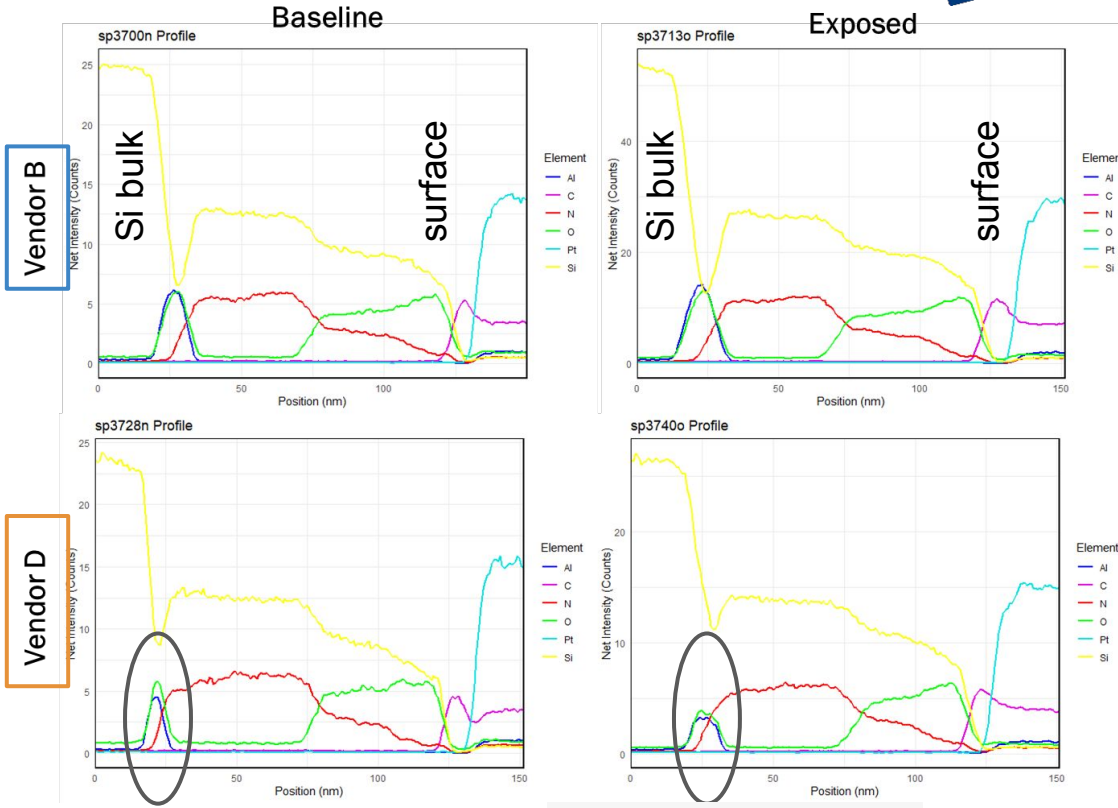
Cross-Sectional TEM of Devices B and D



- Both **B** and **D** have two-step SiO_xN_y deposition
- Sample **D** has thinner Al_2O_3 layer
- Measurements of four samples - four days!



This work was conducted in part at the Nanoscale Research Facility of the Herbert Wertheim College of Engineering at the University of Florida with the valuable assistance of Dr. Nicholas Rudawski

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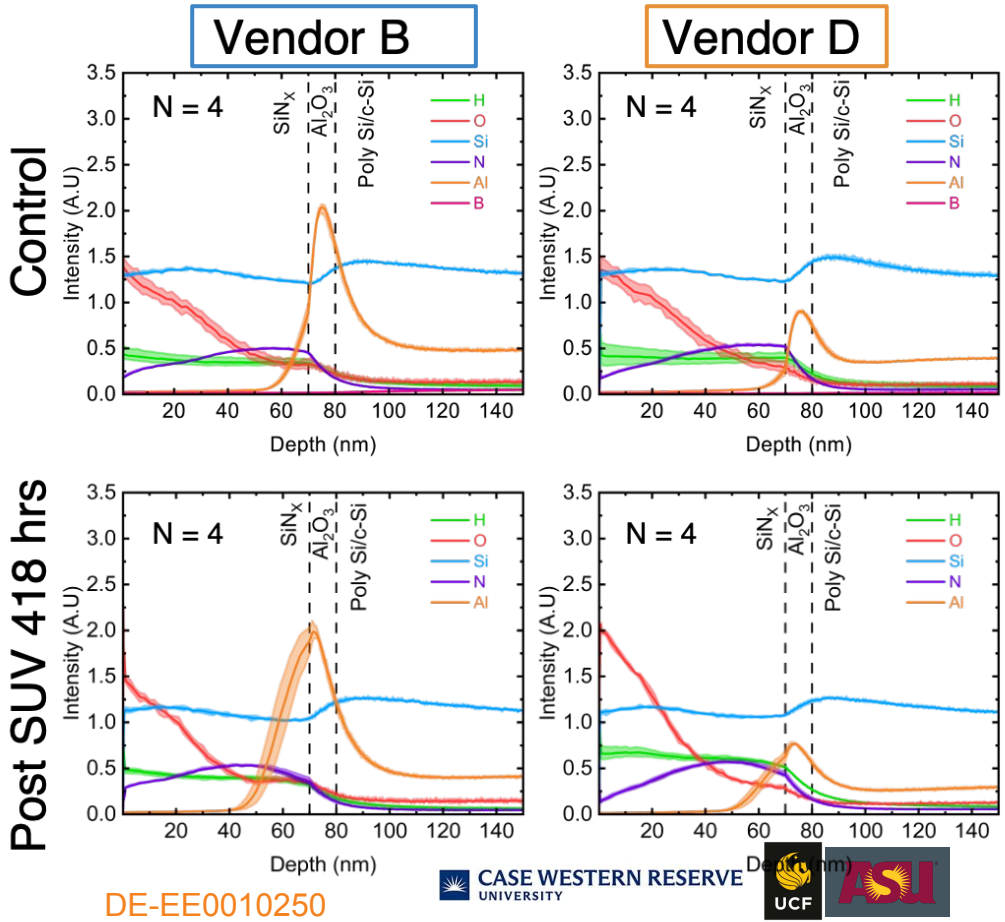
Data-Enabled Photovoltaics

UCF UNIVERSITY OF CENTRAL FLORIDA

Glow Discharge Optical Emission Spectroscopy



- ~10 min a measurement!
- 4 spots per sample
- Vendor D (worst performer) shows gains of O and H in passivation, while Vendor B (best performer) experiences only minor changes
- Smaller Al peak in Vendor D - consistent with TEM

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DEfECT laboratory

Does SUV cause the same UVID over a shorter period of time?

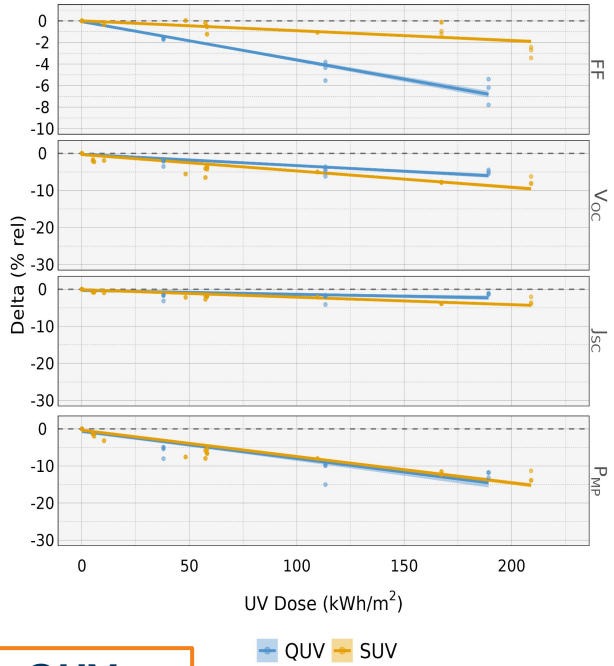
Similar trends in losses to PERC B cells

Differences between exposures in FF, V_{OC}

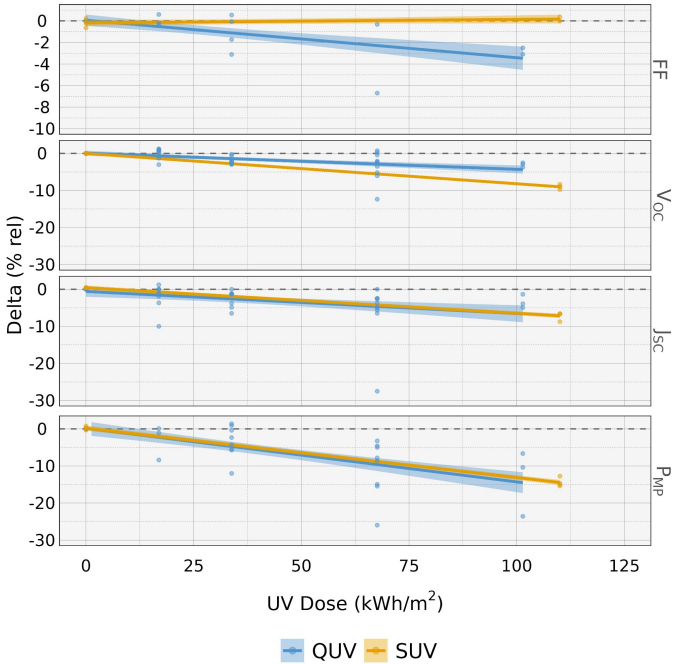
J_{SC}, P_{MP} losses correlate well between exposures

Differences in temperatures (we are working on this)

PERC B: half cells



TOPCon:
QUV - mini-cells
SUV- full cells



***SUV ~30x faster than QUV**

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Rasmussen 2024, DOI: 10.1109/PVSC57443.2024.10749079

Takeaways

- UVID is a degradation mode of concern
- Work to bridge materials, devices, cells, modules
- Work to bridge lab studies and field observations
- Address great variation between vendors
- Statistically relevant sample sets