Degradation of PERC & Al-BSF Photovoltaic Cells with Differentiated Minimodule Packaging Materials

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PERCdegr: Comparative Reliability of PERC w/r to Al-BSF Cells

Reliability and Power Degradation Rates of PERC Modules Using Differentiated Packaging Strategies and Characterization Tools

- Quantify interactions between PERC cells and module packaging strategies
- Identify PERC specific degradation modes and their characteristic signatures

Minimodule Variables

Cell Types: (Full & Half size Cells)
- Multicrystalline monofacial Al-BSF
- Monocrystalline monofacial PERC
- Monocrystalline bifacial PERC
- Multicrystalline bifacial PERC

Encapsulant Types:
- EVA/POE
- [Trans/UV Cutoff]
- [Trans/White]

Backsheet:
- KPX
- KPf
- PPf

+

Exposures

Indoor Accel. Exposures:
- Damp Heat (DH)
- Modified DH
- mDH + Full Spec. Light

Outdoor exposure:
- CWRU SunFarm Cleveland, OH

+

Evaluations:
- *I-V* (Multiple Irradiance levels)
- *Suns-V_{oc}*
- EL(J)
- PL(Irrad.)

Towards 50: How to Extend Module Lifetimes to 50 Years

Towards 50 Year Lifetime PV Modules: Double Glass vs. Glass/Backsheet

- Study influences of different packaging strategies on the degradation of Photovoltaic (PV) modules
- Identify and mitigate relevant degradation modes (corrosion and mechanical)
  - In Glass|Backsheet (GB) and Double Glass (DG) modules with various cells and encapsulant
  - To reduce the power degradation rate to 0.2%/year

Minimodule Variables

Cell Types (Multicrystalline Full Cell):
- Mono-facial
- Bi-facial

Encapsulant Types:
- EVA/POE + (Trans/UV Cutoff)
- (Trans/White)
- (Trans/Trans)

Backside Types:
- Backsheet(KPf / trans. BS)
- Glass

+

Exposures

Indoor Accel. exposures:
- mDH
- mDH + Full spc Light

Outdoor exposure:
- CWRU sunfarm, Cleveland, OH

+

Evaluations:
- *I-V* (Multiple Irradiance levels)
- *Suns-V_{oc}*
- EL & PL
- 4-pt bending proof test

PV Image Machine Learning:

F_{med} = median pixel intensity
F_{FDP} = fraction of dark pixels

Automated Pipelir
Electroluminesce
Degradation

Ahmad Maroof Karimi, *Graduate Student, M*
Shuying Yang, Timothy J. Peshek, Jennifer L

Generalized and Mechanistic
Computer Vision and Machin

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Mehmet Koyutürk † , Roger H. French
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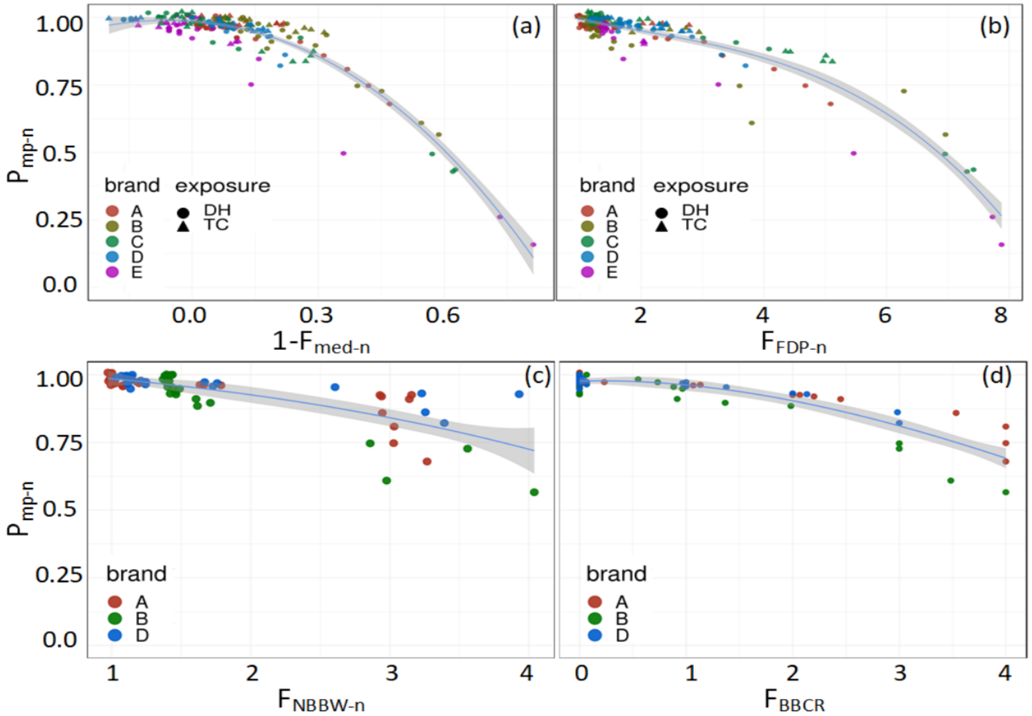
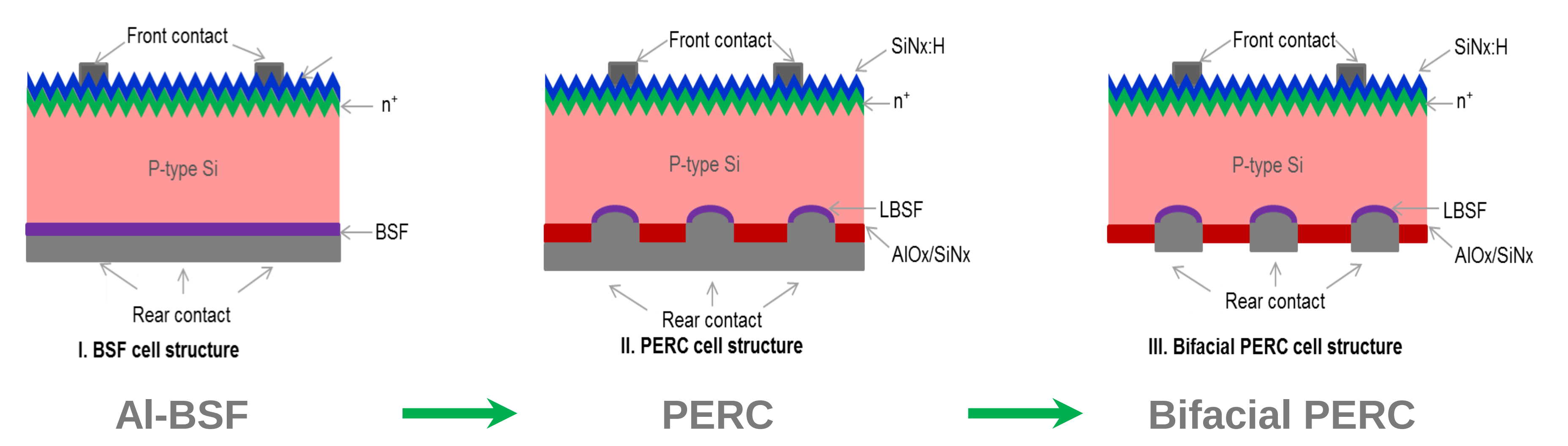


JPV 2019. DOI: 10.1109/JPHOTOV.2019.2920732

Fig. 11: Normalized power P_{mp-n} predictive model using four normalized EL features: (a) $1\text{-}F_{med-n}$, (b) F_{FDP-n}, (c) F_{NBBW-n}, and (d) F_{BBCR}. The gray shaded region along the regression line is the 95% confidence interval.

JPV 2019. In Press

Cell Architectures & Performance

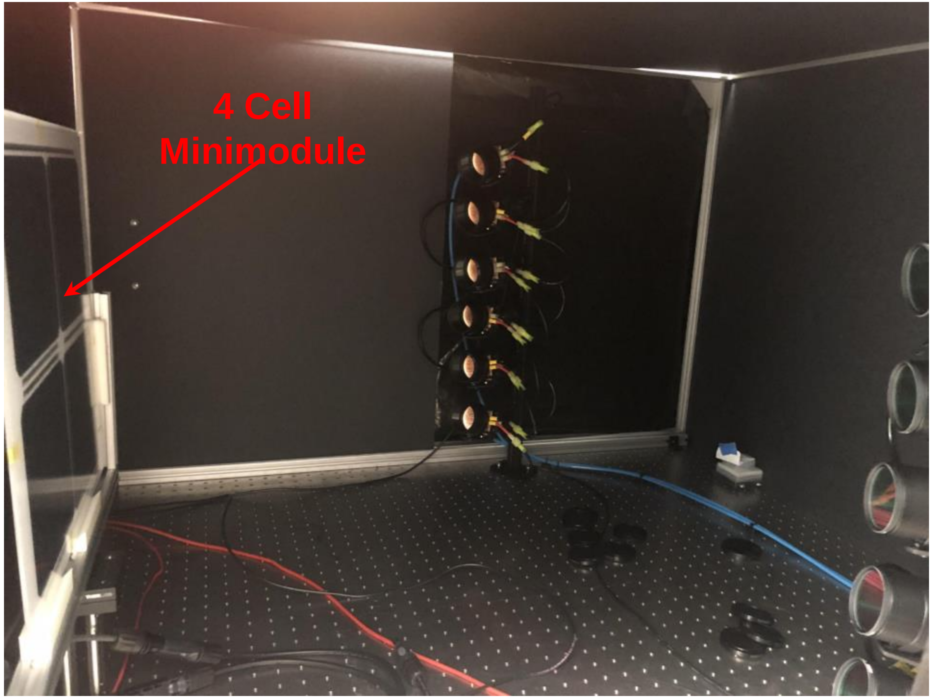


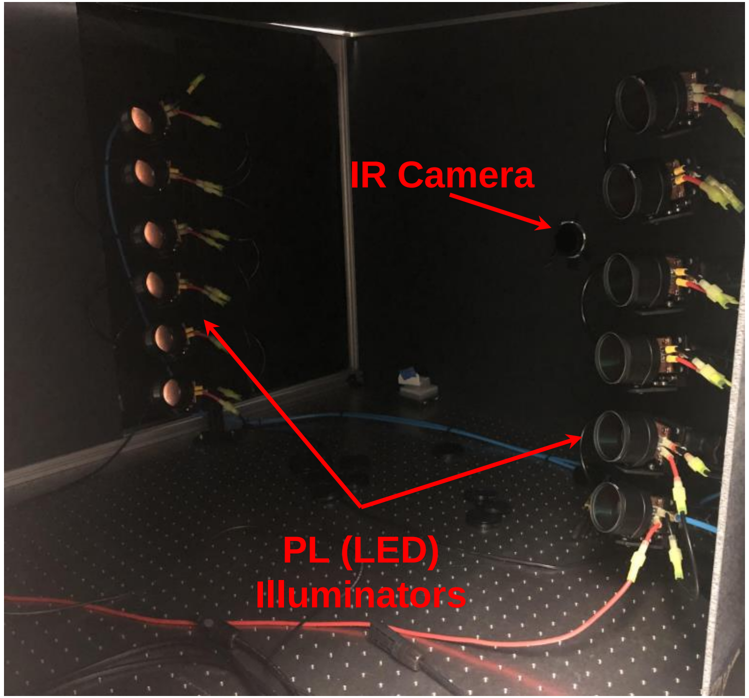
Both Monocrystalline and Multicrystalline Wafers

Electroluminescence & Photoluminescence System

EL/PL system by Tau Science

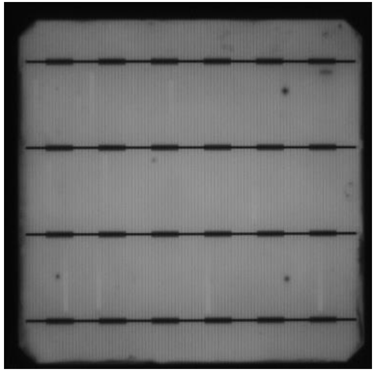
- 20.4 Megapixel Cooled Camera
- LED based PL Illuminator
- Automated acquisition



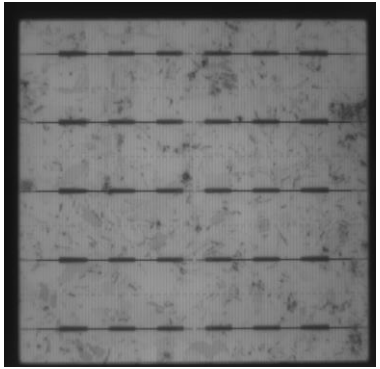


Cell Comparison - Photoluminescence (PL) Images

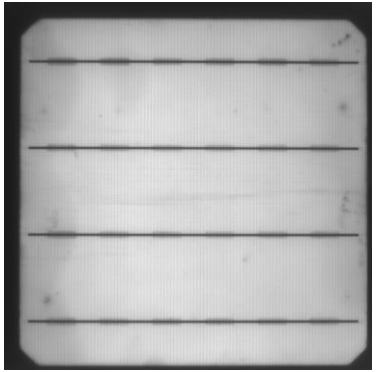
Monocrystal Al-BSF



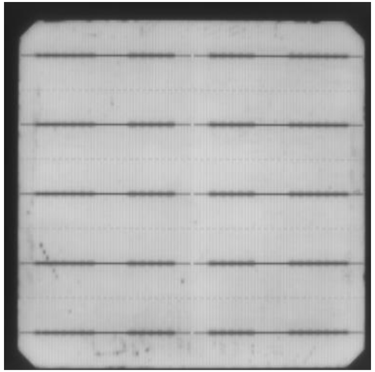
Multicrystal Al-BSF



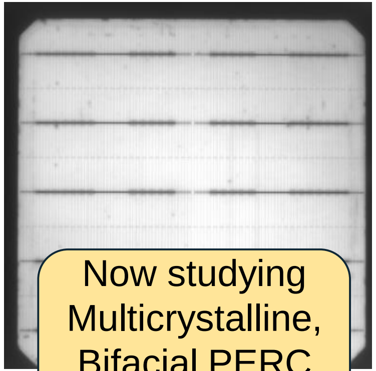
Monocrystal PERC Gen 0 Monofacial



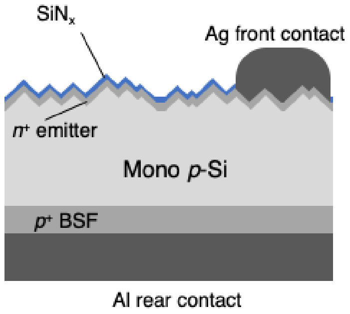
Monocrystal PERC Gen 1 Monofacial

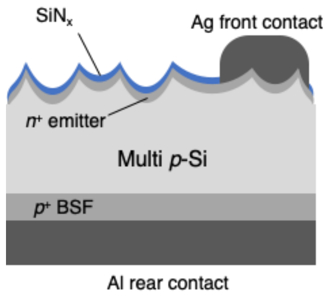


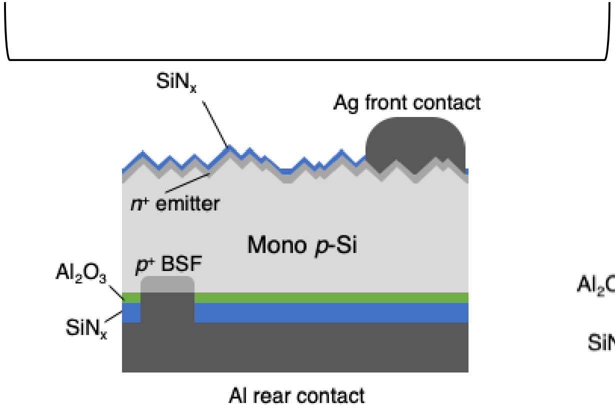
Monocrystal PERC Gen 2 Bifacial

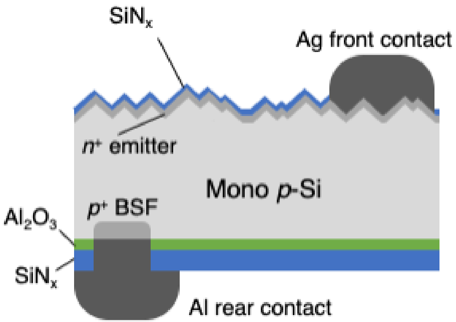


Now studying Multicrystalline, Bifacial PERC Cells









Cell Comparison - J_{SC} and V_{OC}

Strong increase in both current & voltage

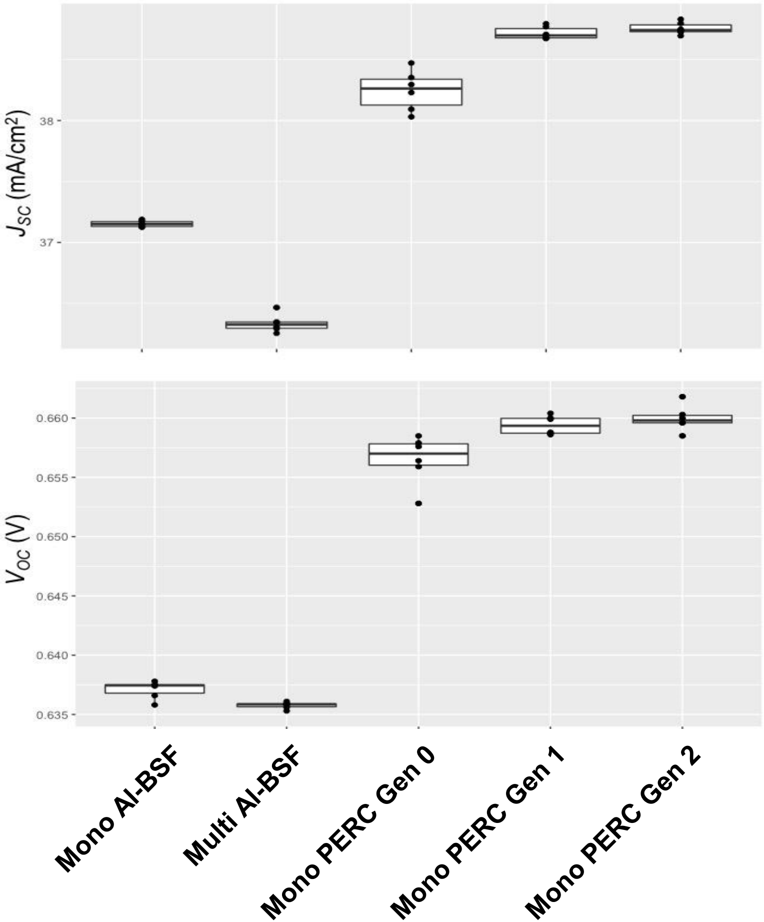
- As expected
- Lower rear surface recombination
- Improved rear optics

PERC clearly outperforms

- Al-BSF technologies

J_{sc} does not consider rear side illumination

- performance in bifacial PERC (Gen 2)
- comparable to monofacial PERC (Gen 1)

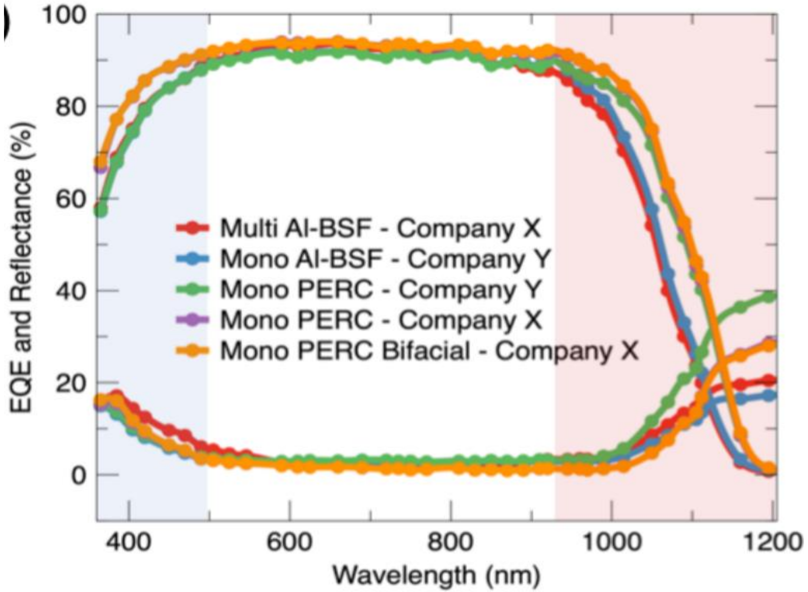


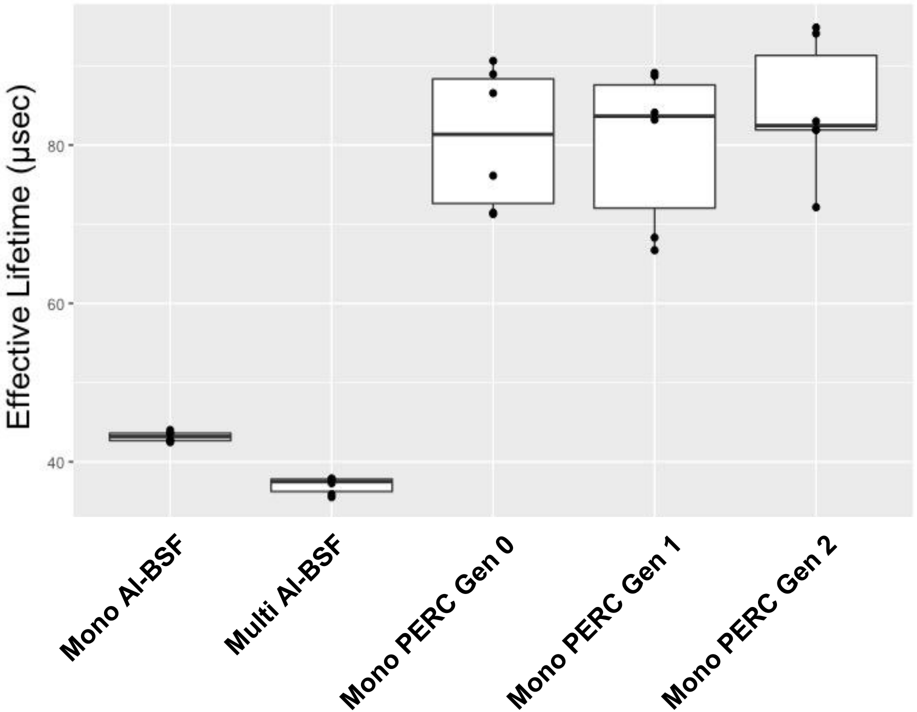
Cell Comparison – Suns-V_{OC}, Effective Carrier Lifetime & EQE

Substantial increase in lifetime

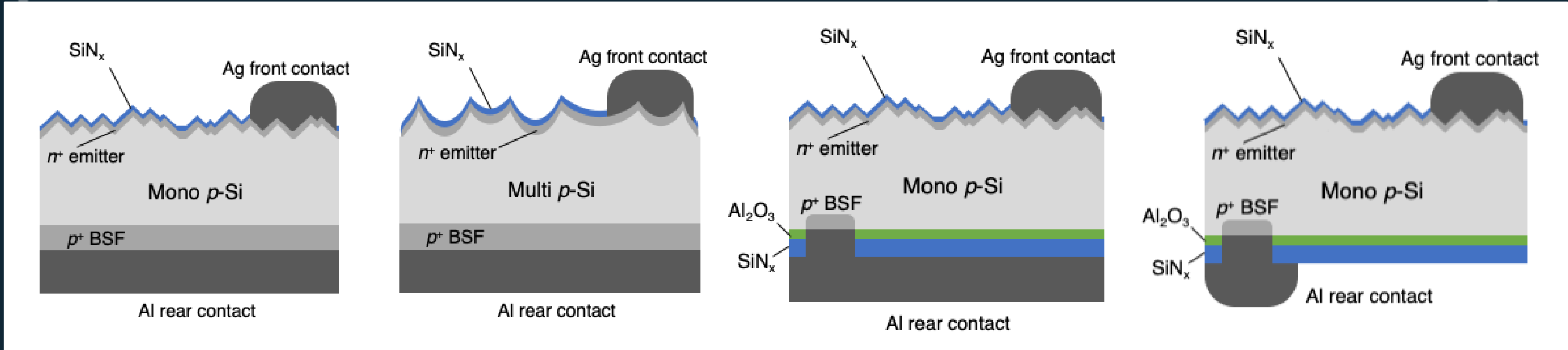
- For PERC cells
- Along with increased variability

Increase in quantum efficiency with PERC

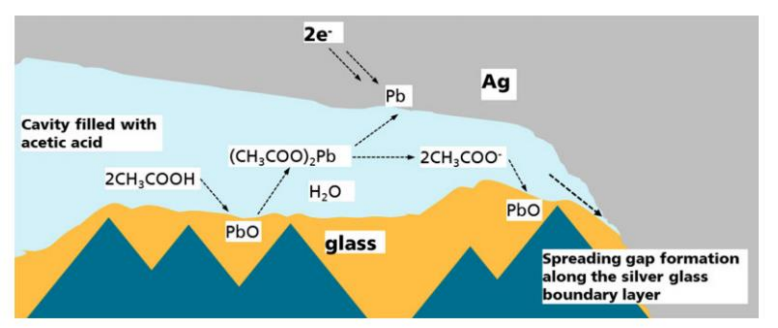




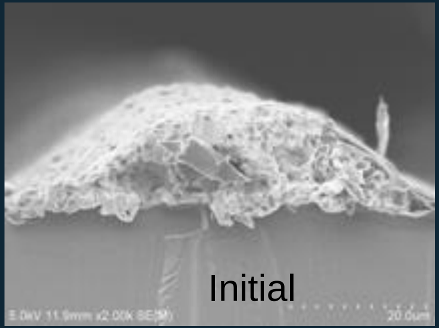
Reliability & Degradation

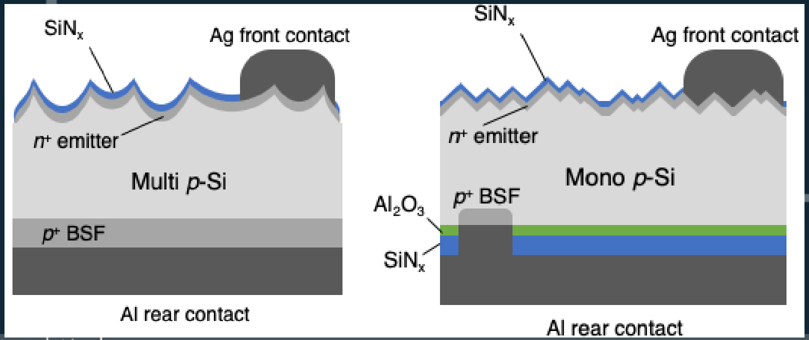


Chemical Stability



Kraft *et al.* “Investigation of Acetic Acid Corrosion Impact on Printed Solar Cell Contacts” *IEEE JPV* (2015)





Damp Heat

↓

EVA hydrolysis

↓

Acetic acid

↓

Corrosion

↓

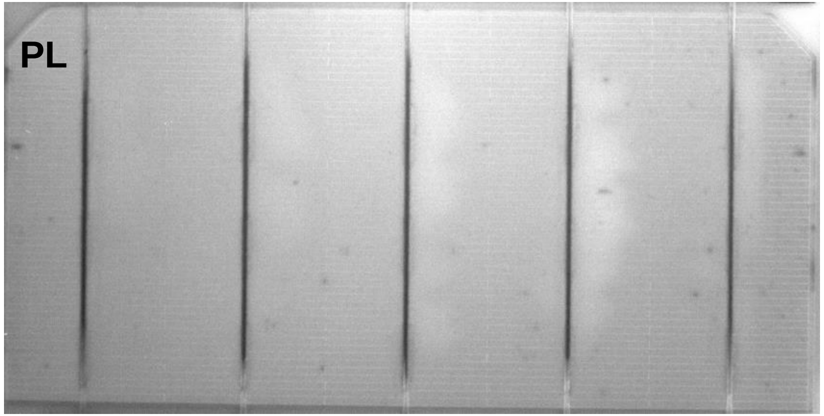
R_S increase

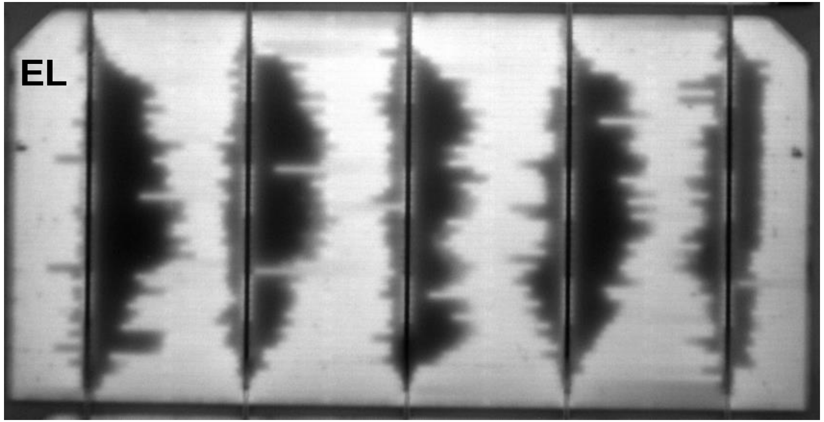
↓

Power loss

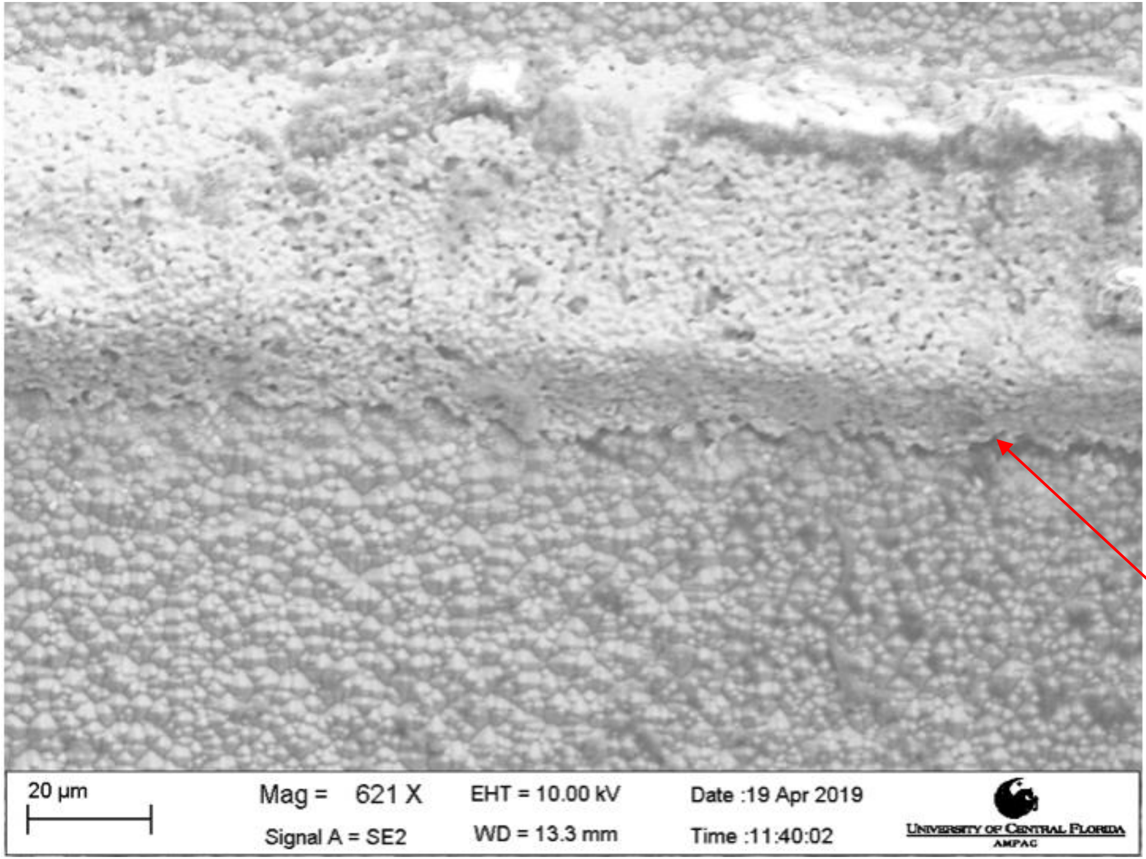
Typical degradation pathway under DH

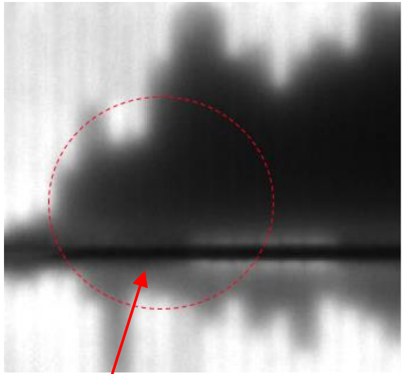
Visible & Electrical Degradation in Full-Size, Half-Cell Modules in Damp Heat





SEM Imaging of Degraded Gridlines

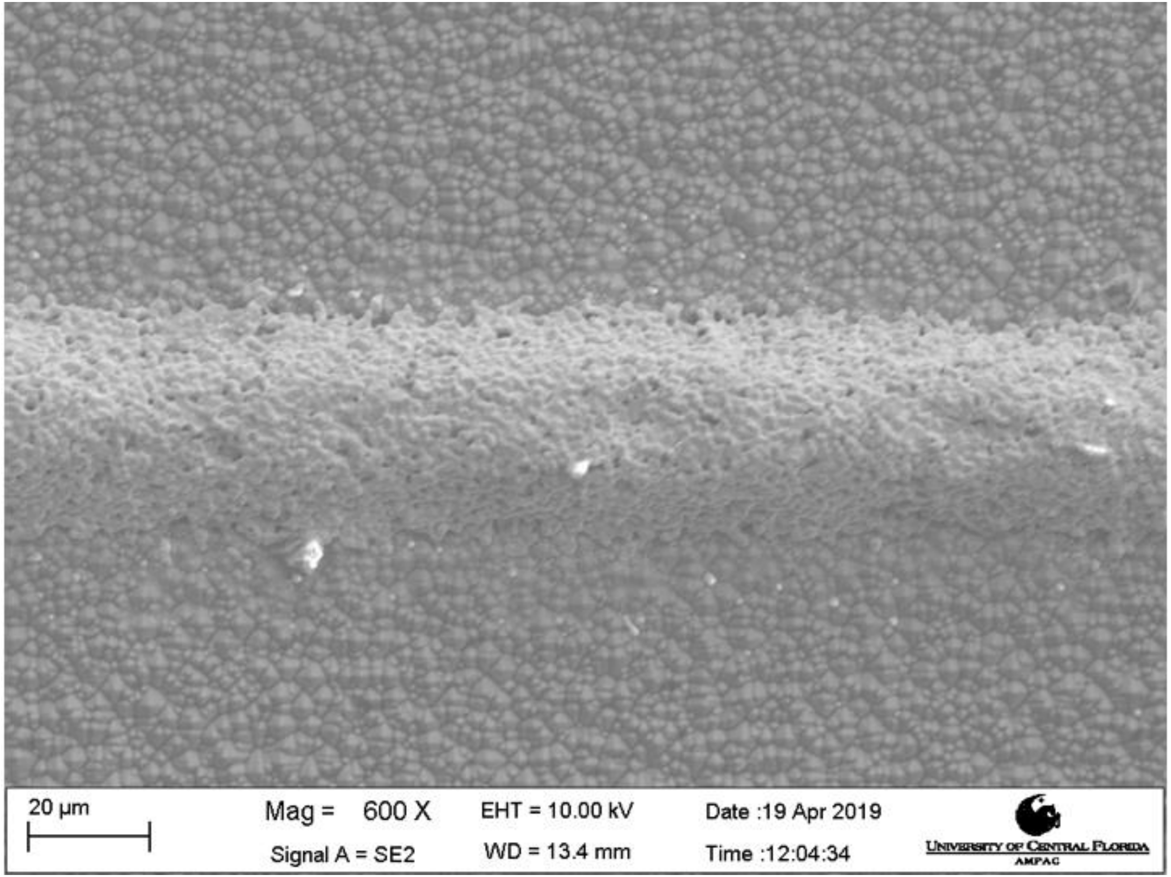


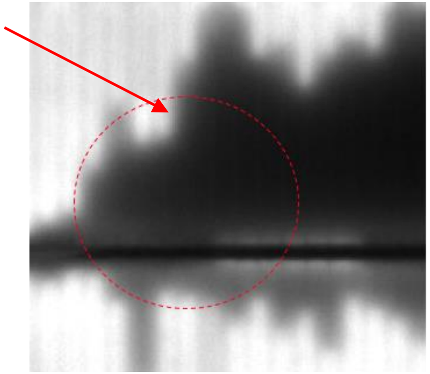


Location of SEM image

Signs of separation between the grid finger and the silicon?

SEM Imaging of Pristine Gridlines



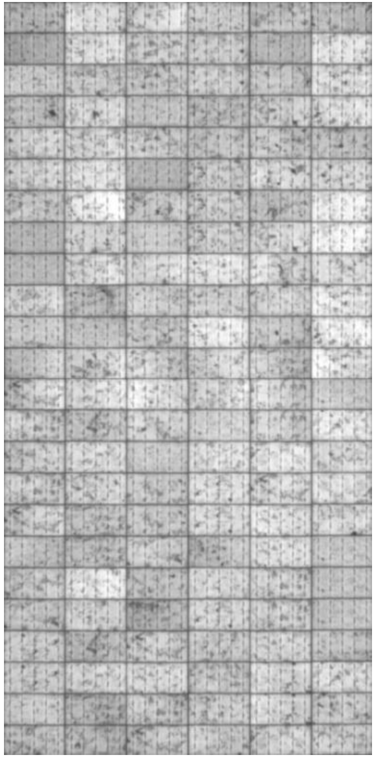


Same signature not visible in "good region"

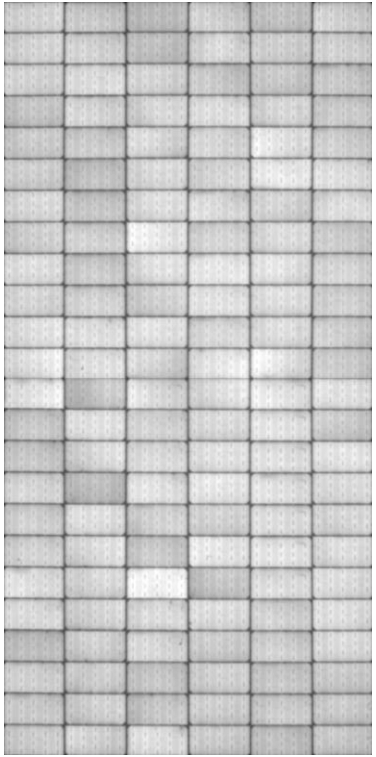
Degradation Mode Analysis - Damp Heat

Unique patterns for multi-xtal-Al-BSF and mono-xtal-PERC

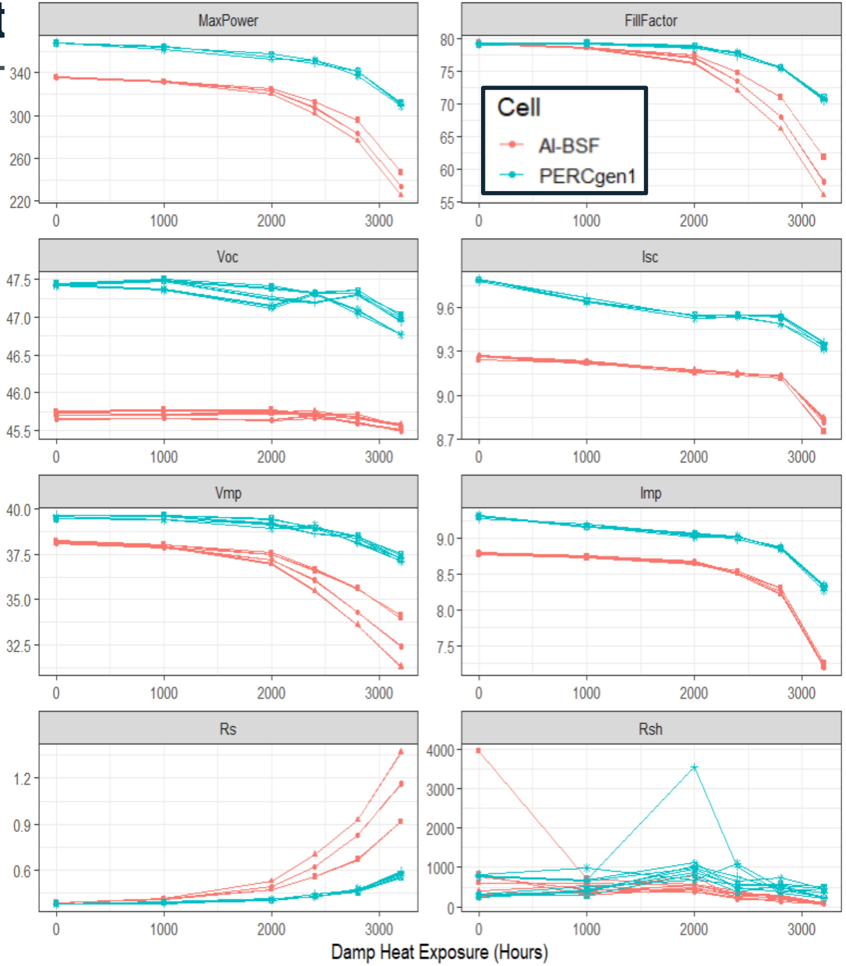
- **after 3200+ hours in Damp-Heat**



Multi Al-BSF



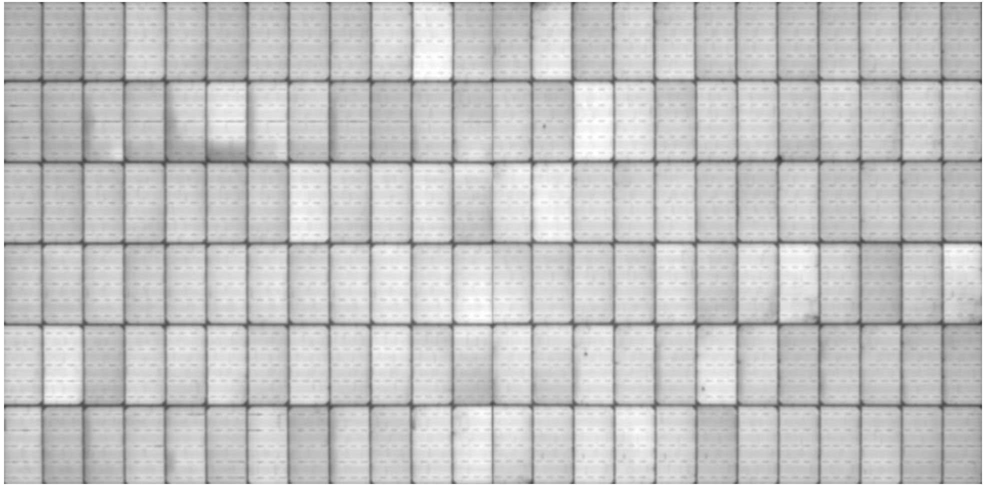
Mono PERC Gen 1



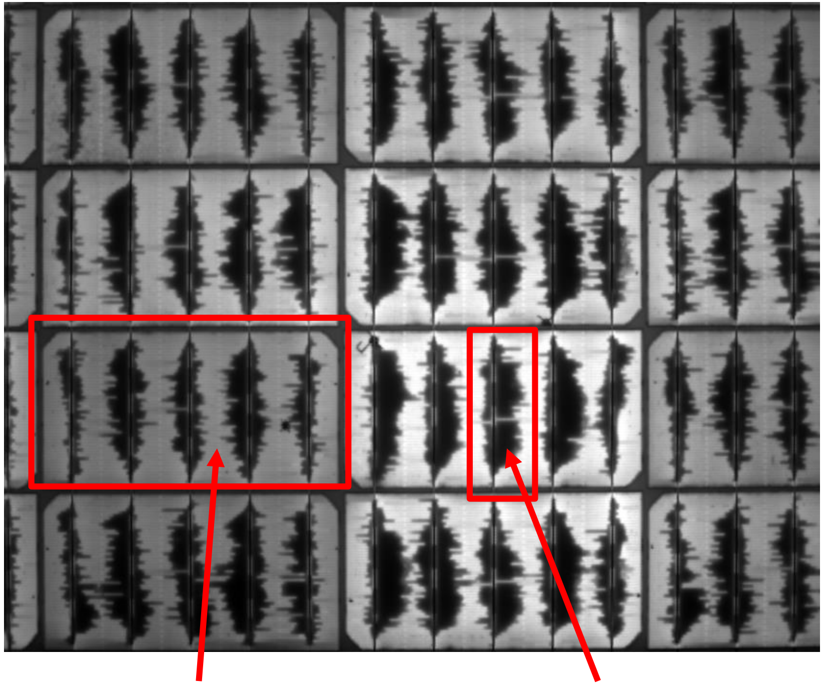
PERC Degradation

Two potential degradation mechanisms

1. **Severe darkening near busbars**
2. **General Darkening of select cells**

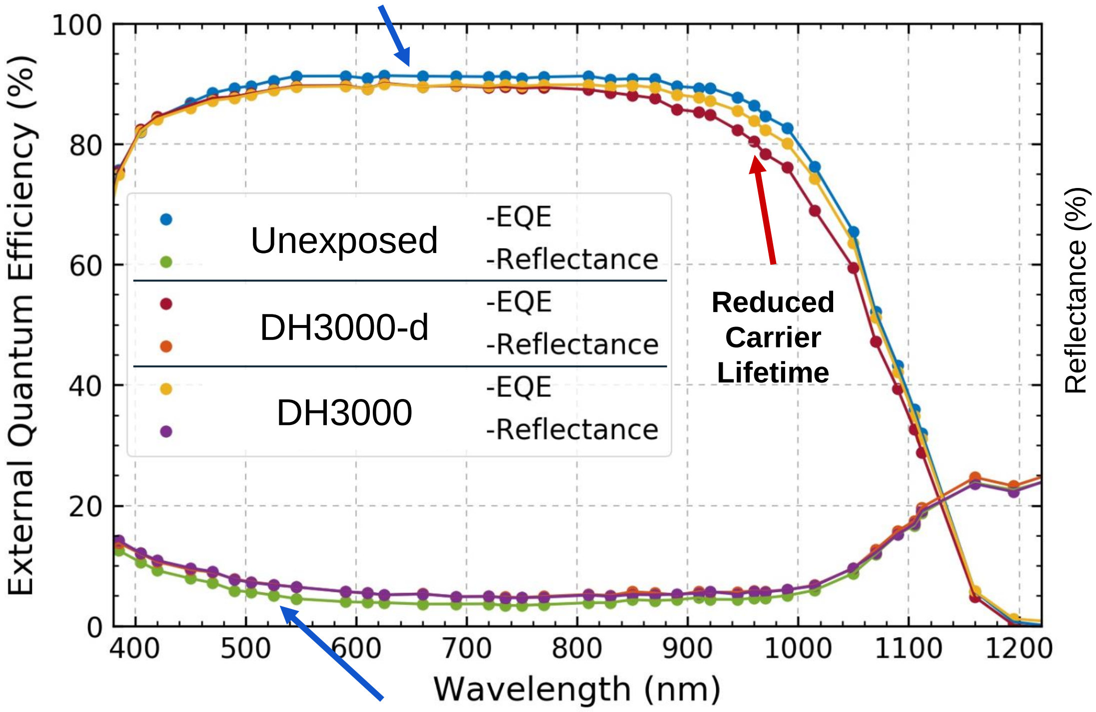


Animation of EL degradation over DH 3200

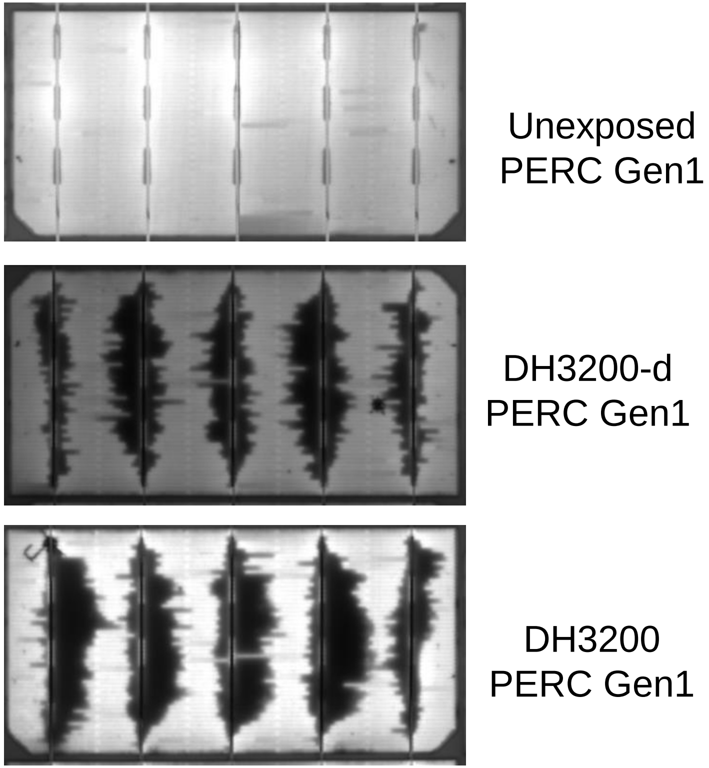


PERC Degradation - External Quantum Efficiency

Degradation of Packaging Material Optical Properties



Degradation of Packaging Material Optical Properties



**Average EQE over cell excluding busbar regions and edges

Packaging Materials

And

Module Architectures

Packaging Materials for Minimodule Fabrication

Backsheet WVTR

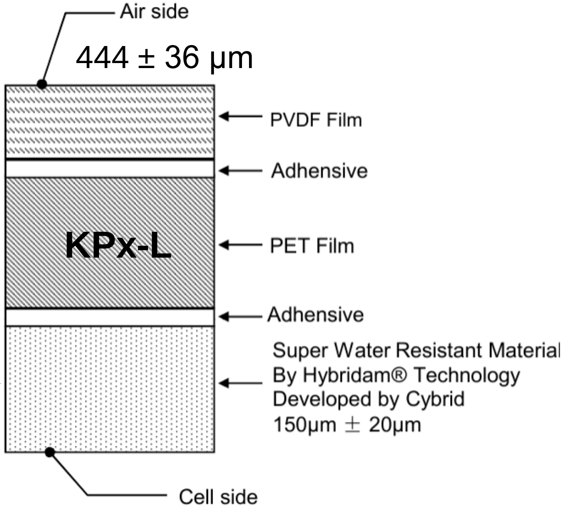
< 1 g/m^{2}day

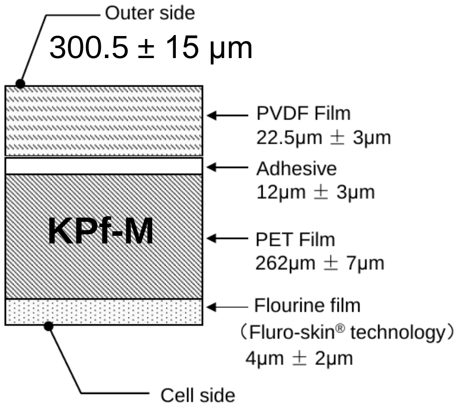
< 2 g/m^{2}day

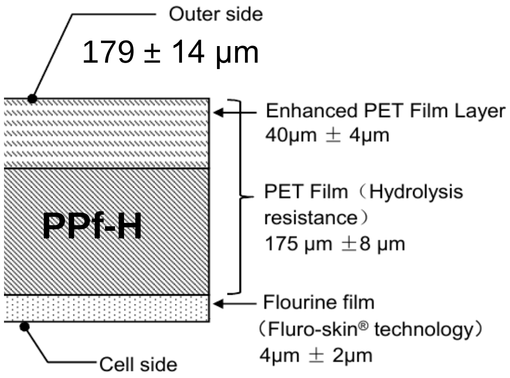
< 3.5 g/m^{2}day

Backsheet

PE/PP

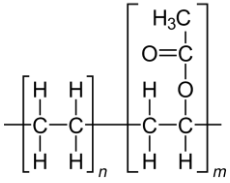




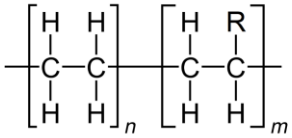


Encapsulant

880 ± 90 μm



Ethylene vinyl acetate (EVA)



Polyolefin elastomer (POE)

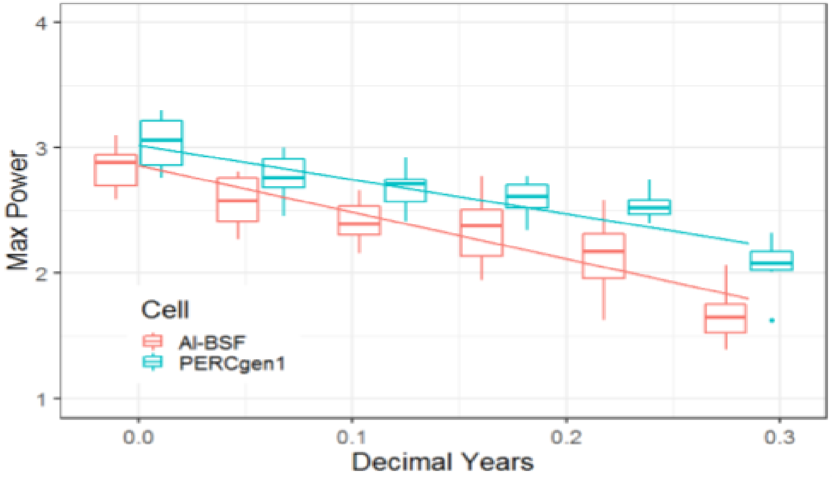
DH exposure

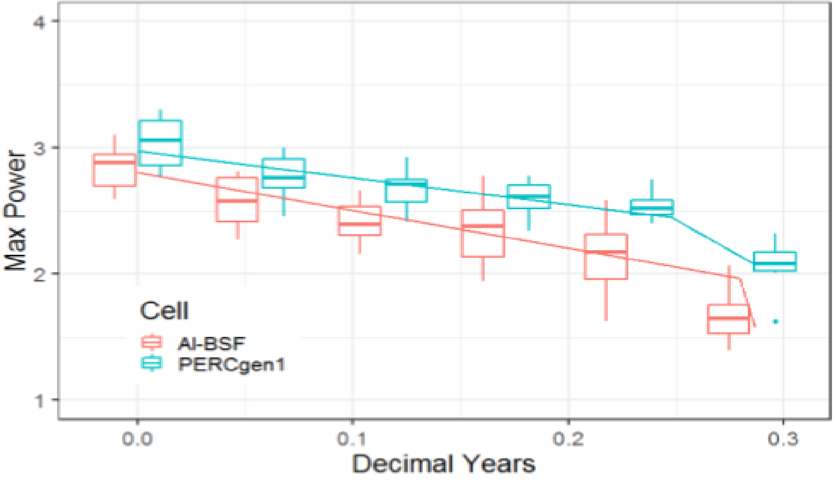
Comparing
- Monocrystalline monofacial PERC
- With multicrystalline monofacial Al-BSF

Cell
- Monocrystalline PERC performs better

Backsheet: Rank Order
- KPf > PPf > KPX
  - Not correlated to WVTR

No significant difference between
- EVA: UV Cutoff
- POE: UV Cutoff





Backsheet performance in DH

Normalized P_{mp} retained after 2500h DH

For minimodules with EVA encapsulant

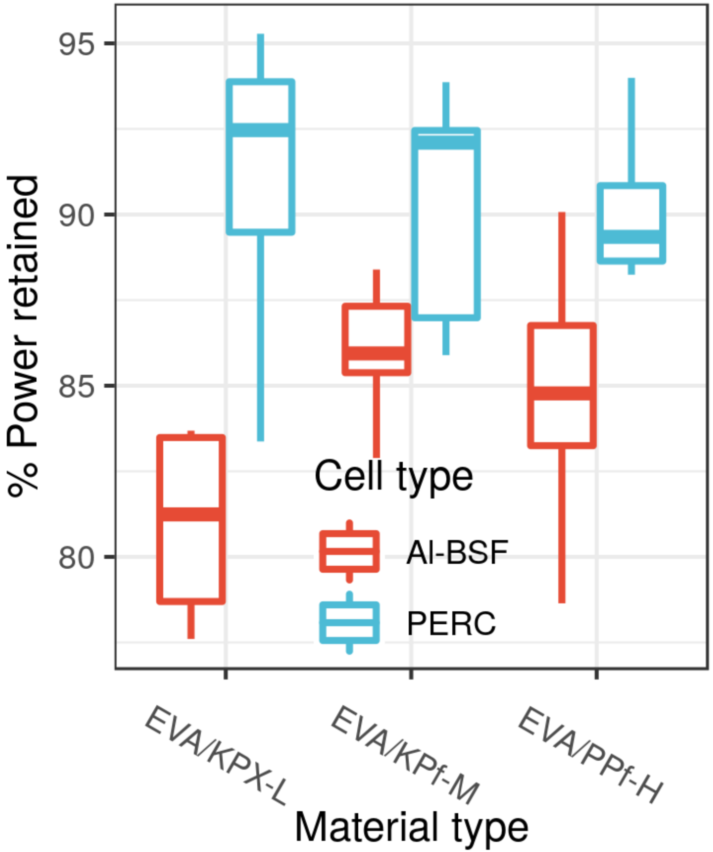
- (UV trans + UV cutoff)

For **Al-BSF** cells, Backsheet rank order

- **KPf > PPf > KPX**

For **PERC** cells

- No significant difference between backsheets



mDH Exposure - Power loss modeling: White EVA w/ Al-BSF

White Encapsulant with bifacial cells

- Produces monofacial module

Comparing

- Multicrystalline monofacial Al-BSF
- Monocrystalline bifacial PERC
- Multicrystalline bifacial PERC

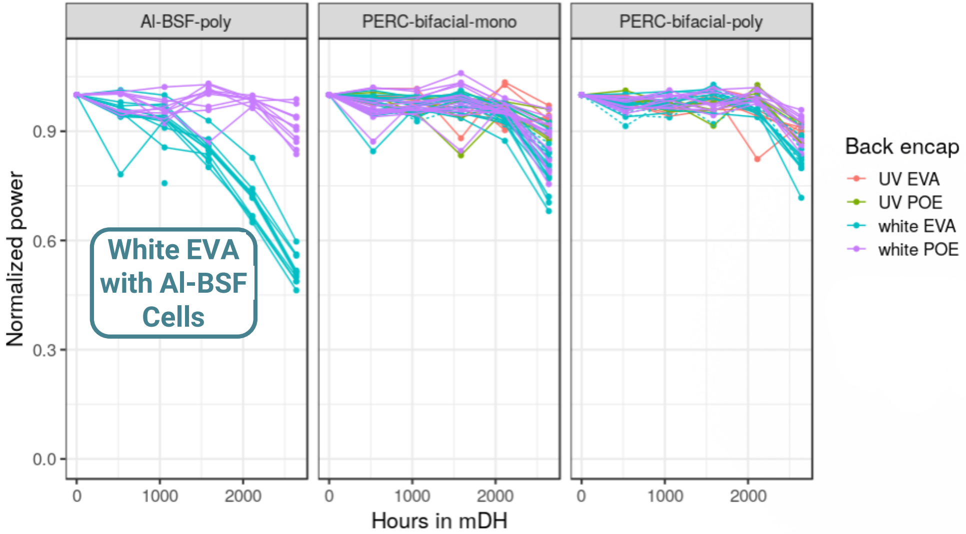
Modified DH Exposure: 80ºC / 85% RH

Al-BSF shows significant loss

- With white EVA
- Around 50% power loss
  - Compared to 10-30% loss
  - in other modules 0.3 year total exposure

Rank ordering of backside encapsulants

1. UV cutoff EVA
2. UV cutoff POE
3. White POE
4. White EVA



Cell	Back encapsulant	Model	β_0	β_1	β_2	ψ	$Adj\,R^2$
Al-BSF-poly	white EVA	seg	1.00	-0.78	-2.40	0.20	0.93
Al-BSF-poly	white POE	seg	0.99	-0.04	-8.16	0.29	0.39
PERC-bifacial-mono	white EVA	seg	0.99	-0.17	-4.35	0.27	0.76
PERC-bifacial-mono	white POE	seg	0.99	-0.08	-1.49	0.24	0.52
PERC-bifacial-mono	UV EVA	seg	1.00	-0.13	-0.28	0.18	0.54
PERC-bifacial-mono	UV POE	seg	1.00	-0.11	-0.82	0.26	0.43
PERC-bifacial-poly	white EVA	seg	0.99	-0.04	-2.18	0.23	0.77
PERC-bifacial-poly	white POE	seg	0.99	-0.01	-4.73	0.28	0.62
PERC-bifacial-poly	UV EVA	seg	0.99	-0.09	-0.58	0.19	0.52
PERC-bifacial-poly	UV POE	seg	0.99	-0.05	-1.33	0.25	0.63

T50 Baseline Electrical Perf. vs. Packaging Materials & Architecture

Glass/Backsheet Architecture

- Higher performance

POE Encapsulant

- Can have higher performance

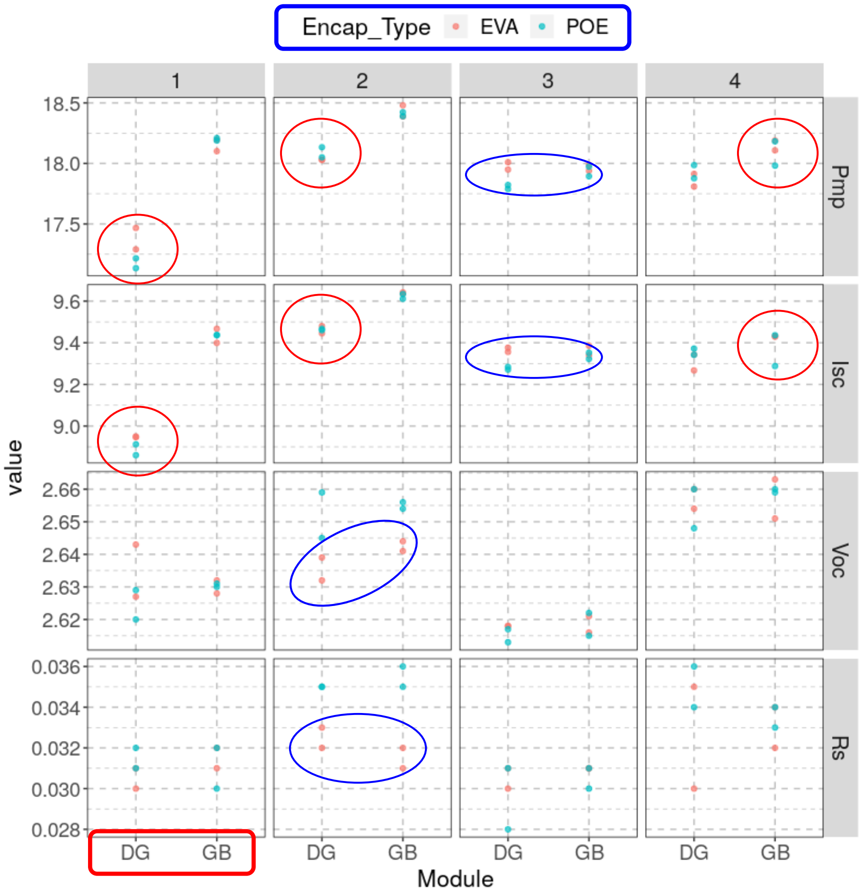
4 cell minimodule BOM

- (2 * 16 types) fabricated by CSI

DG / GB comparions in red

EVA / POE comparions in blue

Minimodule Set #	Cell Type	Encapsulant	Backside Encapsulant	Module Type
1	monofacial	EVA	UV-Cut	GB
1	monofacial	EVA	UV-Cut	DG
1	monofacial	POE	UV-Cut	GB
1	monofacial	POE	UV-Cut	DG
2	bifacial	EVA	White	GB
2	bifacial	EVA	White	DG
2	bifacial	POE	White	GB
2	bifacial	POE	White	DG
3	monofacial	EVA	White	GB
3	monofacial	EVA	White	DG
3	monofacial	POE	White	GB
3	monofacial	POE	White	DG
4	bifacial	EVA	UV-Cut	GB
4	bifacial	EVA	Trans	DG
4	bifacial	POE	UV-Cut	GB
4	bifacial	POE	Trans	DG



Conclusions

Rapid changes in cell and module technologies & architectures

- Combined with continuing advances in packaging materials

Require new module/minimodule characterization methods

- e. g. EL/PL imaging tools
- Provide opportunities for new machine learning approaches
    - Benefiting from large datasets and high information density of images

Statistically informed study designs helps define significance of findings

- How to pull apart complex, multi-factor phenomena

PERC cells have replaced Al-BSF

- And show comparable, or better reliability

Bifacial PERC cells

- Show less curvature than Al-BSF
- May be more reliable in the long run