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Evaluating Solar Panel Mechanical Durability of Commercial Modules

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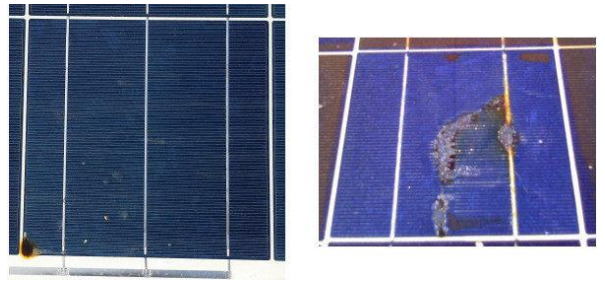
Outline

- **Motivation:** Impact of Cell Cracks and their Origin
- **Methodology:** Typical Mechanical Evaluation Approaches
- **Experimental Results:** Case Study of Commercial Modules
- **Discussion / Conclusions**

Module Mechanical Durability

- PV modules experience a wide range of mechanical stressors over their lifetime that may cause cell cracking
  - shipping, installation, snow, wind, thermal cycling

- Cell cracks pose a risk to long term performance
  - Increase in **series resistance**
  - Increase in “dead area” leading to **current mismatch**
  - Potential for **hot spot** generation
  - Severe hot spots are a potential **safety hazard**



Example severe hot spot caused due to cell cracks [1]

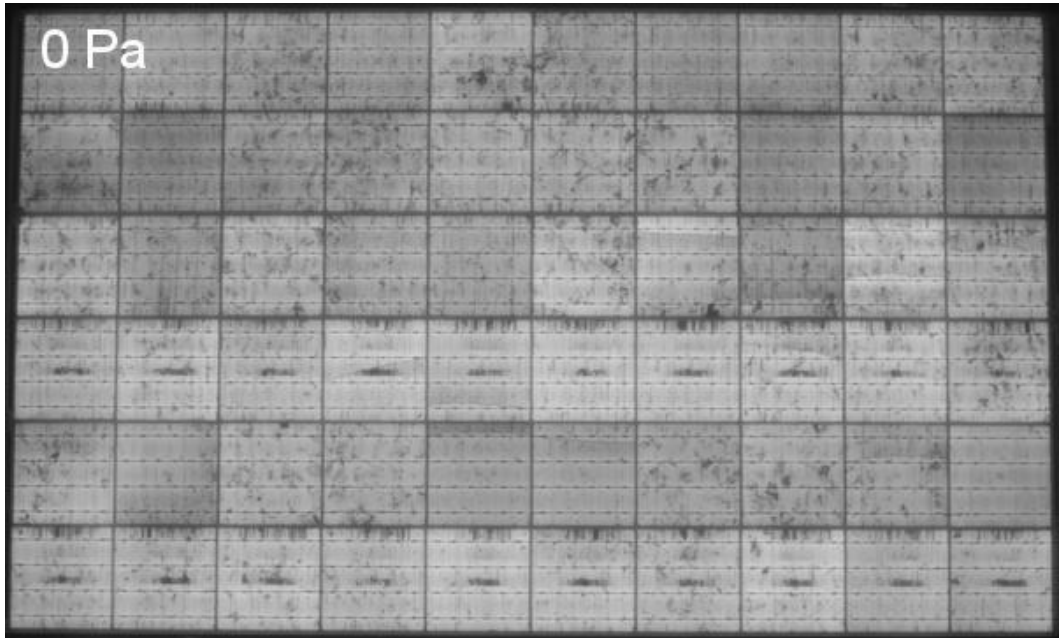
- In this work, a modified mechanical durability test sequence is investigated to evaluate module design with respect to crack durability

[1] “Hot spots: Causes and Effects” *PV Magazine* 2017

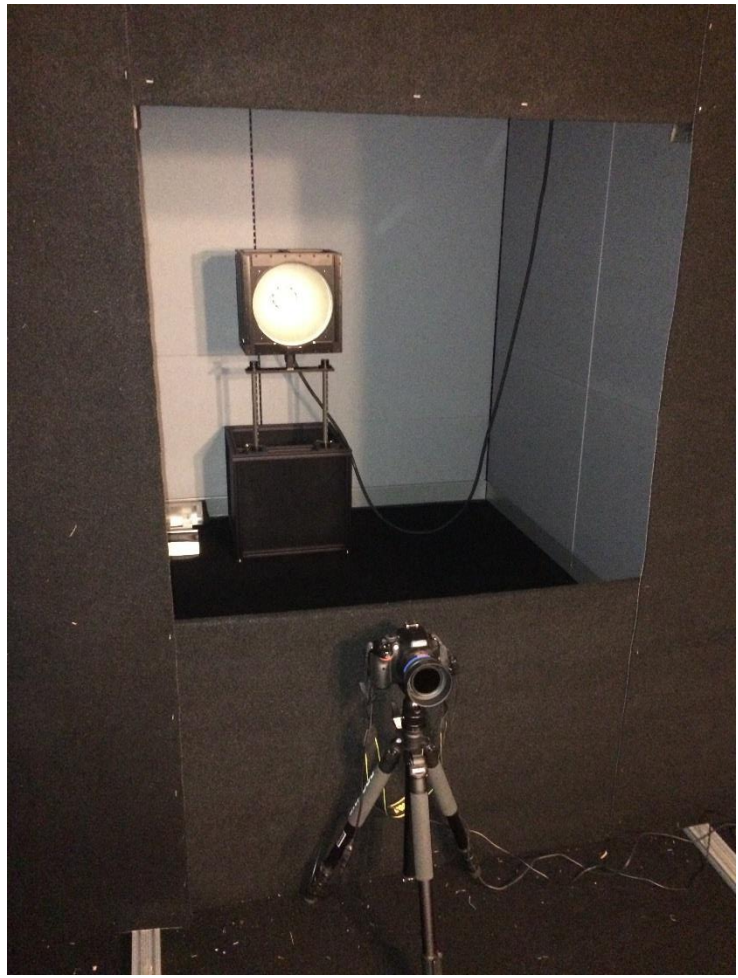
METHODOLOGY

Mechanical Testing Equipment - *LoadSpot*

- Front side is unobstructed to allow for *in-situ* characterization under load
- Electroluminescence Camera and Sinton FMT solar simulator are used for characterization



BrightSpot Automation



Sinton instruments

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Typical Mechanical Evaluations – Front Side Loads

- A front side mechanical load puts cells into tension, which propagates micro-cracks into full cell cracks.
- These cell cracks tend to close upon removal of the mechanical load
- This results in very minimal power degradation even with a large number of fractured cells

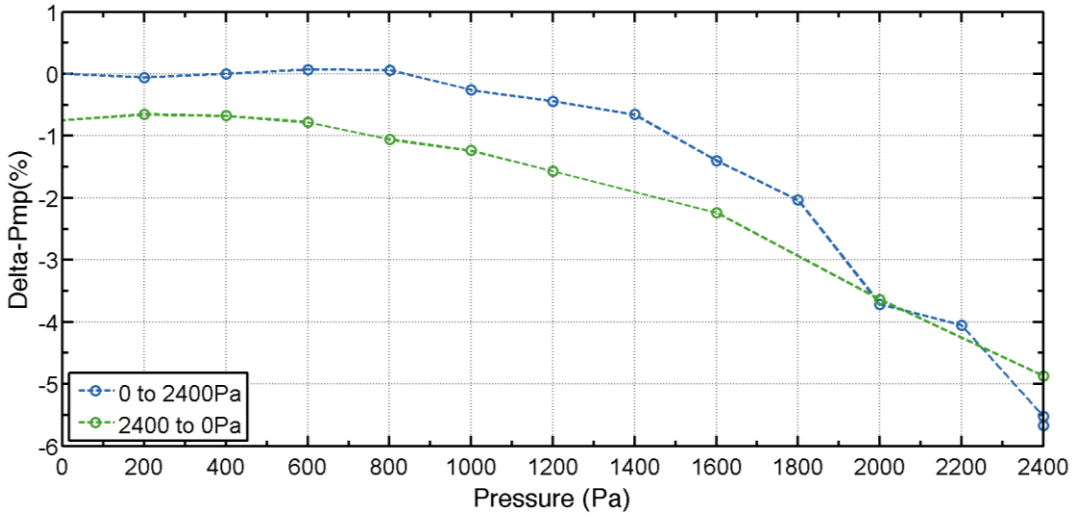
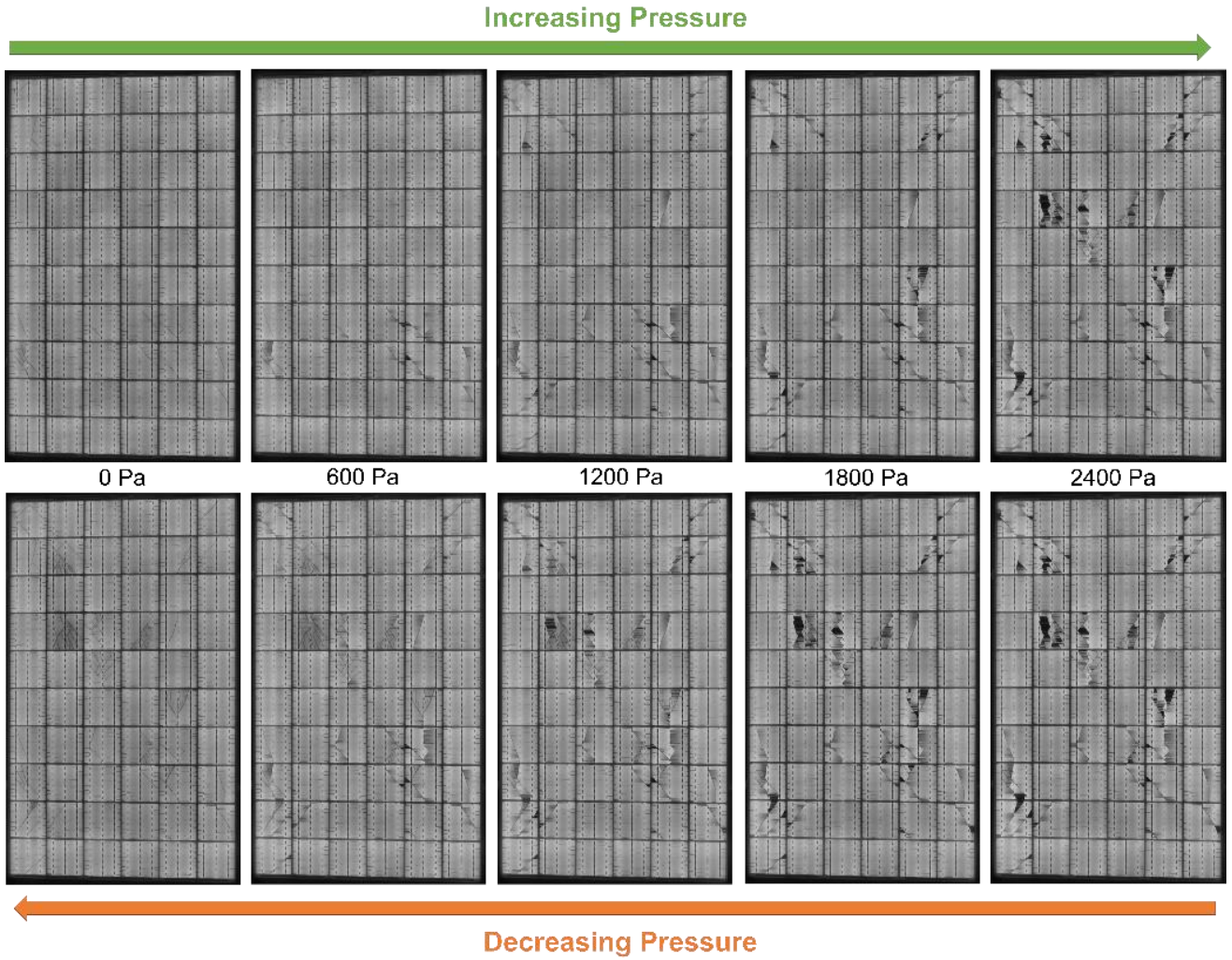


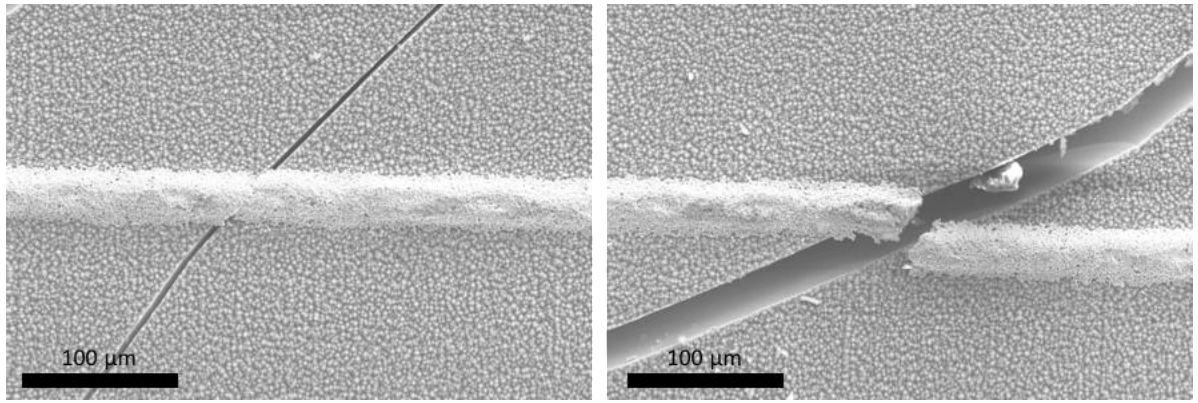
Figure: Change in maximum power as a function of applied load for both increasing (blue) and decreasing (green) pressure



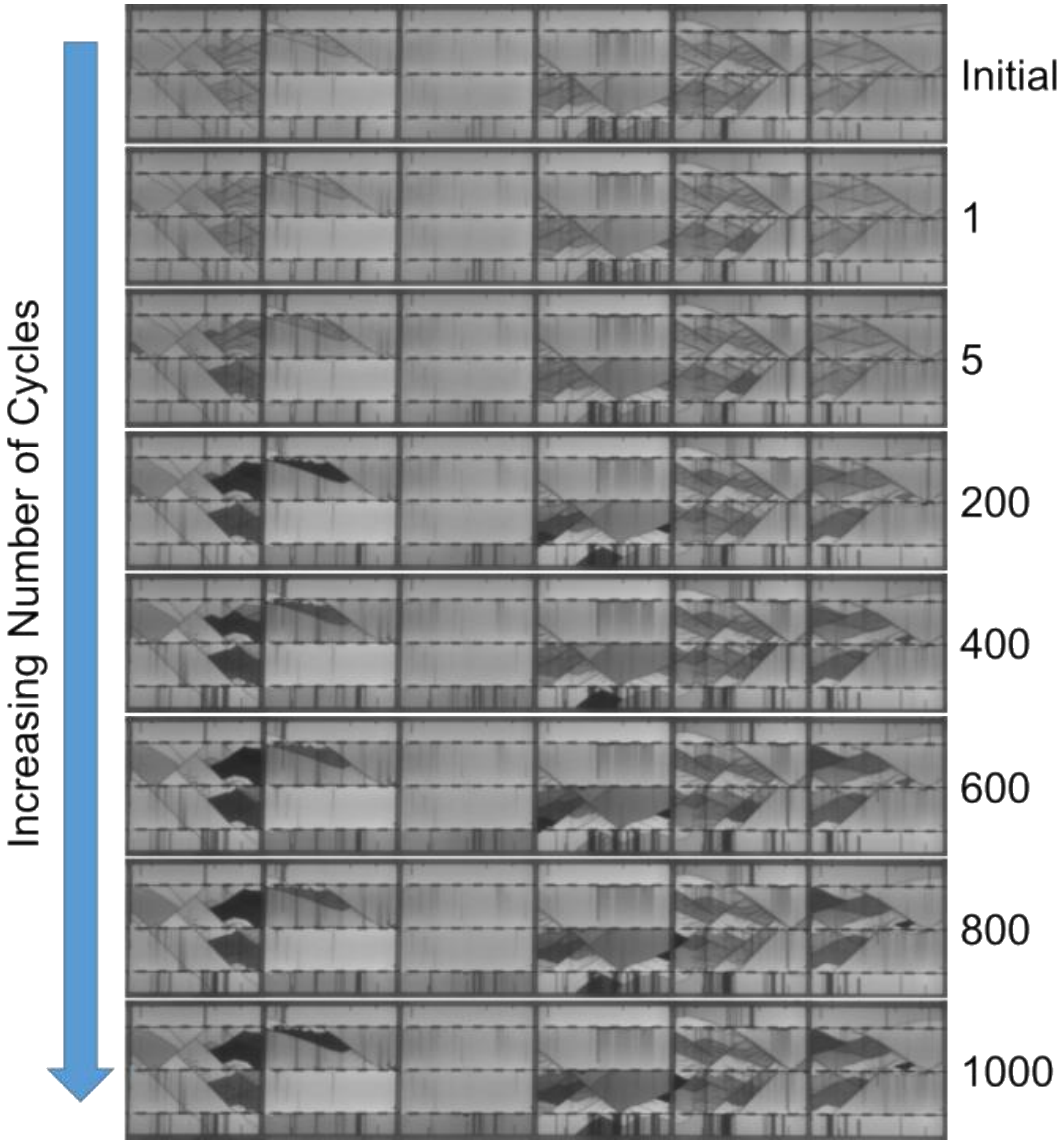
[1] Schneller et al. "Evaluating Solar Cell Fracture as a Function of Module Mechanical Loading Conditions" *2017 IEEE PVSC*

Typical Mechanical Evaluations – Cyclic Loading

- Standard Cyclic loading sequence is 1000 cycles of ±1000Pa
- Cyclic loading assists in the transition of benign cracks into electrical isolation
- Electrical isolation has been directly related to power loss

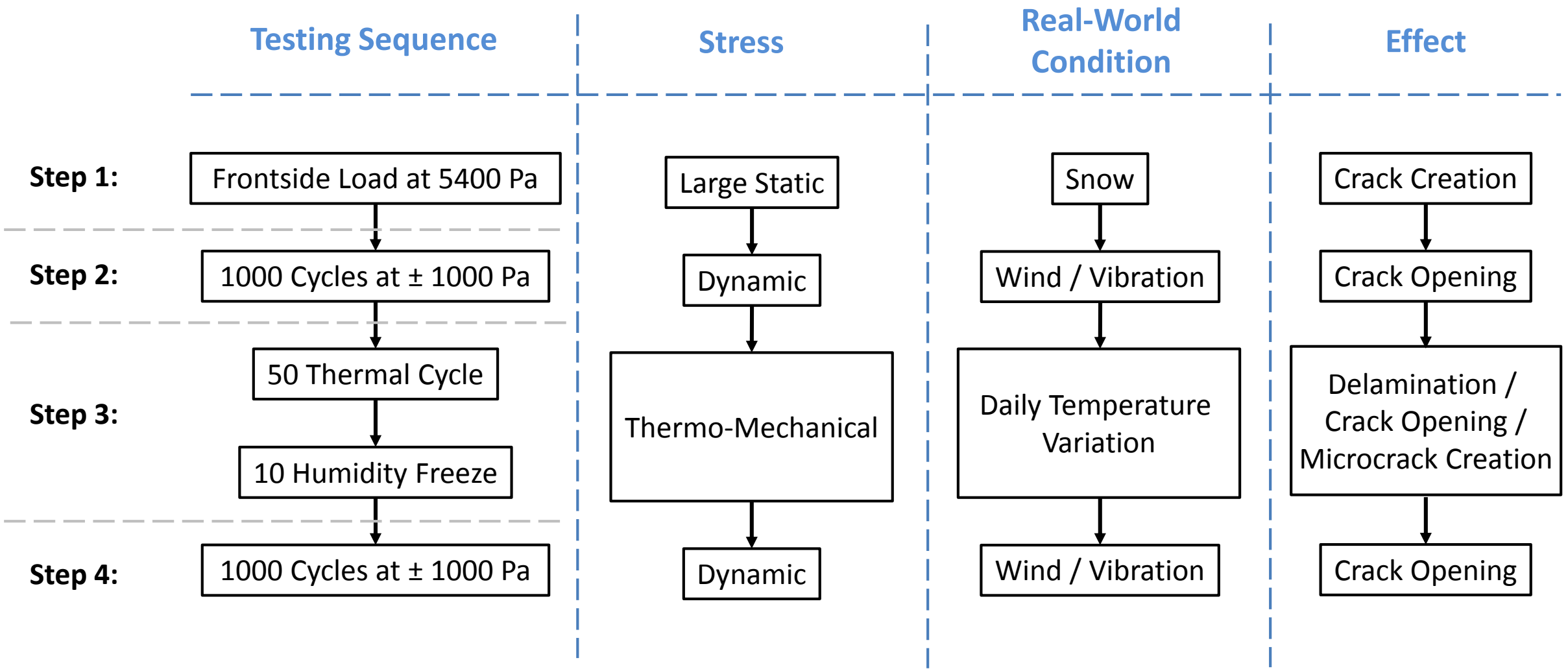


SEM images of cell cracks that exhibit electrical conduction (left) and electrical isolation (right) of the metallization



[1] Schneller et al. "Evaluating Solar Cell Fracture as a Function of Module Mechanical Loading Conditions" *2017 IEEE PVSC*

Mechanical Evaluation Protocol



Objective: Evaluate a module design with respect to crack creation and crack opening

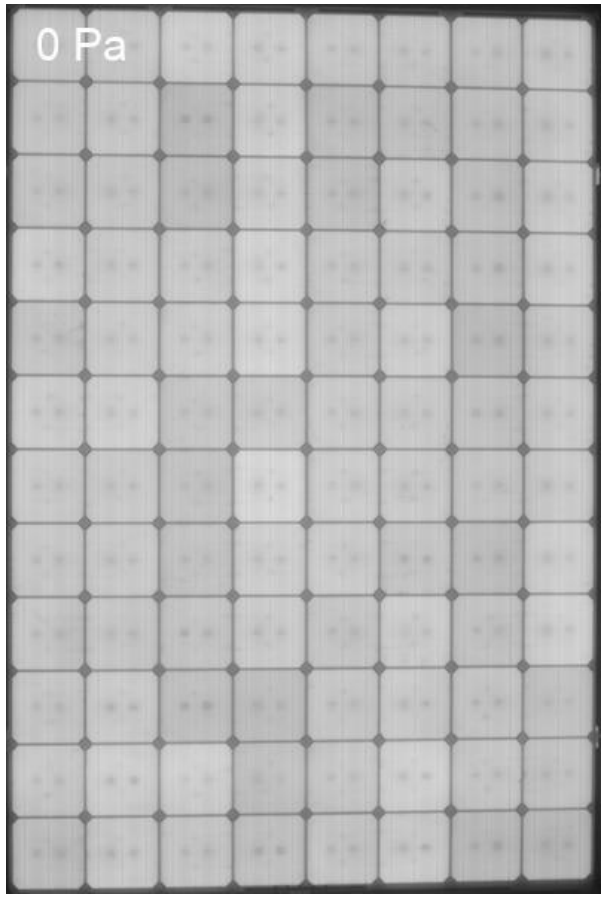
EXPERIMENTAL RESULTS

Module Technologies

Cell Technology	Interconnect Technology	Cell Size	Number of Cells
HIT	3 Busbar Low Temperature Interconnects	5 inch pseudo-square	96
Mono-PERC	4 Busbar Solder Interconnects	6 inch pseudo-square	60
Multi-PERC	4 Busbar Solder Interconnects	6 inch square	60
Mono-PERT	Wire Interconnects	6 inch pseudo-square	60

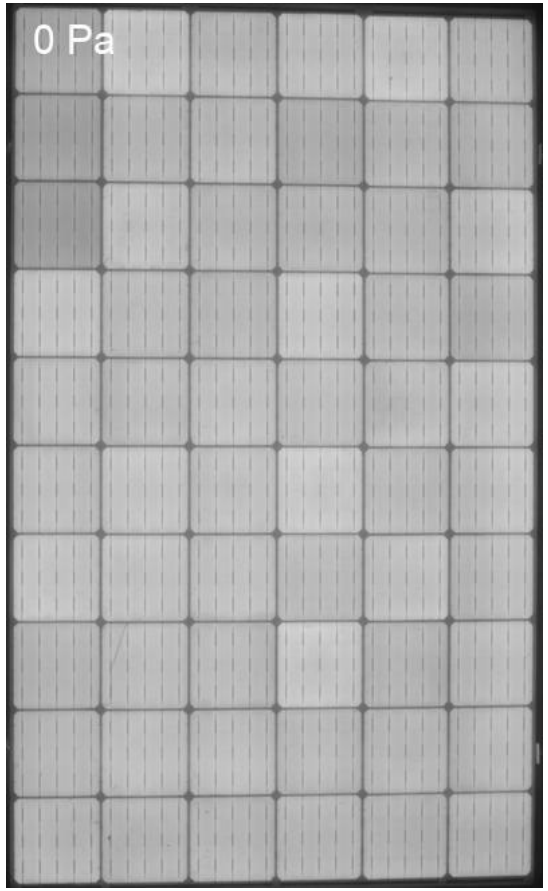
Step 1 – Static Load – Crack Creation

Frontside Load up to 5400Pa



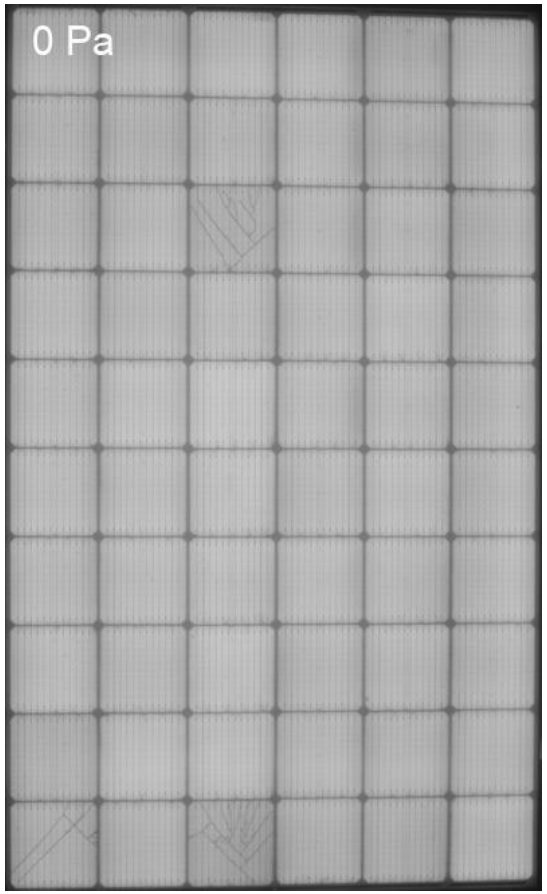
HIT

0 Cracked Cell



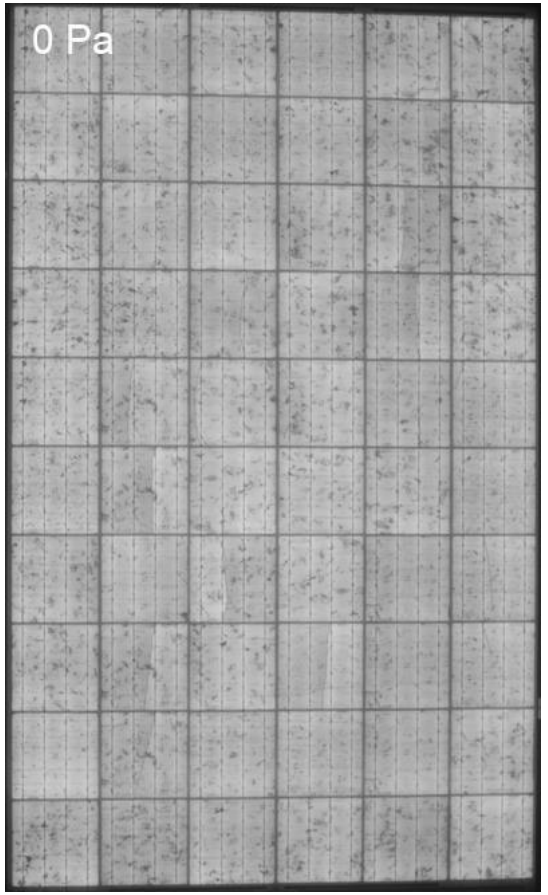
Mono-PERC

4 Cracked Cells



Mono-PERT

7 Cracked Cells



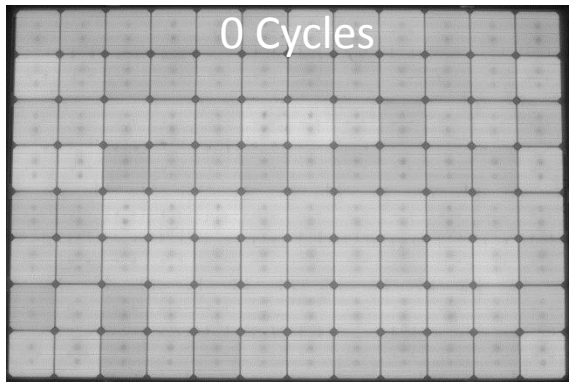
Multi-PERC

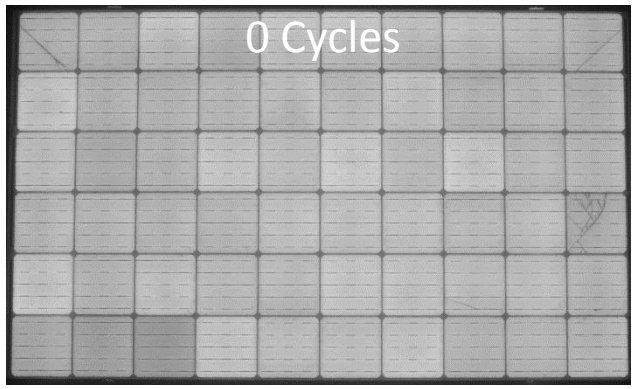
37 Cracked Cells

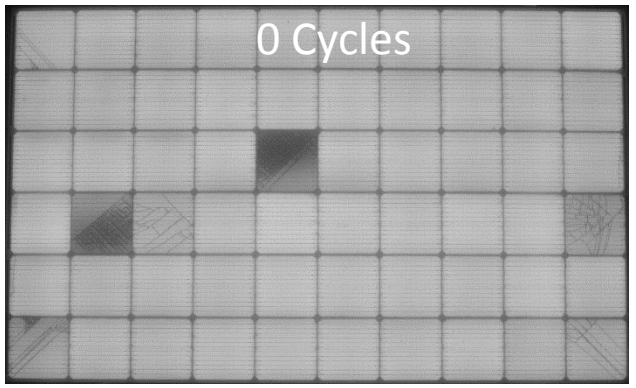
- There is a clear differentiation between module designs with respect to crack creation with a front-side load up to 5400 Pa

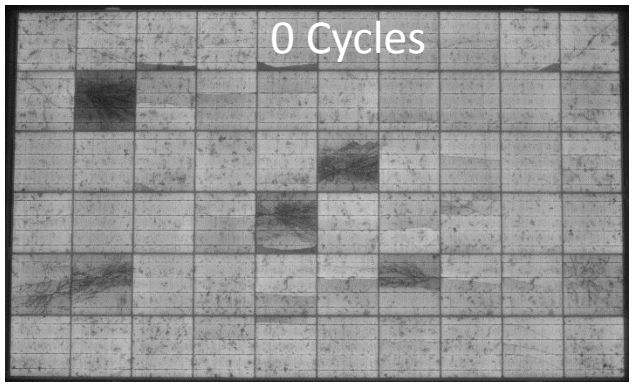
Step 2 – Cyclic Loading – Crack Opening

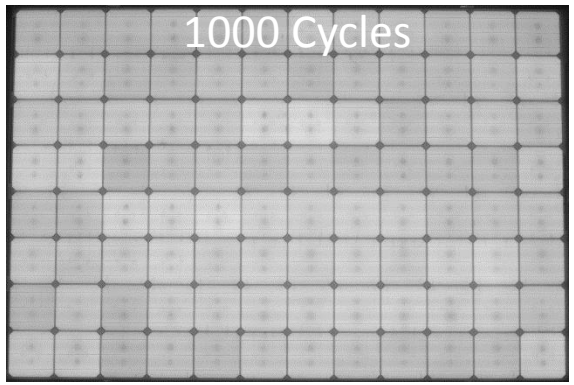
1000 Cycles at ± 1000Pa

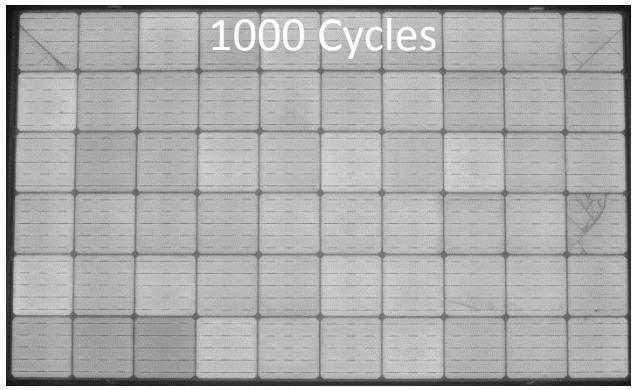


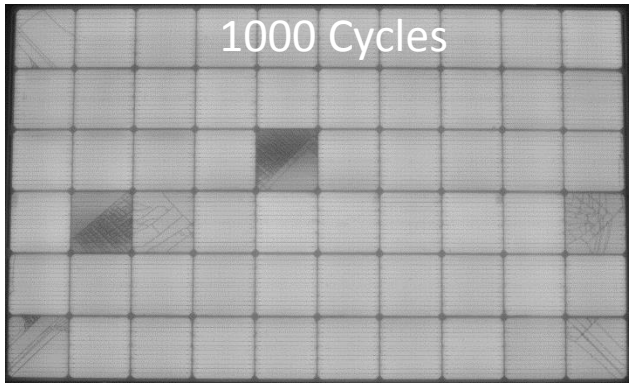


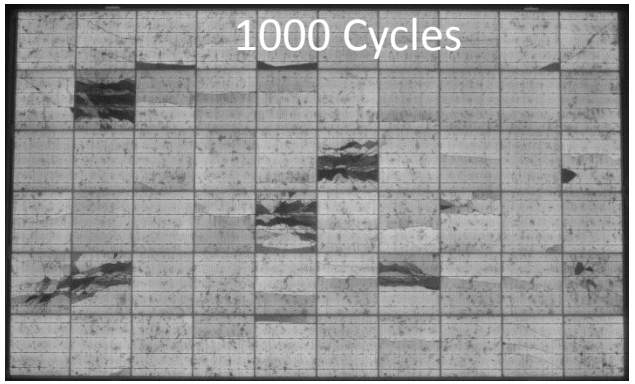












HIT

No Change

Mono-PERC

No Change

Mono-PERT

No Change

Multi-PERC

Multiple Open Cracks Form

- Cyclic loading tends to open cracks on heavily damaged modules (see Multi-PERC)
- Wire interconnects appear to prevent crack opening due to redundant design (see Mono-PERT)

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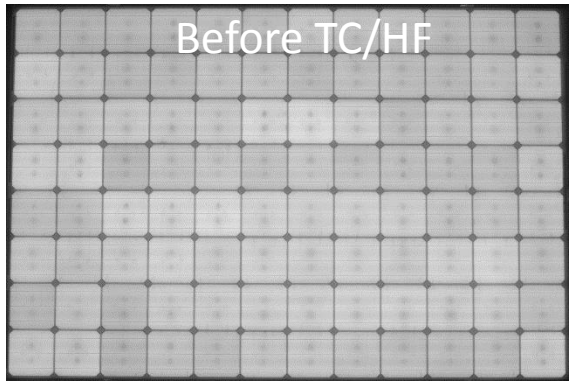
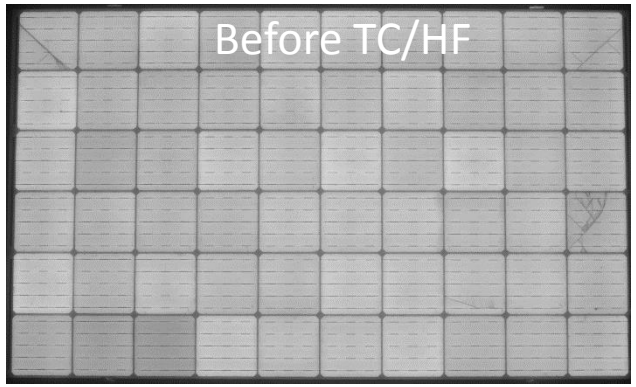
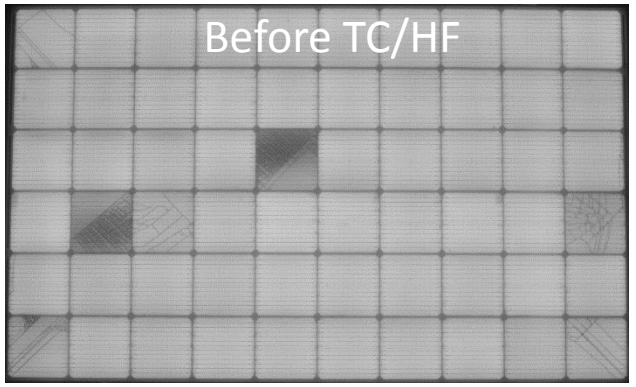
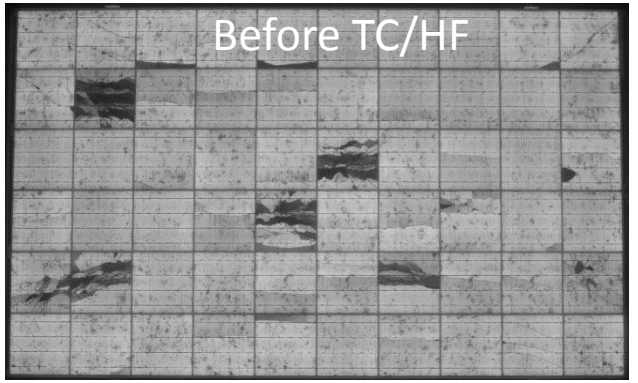
Step 3 – Environmental Chamber

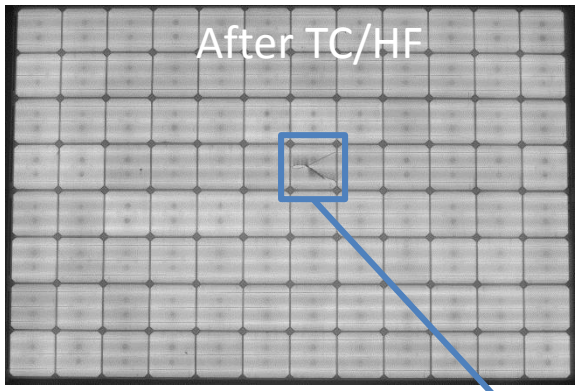
TC50 / HF10

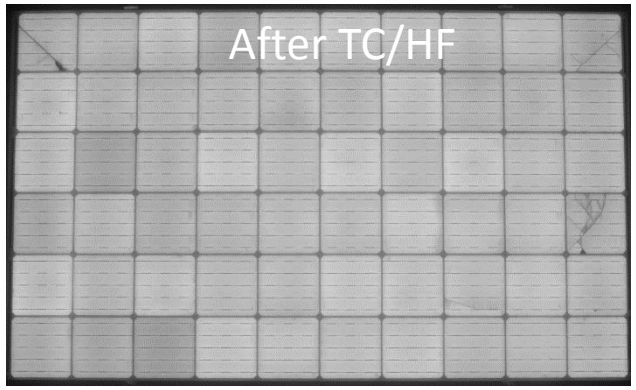


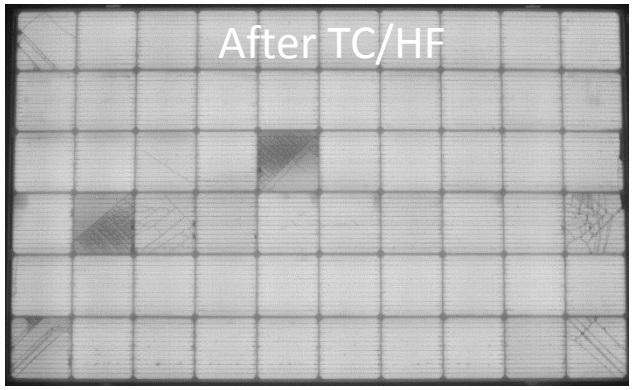


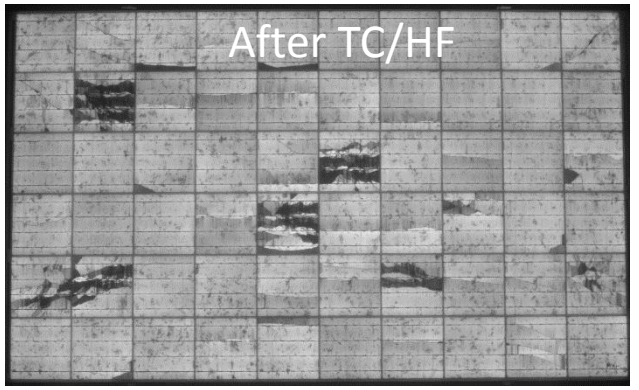












HIT

No Change

Handling Mistake During Transportation

Mono-PERC

No Significant Change

Mono-PERT

Several New Cracks Form

Multi-PERC

Slight Increase in Crack Opening

- Very minimal change in power for all modules
- Minor change in number of cracks and dark area associated with cracks for Mono-PERT and Multi-PERC

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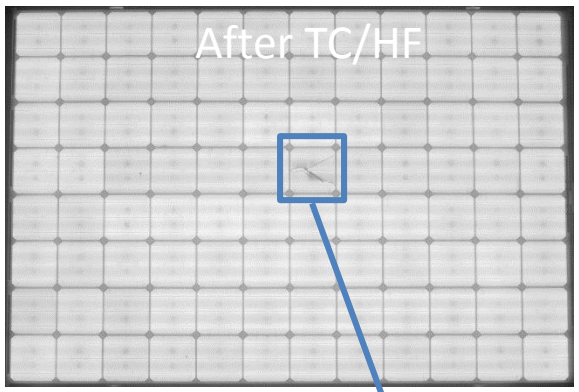
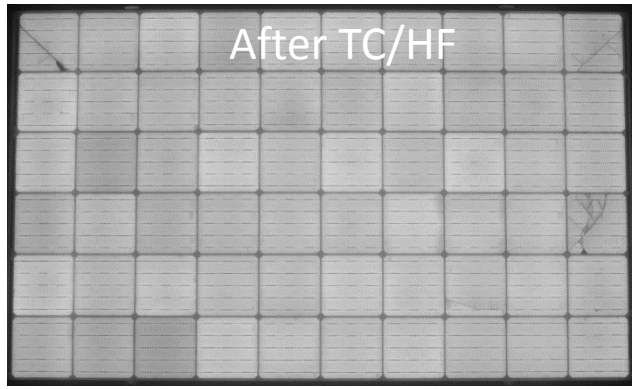
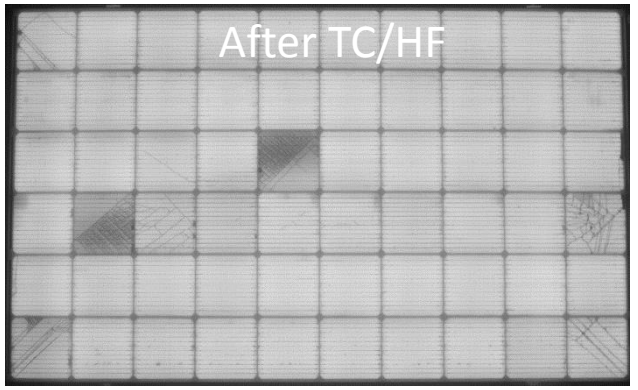
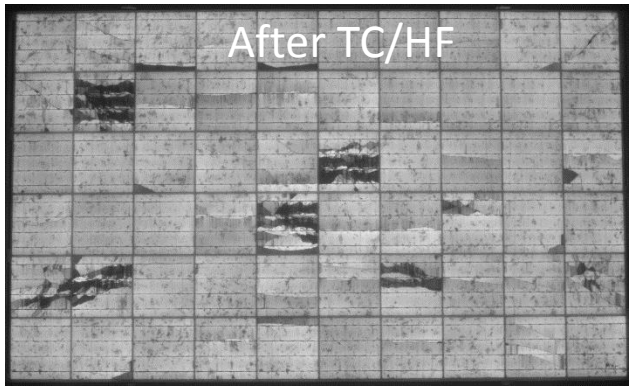
Step 4 – Final Mechanical Stress

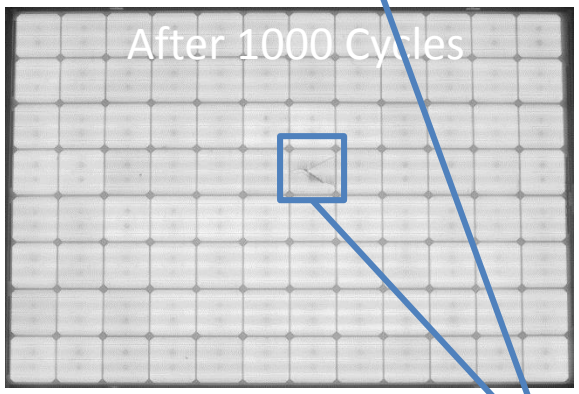
1000 Cycles at ± 1000Pa

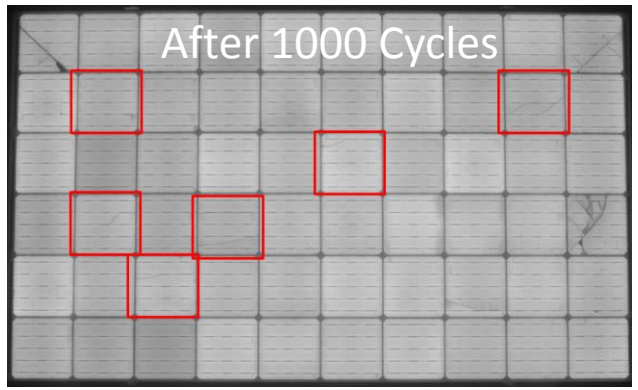


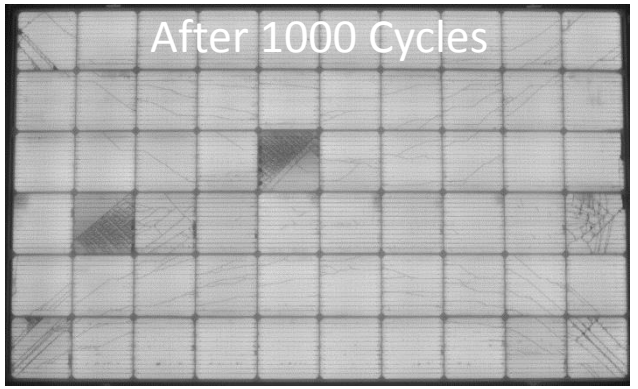


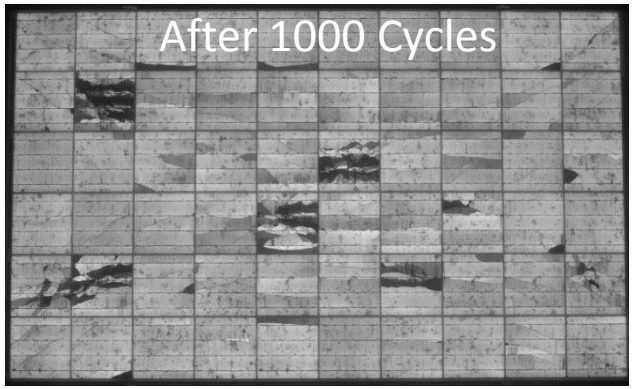












HIT

No Change

Handling Mistake During Transportation

Mono-PERC

6 Cracked Cells

Mono-PERT

Many New Cracked Cells

Multi-PERC

Many New Cracked Cells

- Thermal Cycling has a major impact on the creation of micro-cracks[1,2]
- Cell cracks appear to initiate near busbars and propagate with only a mild load of 1000 Pa for Mono-PERT and Multi-PERC Modules.
- The interconnect scheme and choice of encapsulant is the likely reason for superior performance of HIT Modules

[1] Seigneur, Hubert et al. “Micro-crack Formation in Silicon Solar Cells during Cold Temperatures” *In Press - IEEE JPV*

[2] Rowell, Michael et al. “The Effect of Laminate Construction and Temperature Cycling on the Fracture Strength and Performance of Encapsulated Solar Cells.” *2018 IEEE WCPEC* 3927-3931.

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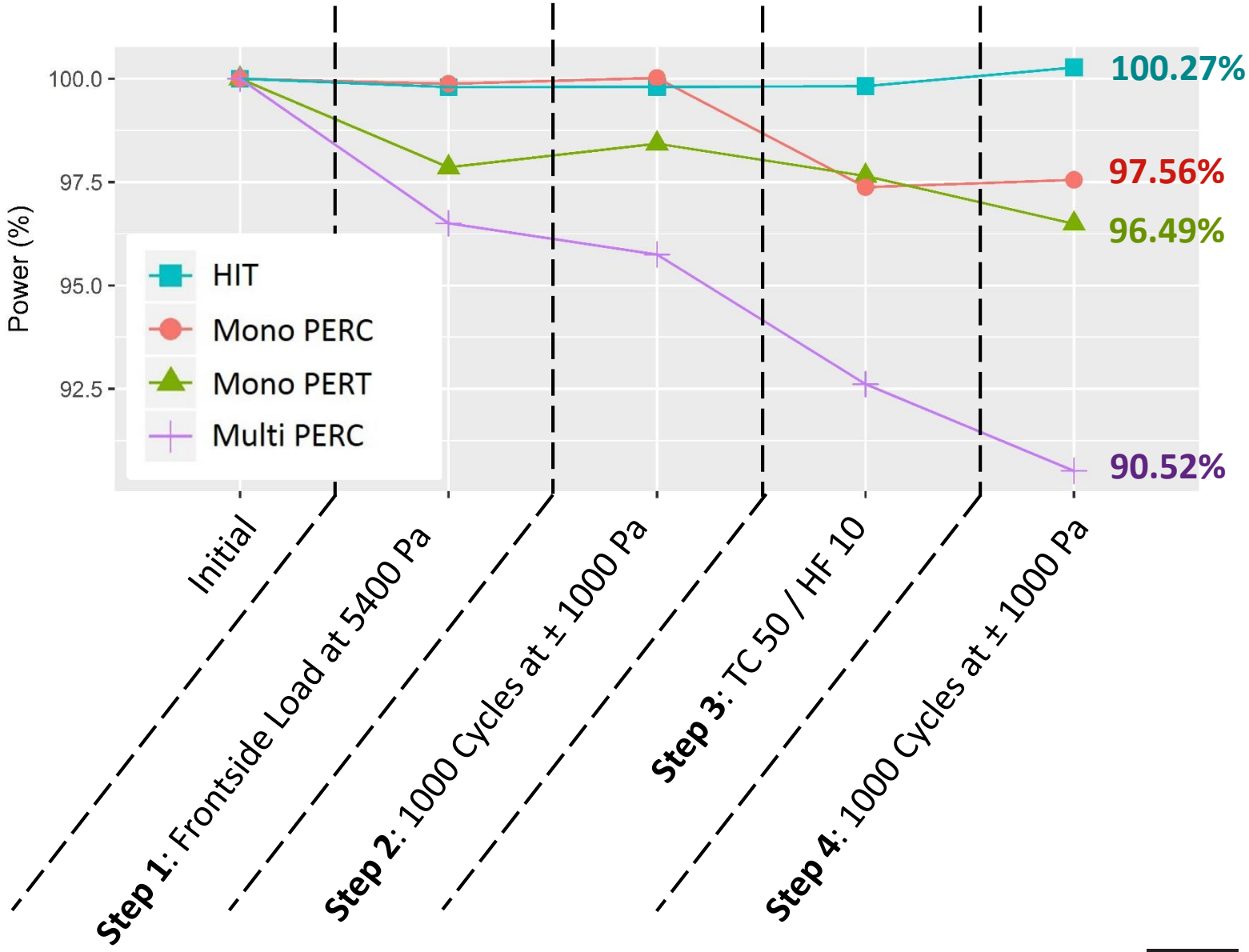
Power Degradation

I-V data was captured to assess the impact on performance due to each exposure step.

High Power Loss (> 5%)
- Multi PERC

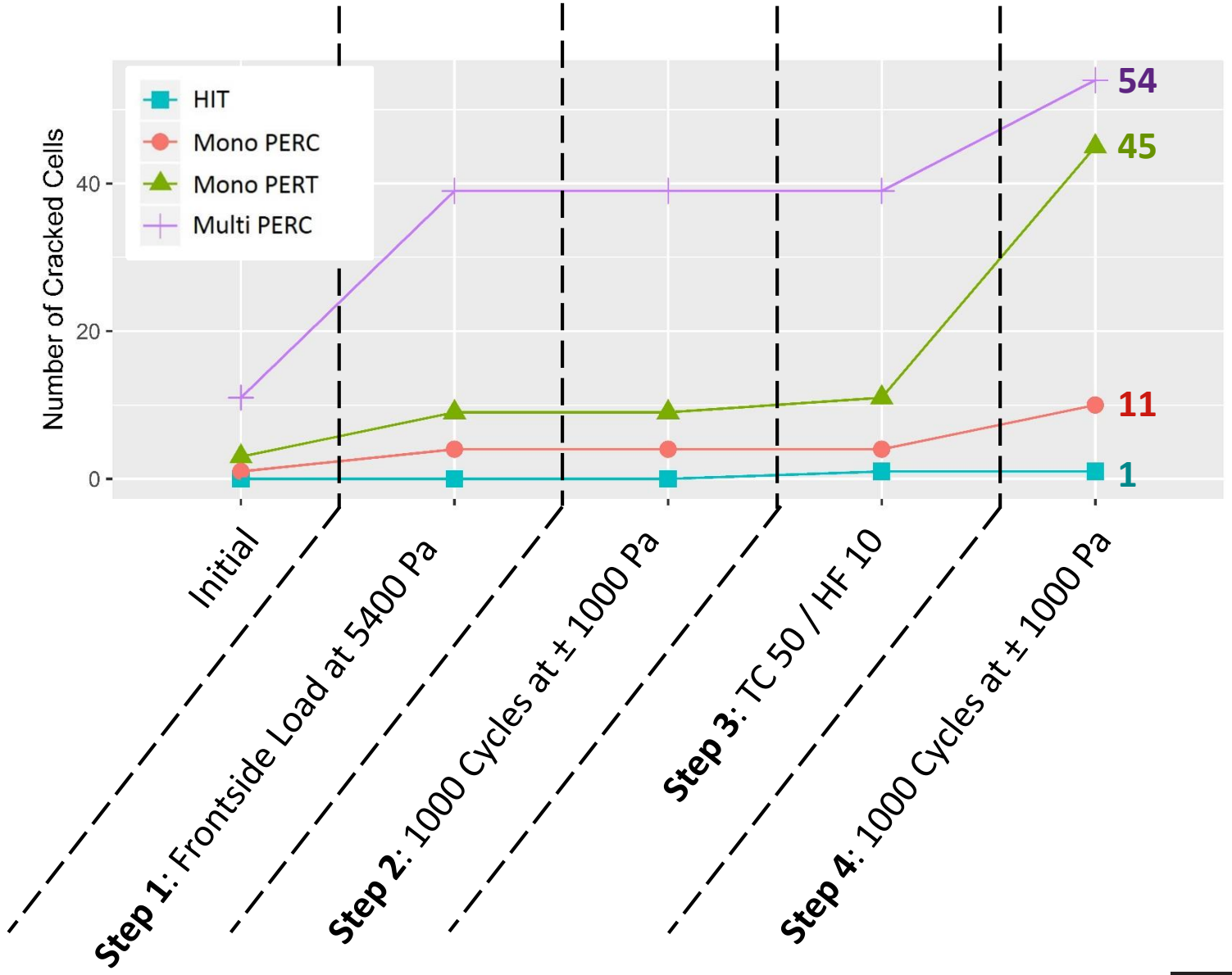
Mild Power Loss (2-5%)
- Mono PERT
- Mono PERC

No Significant Power Loss
- HIT



Crack Creation

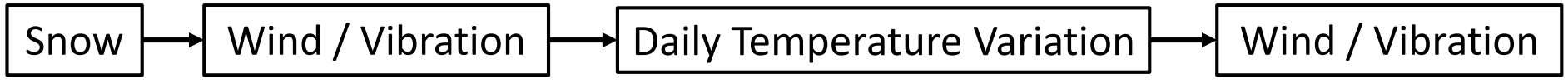
- The number of cracked cells were counted to identify which exposure steps contributed to cell cracks
- The initial frontside load of 5400Pa and the mechanical load after TC/HF contributed the most number of new cracked cells
- The HIT module only exhibited a single crack, which was the result of a handling mistake during transportation



DISCUSSION / CONCLUSION

Discussion

- A modified testing sequence was proposed to evaluate module design with respect to crack durability
  - A large front side static load is used to create cracks
  - Subsequent cyclic loading and thermal cycling is used to open cracks



- Key Takeaways
  1. Large variation in crack durability across commercially available modules
  2. HIT modules, utilizing a symmetric cell structure and low temperature interconnect process, exhibit high durability with respect to crack generation
  3. Mechanical loading after thermal cycling causes a significant number of new cracks for modules with solder interconnects

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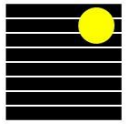
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

This material is based in part upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number DE-EE0008152

Panasonic



BrightSpot Automation

THANK YOU

eschneller@fsec.ucf.edu

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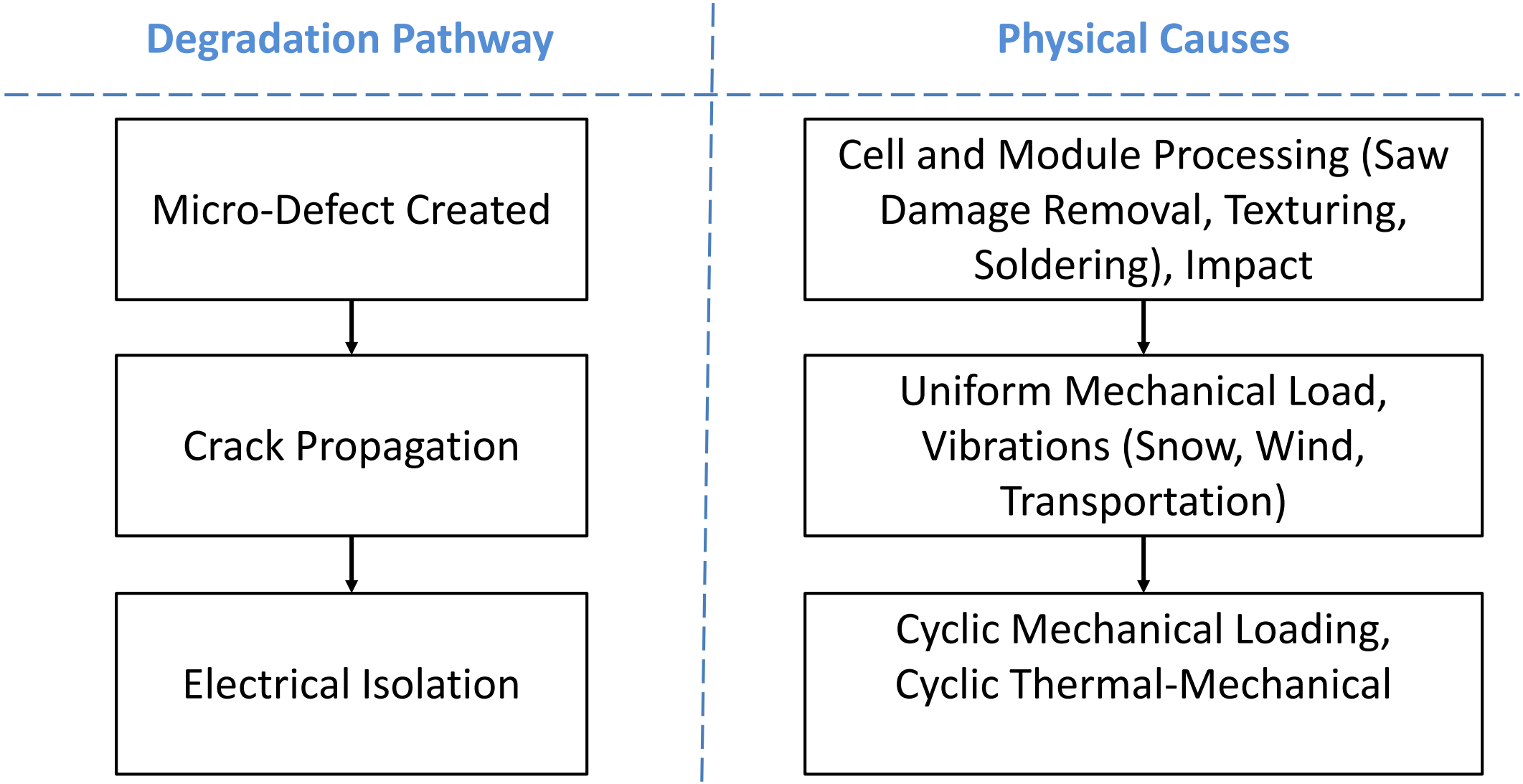
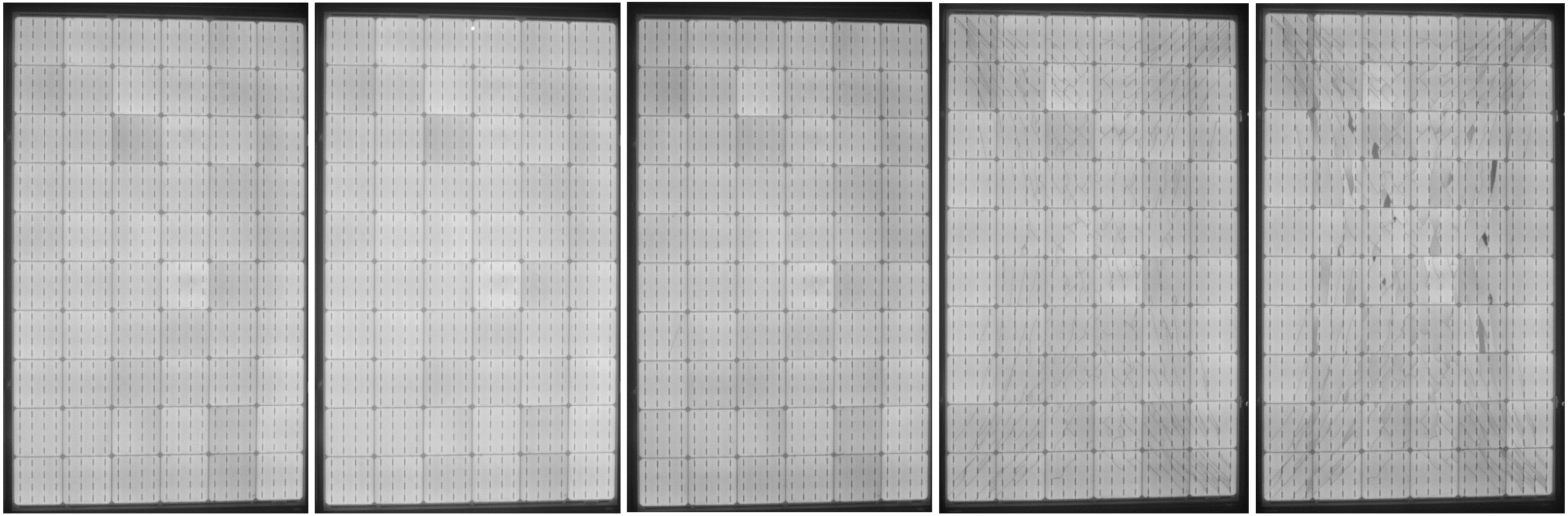
EXTRA SLIDES

Origin of Cell Cracks



Impact of Single Thermal Cycle



Initial | 3600Pa Load | 1 Thermal Cycle | 3600Pa Load | 1000 Cycles at ± 1000 Pa

[1] Schneller et al. “The Impact of Cold Temperature Exposure in Mechanical Durability Testing of PV Modules” *2019 IEEE PVSC*

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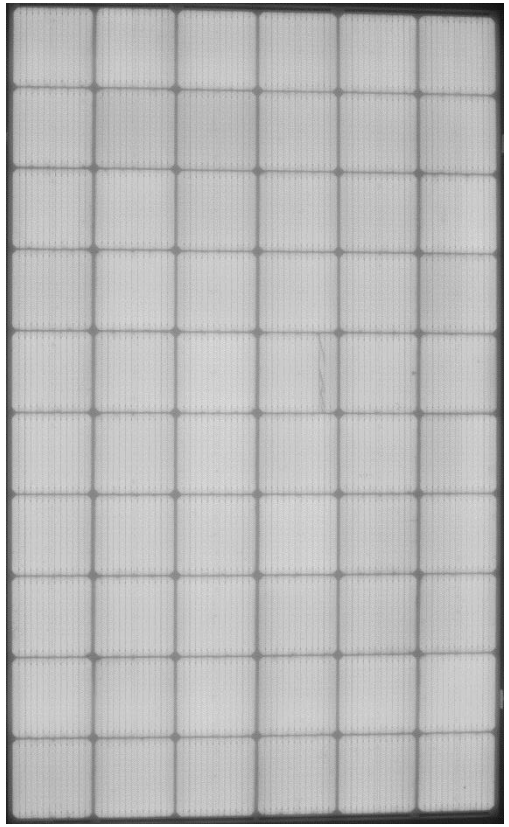
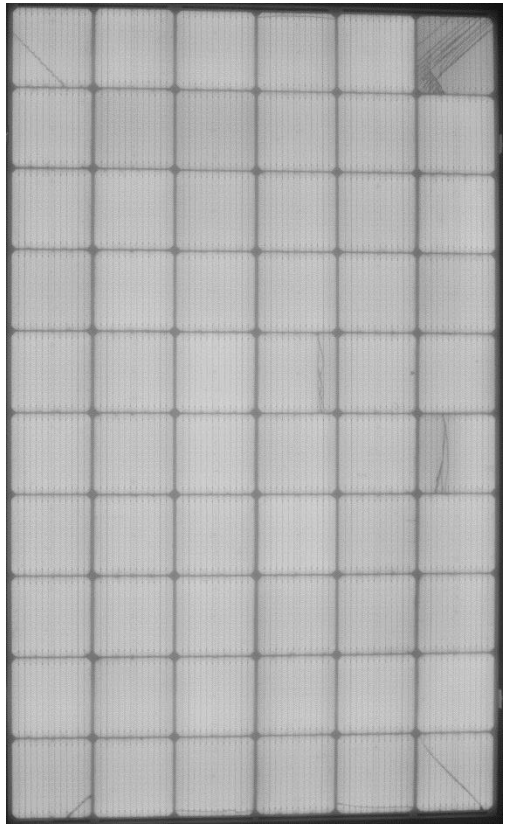
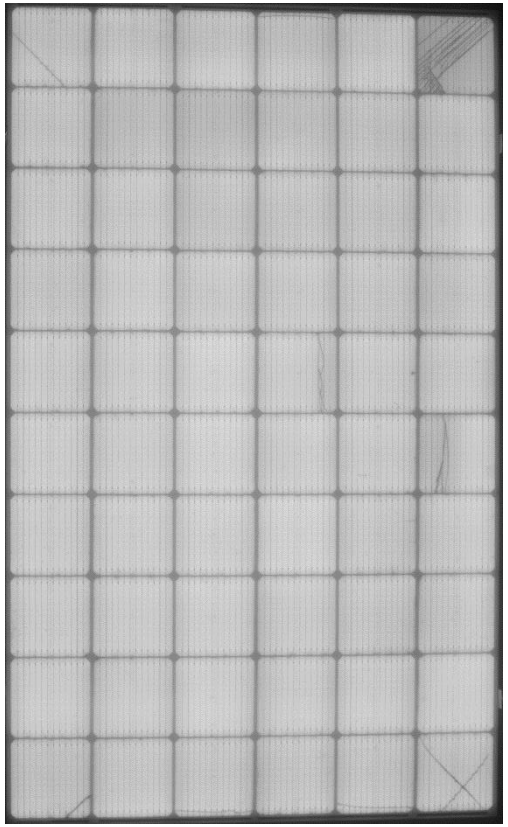
Cold Exposure on Wire Interconnect Module



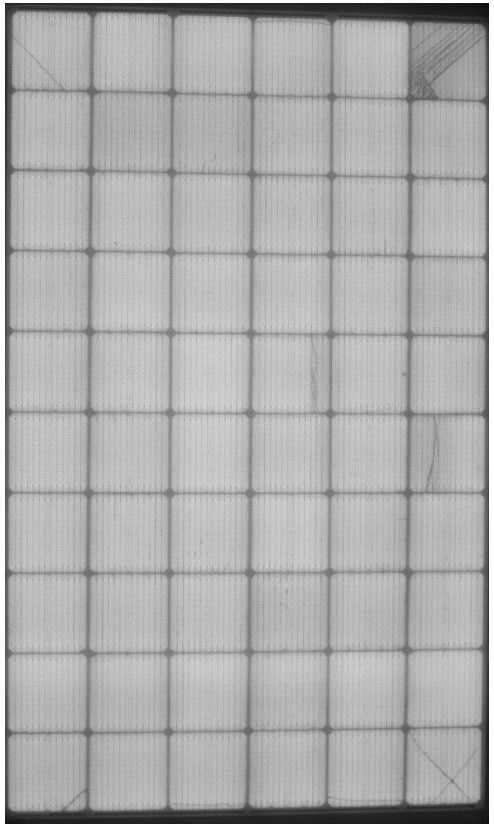
Initial



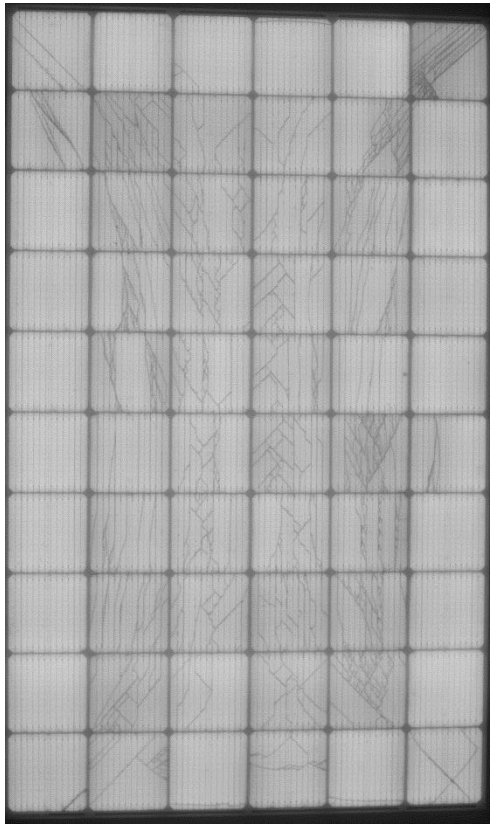
5400Pa Load



1000 Cycles at ± 1000 Pa



1 COLD Cycle



2400Pa Load

[1] Schneller et al. “The Impact of Cold Temperature Exposure in Mechanical Durability Testing of PV Modules” *2019 IEEE PVSC*

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