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*

- 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
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

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

Objective: Evaluate a module design with respect to crack creation and crack opening.
EXPERIMENTAL RESULTS
## Module Technologies

<table>
<thead>
<tr>
<th>Cell Technology</th>
<th>Interconnect Technology</th>
<th>Cell Size</th>
<th>Number of Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>3 Busbar Low Temperature Interconnects</td>
<td>5 inch pseudo-square</td>
<td>96</td>
</tr>
<tr>
<td>Mono-PERC</td>
<td>4 Busbar Solder Interconnects</td>
<td>6 inch pseudo-square</td>
<td>60</td>
</tr>
<tr>
<td>Multi-PERC</td>
<td>4 Busbar Solder Interconnects</td>
<td>6 inch square</td>
<td>60</td>
</tr>
<tr>
<td>Mono-PERT</td>
<td>Wire Interconnects</td>
<td>6 inch pseudo-square</td>
<td>60</td>
</tr>
</tbody>
</table>
Step 1 – Static Load – Crack Creation

- 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

- 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)

HIT

Mono-PERC

Mono-PERT

Multi-PERC

Multiple Open Cracks Form
Step 3 – Environmental Chamber

TC50 / HF10

Before TC/HF

After TC/HF

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
Step 4 – Final Mechanical Stress

1000 Cycles at ± 1000Pa

- 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

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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
THANK YOU

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EXTRA SLIDES
Origin of Cell Cracks

**Degradation Pathway**

- Micro-Defect Created
- Crack Propagation
- Electrical Isolation

**Physical Causes**

- Cell and Module Processing (Saw Damage Removal, Texturing, Soldering), Impact
- Uniform Mechanical Load, Vibrations (Snow, Wind, Transportation)
- Cyclic Mechanical Loading, Cyclic Thermal-Mechanical
Impact of Single Thermal Cycle

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

Cold Exposure on Wire Interconnect Module

Initial 5400Pa Load 1000 Cycles at ± 1000 Pa 1 COLD Cycle 2400Pa Load