Mechanical Load Testing of Solar Panels – Beyond Certification Testing

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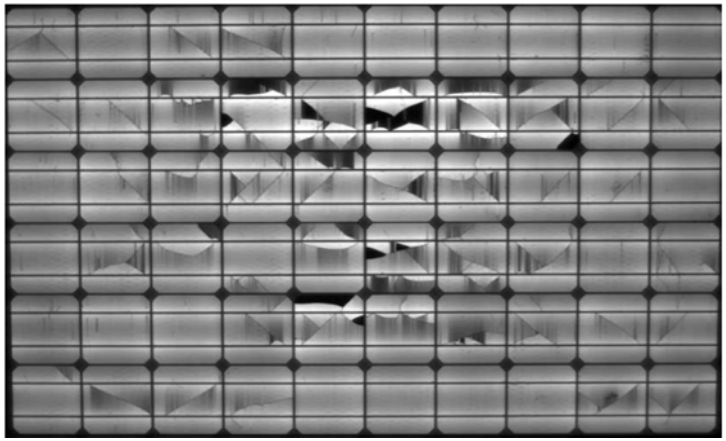
Motivation

- Hatred of cracked cells
  - Transition from 300 to 180 micron thick wafers
- Are we confident in the degradation rate of panels made in the last decade?
  - What testing are we doing now to examine degradation related to cracked cells?
  - What new testing is needed?



We can do better!

Content

- Mechanical load testing background
- Cell cracking and panel degradation
- **LoadSpot** tool
- Finite Element Modeling of stress vs load
- Conclusions

Mechanical Load Testing

BrightSpot Automation

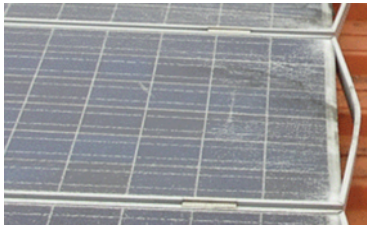
- Replicate stresses related to snow and wind loads
- Part of panel certification testing sequences since early JPL Block V Tests (1981)
- IEC 61215 – Static test: 3 cycles of 2400 Pa, 1 hour on each side of panel (static)
- IEC-TS-62782 – Cyclic (dynamic) test: 3-7 cycles/min, +/- 1000 Pa
  - Will likely be folded into IEC 61215 in coming years

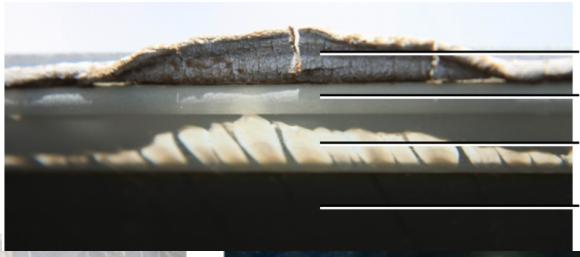
Table 2. Project Block V Module Qualification Tests

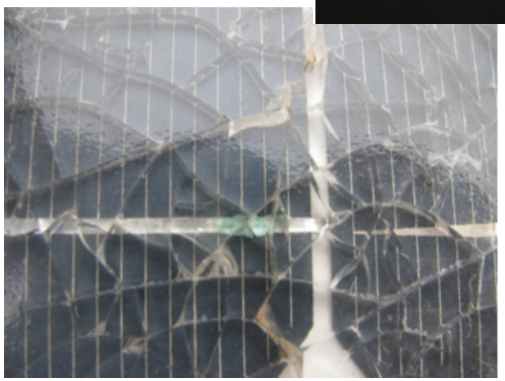
Test	Level and Duration
Temperature cycling	200 cycles; each cycle: 4 h, −40°C to +90°C
Humidity-freeze	10 cycles; each cycle: 20 h at 85°C, 85% RH followed by 4 h excursion to −40°C
Cyclic pressure loading	10000 cycles, ± 2400 Pa (± 50 lb/ft^2)
Wind resistance (shingles only)	Underwriters Lab Standard UL 997 1.7 k Pa (35 lb/ft^2)
Hail impact	10 impacts at most sensitive locations using 25.4 mm (1 in.) iceball at 23.2 m/sec (52 mph)
Electrical isolation	Leakage current ≤50 μA at twice worst-case system open circuit voltage plus 1000 V
Hot-spot endurance	3 cells back-biased to maximum bypass-diode voltage and cell-string current for 100 h of on-time

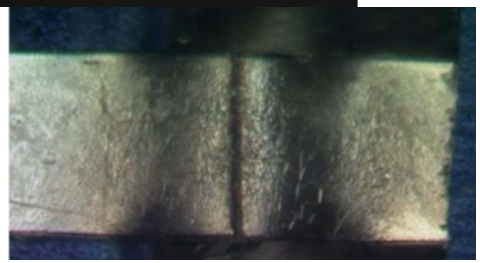
Problems Revealed by Load Testing

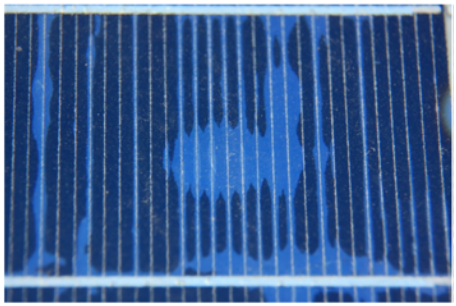
- Permanent distortion of framing elements
- Edge seal failure
- Shattering of cover-glass
- Fatigue of interconnect wires
- Solder joint failure
- Delamination
- Cracking of cells

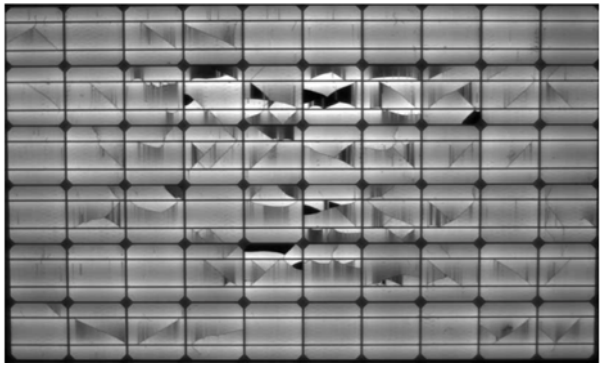












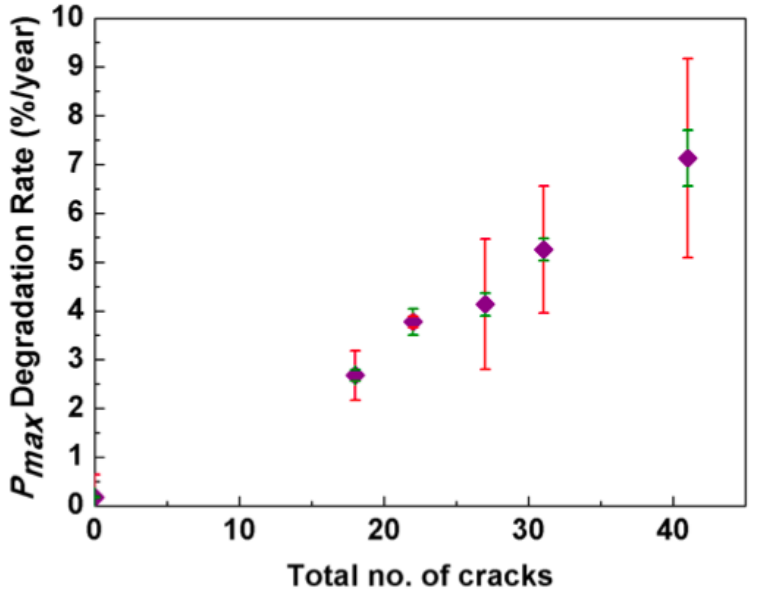
Cell cracking in the field

- Very common after shift in wafer thickness to <200 μm
- Reports of high degradations rates

Snail Trails: c-Si

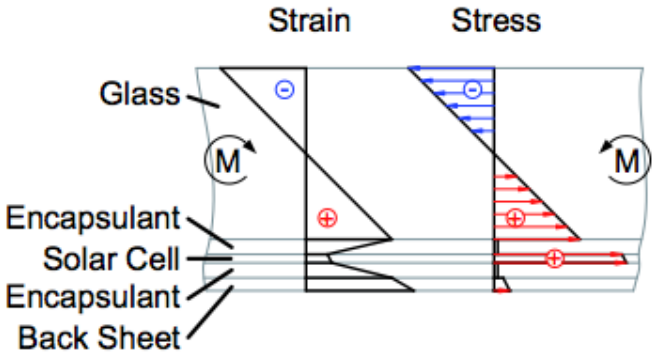
Climatic Zone	Age Groups				Total
	0-5 Years	5-10 Years	10-20 Years	20-30 Years	
Hot & Dry	35% (74)	NA	0% (29)	0% (39)	18% (142)
Warm & Humid	17% (93)	0% (58)	0% (119)	0% (2)	6% (272)
Composite	0% (125)	0% (7)	6% (124)	NA	3% (256)
Moderate	56% (123)	NA	8% (12)	NA	52% (135)
Cold & Sunny	50% (34)	NA	0% (22)	NA	30% (56)
Cold & Cloudy	44% (112)	NA	NA	NA	44% (112)

[Kottantharayil, IIT, *Lessons Learned from the All India Survey of Photovoltaic Modules*, NREL PVMRW 2016]



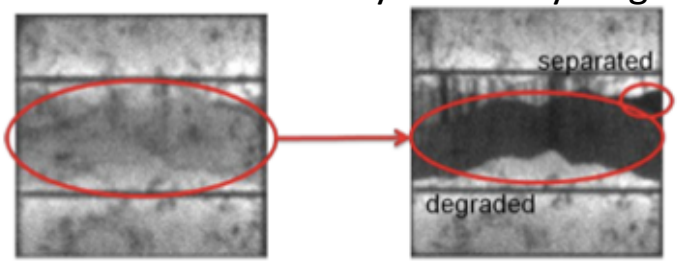
Cell Cracking/Degradation Model

- Most cells are fine in the factory
  - Even if there are cracks they are tightly closed and cause no power loss and weak if any EL signal
- Wind gust or heavy snow in field (or abuse during shipping/installation) puts cells into tensile stress
  - Microcracks formed during the soldering process propagate into cracks
- Snail trails can form relatively quickly
- Over years, closed cracks gradually become open leading to power degradation



[Sander, Fraunhofer CSP, Solar Energy Materials & Solar Cells 2013]

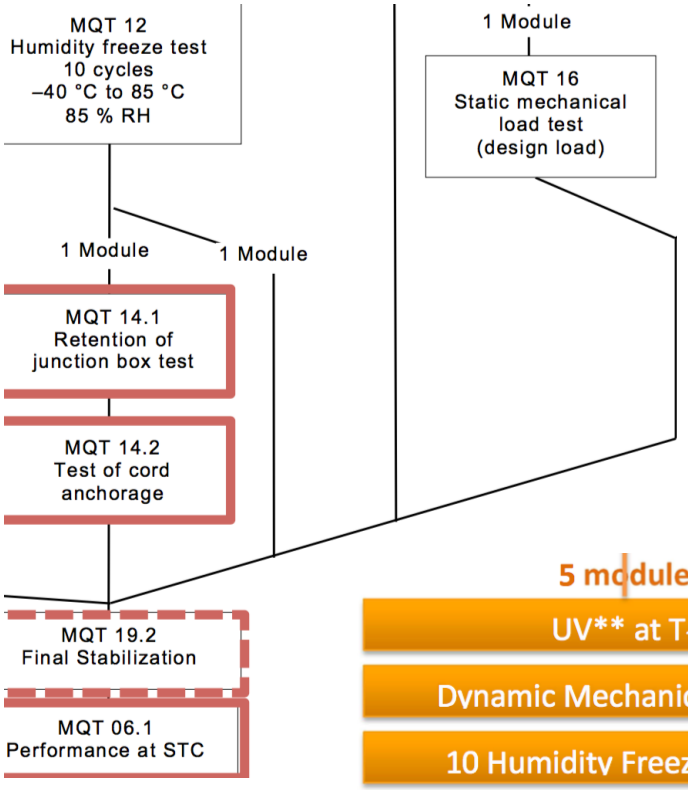
Humidity Freeze Cycling



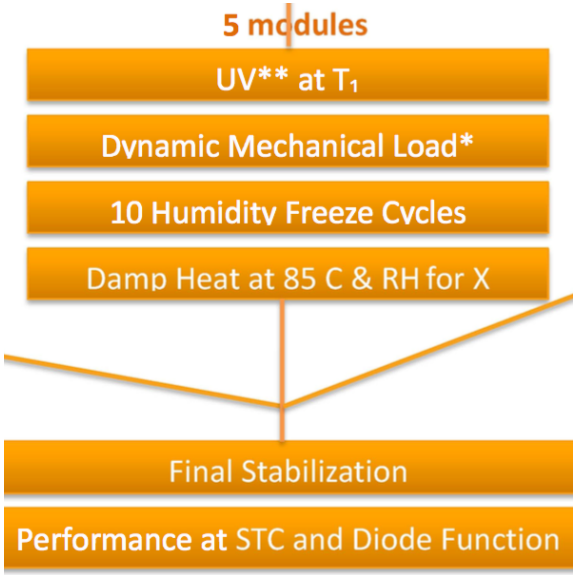
[Köntges, ISFH, PVSEC 2010]

Shortcoming of IEC 61215

- Newest version of IEC 61215 still does not follow load testing with environmental chamber testing to open up cracks
  - Most cracks remain tightly closed without power loss
- PVQAT testing does



[Beck, Siva, NREL PVMRW 2016]



[Wohlgemuth, NREL, PVSC 2014]

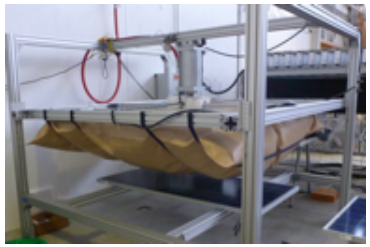
Cell Cracking Solutions

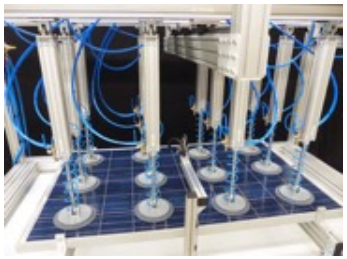
Method	Cure/ Bandaid	Desirability
Optimize soldering and QC	Cure	High
Improved metallization	Cure	High
Racking to reduce bending	Cure	High
Glass/glass construction	Cure	High
Stiffer modules	Cure	High
Compressive stress from backsheets	Cure	High
Conductive adhesives	Cure	High
More wires	Bandaid	High
Wires closer to edges	Bandaid	High
Low reverse breakdown	Bandaid	High
Strings wired in parallel	Bandaid	Med
Cells wired in parallel	Bandaid	Med
Rectangular cells + thin wires	Cure	Med
Module level electronics	Bandaid	Med
Increased bypass diodes	Bandaid	Med
Thicker wafers	Cure	Low

[Gabor, BrightSpot Automation, NREL PVMRW, 2015]

Load Testing Methods

- Sandbags
  - Time consuming, static only, uniformity?
- Air bladder
  - Single sided
- Suction cups
  - Dominant method for cyclic, uniformity?
- Vacuum/Air-Pressure
  - Very uniform, little attention, can constrain the edges



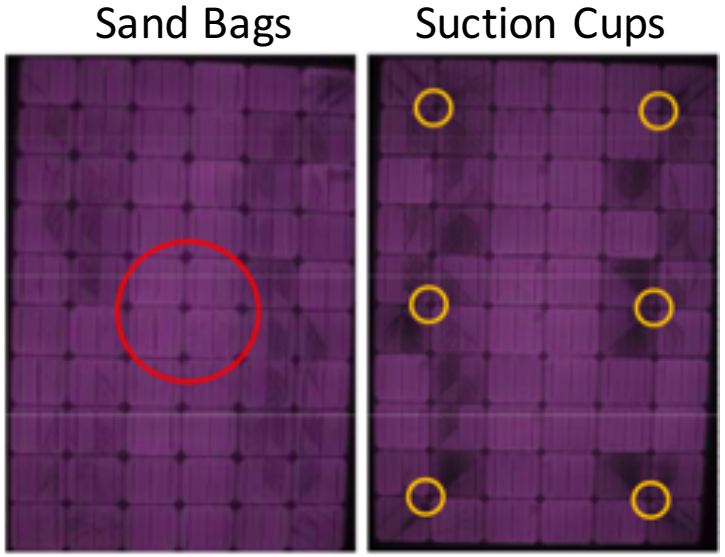


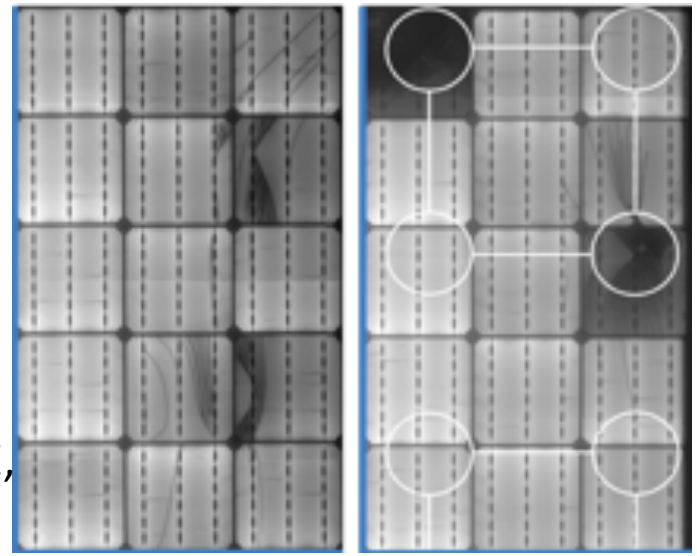
[Gade, Jabil, NREL PVMRW, 2015]

Point Loading with Suction Cups

- Reports of more cell cracking seen under suction cups locations
- IEC-TS 62782 cyclic loading test requires center-to-center distance between suction cups be <20 cm
  - Good enough?
  - Static loading in IEC 61215?

[Baek, Samsung SDI, NREL PVMRW, 2014]

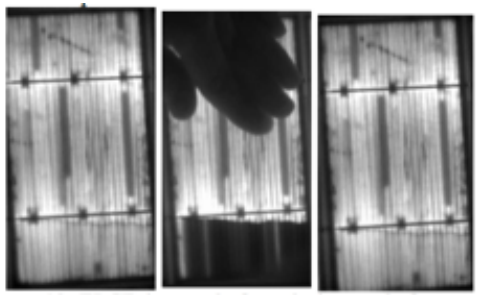




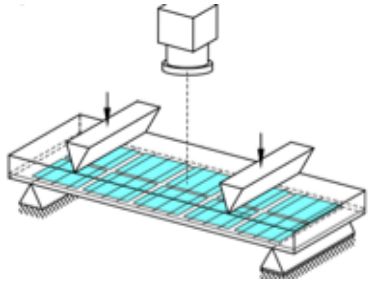
[Mülhöfer, ISE, PVSEC 2013]

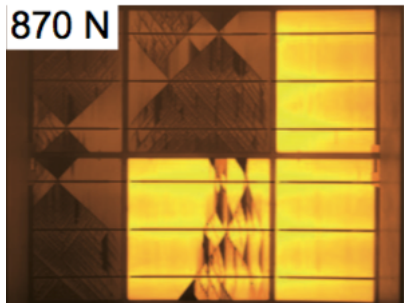
EL Under Front Side Load

- Light pressure
  - Opens up pre-existing cracks
  - Cracks reclose upon release of pressure
- EL and IV testing can compare these 2 states
  - Predict degradation once cracks open up the field



[Gabor, Evergreen Solar, PVSEC 2006]



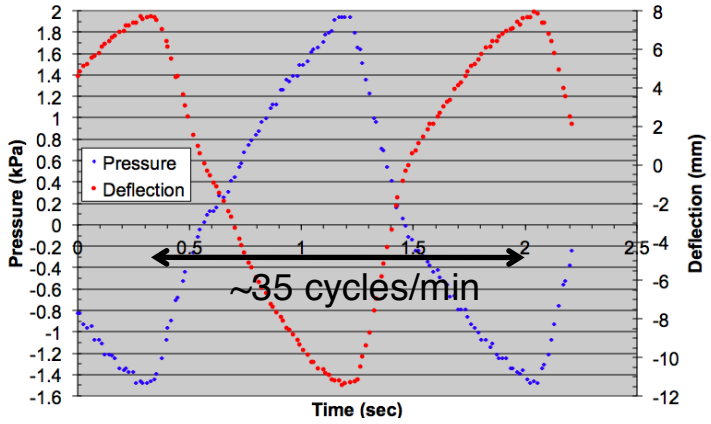


[Sander, Fraunhofer CSP, Solar Energy Materials & Solar Cells 2013]

LoadSpot *a better way to bend*

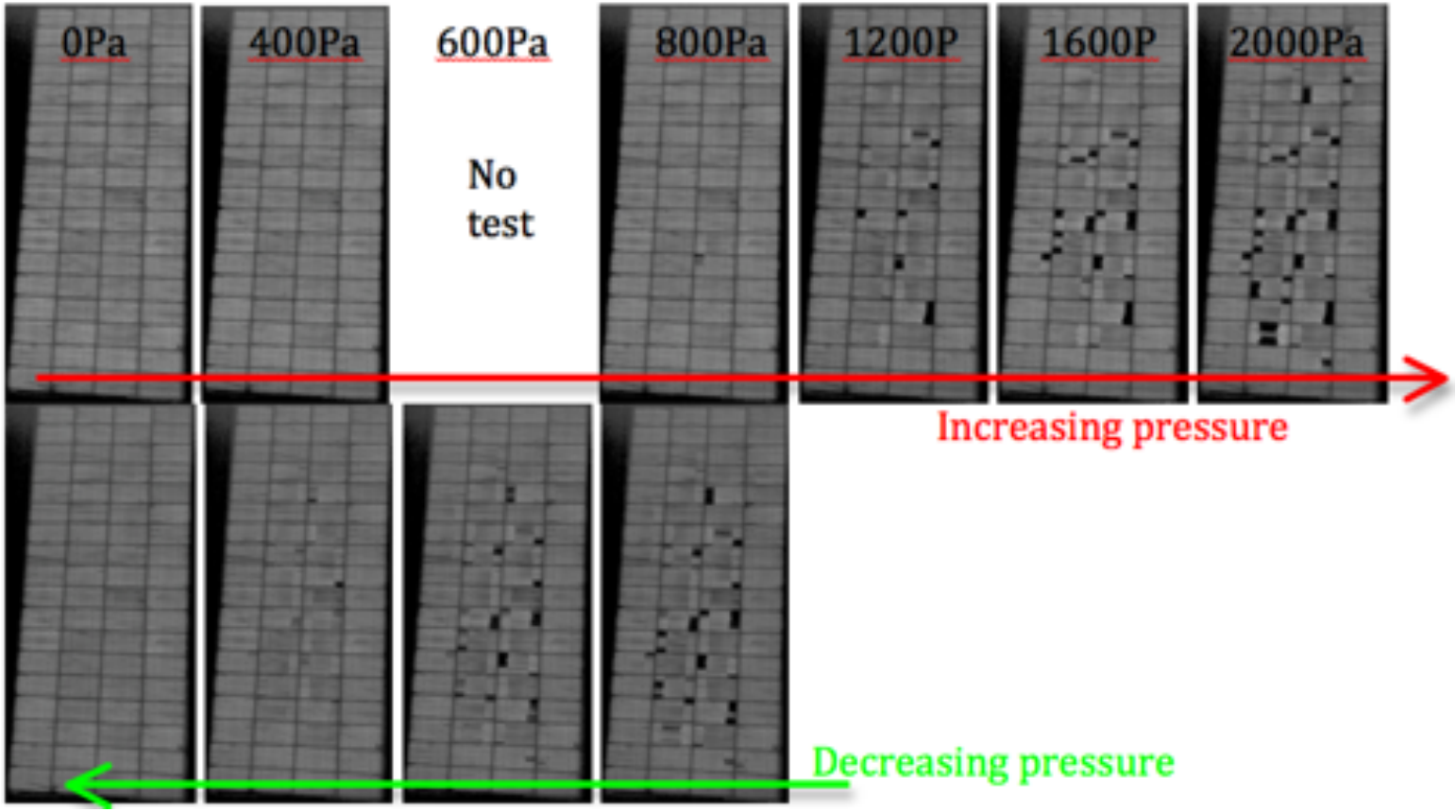
BrightSpot Automation

- Rear-side vacuum/air-pressure cavity
  - Front side open for IV/EL
  - Seal without constraining edges of panel
- Can perform IEC load tests
- Flexible panel size (up to 72 cells)
- +/- 5400 Pa
- Faster than 2 sec cyclic mode
- Deflection monitoring
- Constraints at 4 mounting points using desired clamps
- First unit ships to FSEC, July 2016
  - Available for orders now



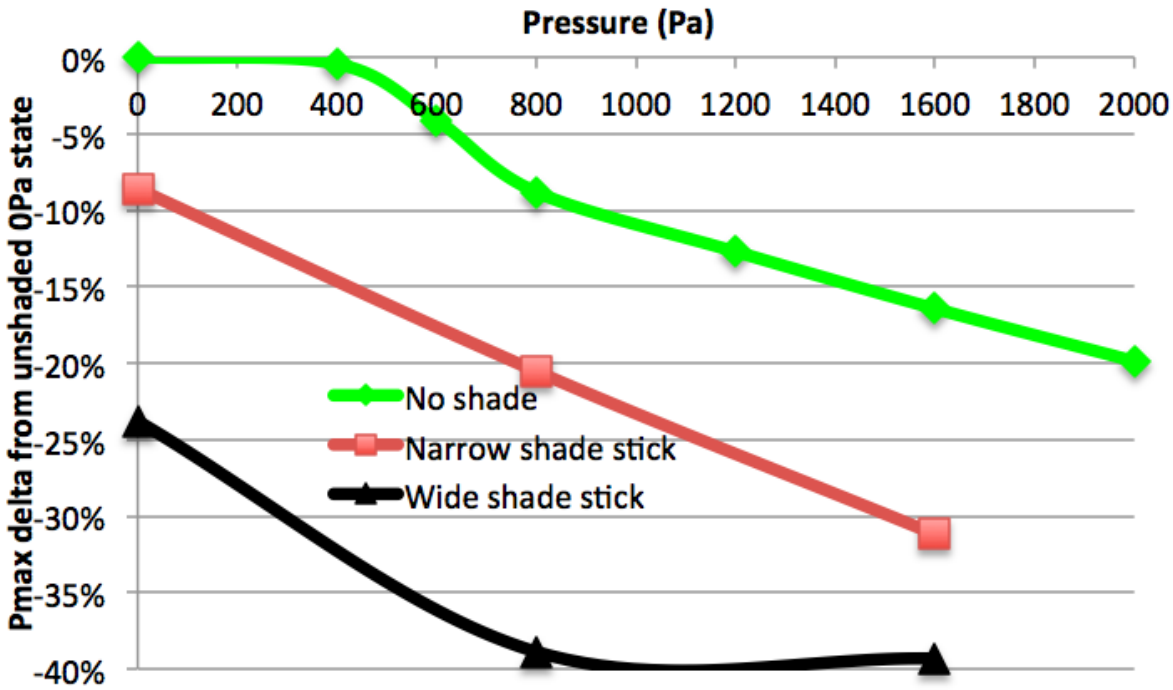
Window – open existing cracks

- New cracks start forming above 1000 Pa
- Still open at 600 Pa

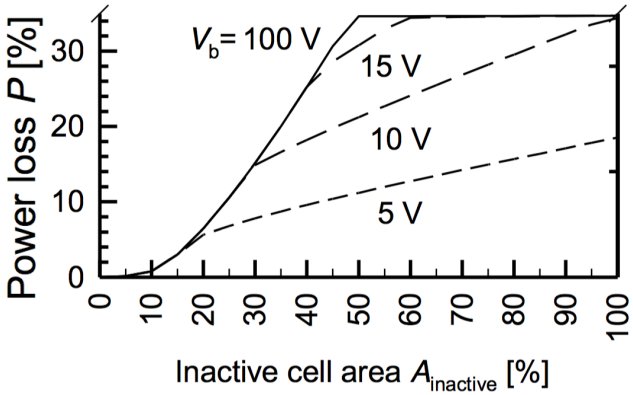


Interaction with Shading

- Pre-existing cracks
- Shading loss ~9% at 0 Pa
- Incremental shading loss ~12% at 800 Pa
- Explanation
  - Little power loss below 10% inactive area
  - Inactive areas from shading and open cracks are additive



[Köntges, ISFH, PVSEC 2010]



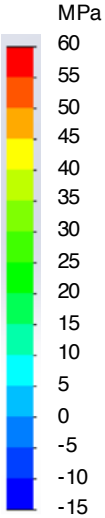
Finite Element Modeling @ 2400 Pa

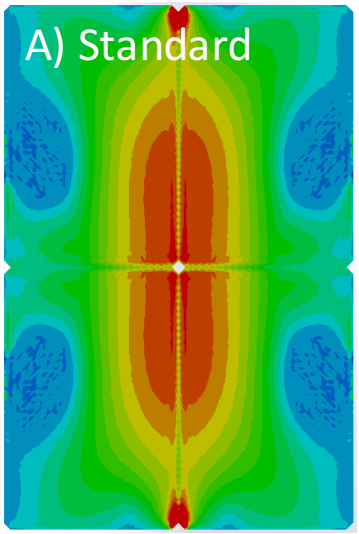
BrightSpot Automation

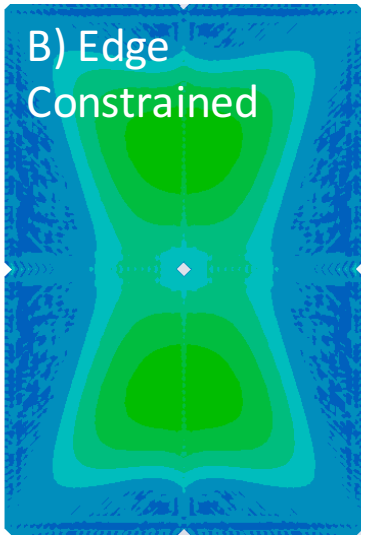
MODELED CONFIGURATIONS

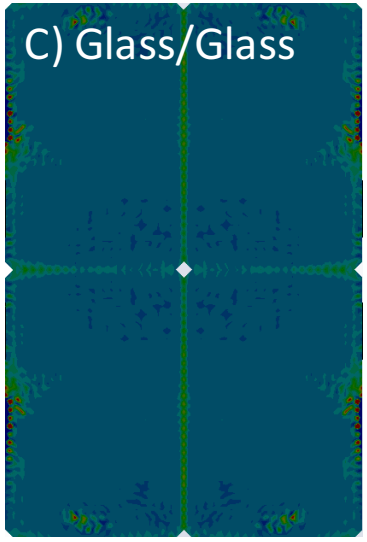
#	Glass	BackSheet	Frame	Back Rail	Constrain
A	3.2mm	Polymer	Perimeter	None	4 clamps
B	3.2mm	Polymer	Perimeter	None	Perimeter
C	2mm	2mm glass	none	none	4 clamps
D	3.2mm	Polymer	None	3 short	BackRails

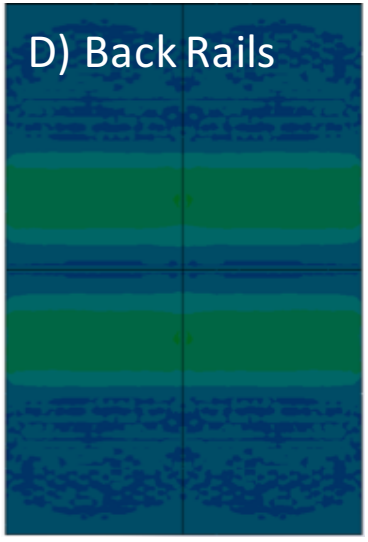
- High stresses with standard construction and mounting
- Load testing with edge constraints does not accurately replicate real conditions
- Minimal stress to Si in glass/glass (neutral axis)
- Minimal stress to Si if substitute perimeter Al frame mass with 3 glued back rails

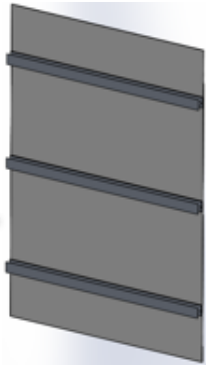












FLORIDA SOLAR ENERGY CENTER

Walking on Sunshine

- Assumptions
  - Standard panel construction
  - 180 lbs on one foot in center of panel

Walking on Sunshine

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  - Standard panel construction
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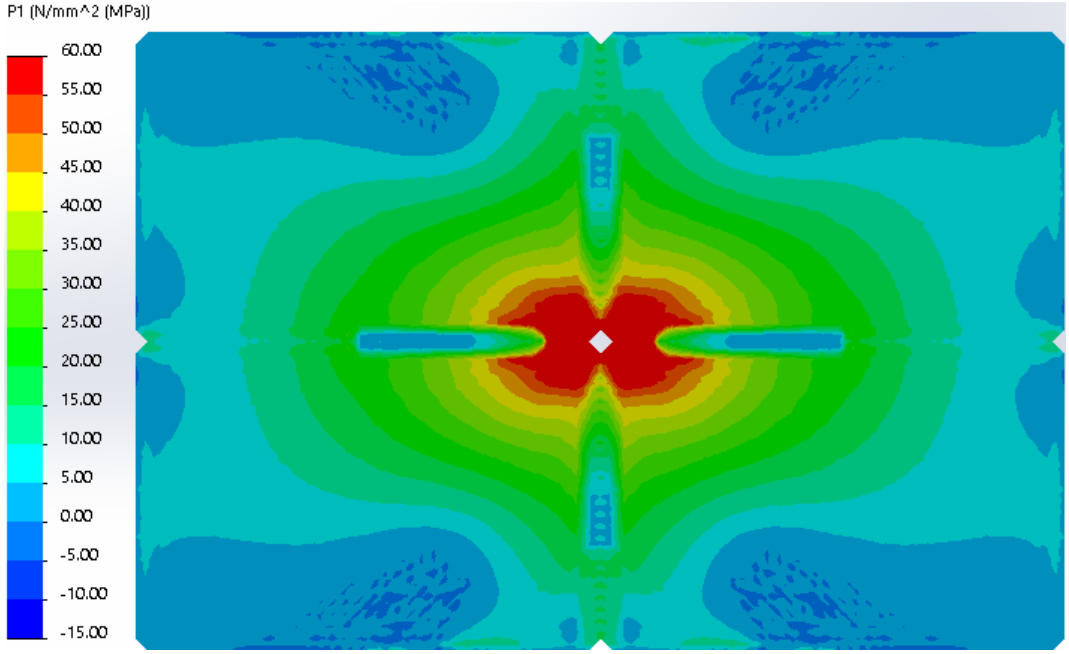
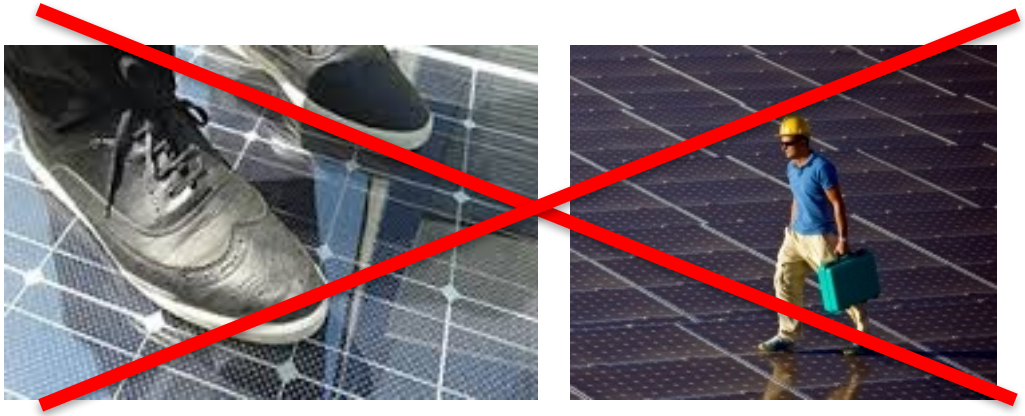
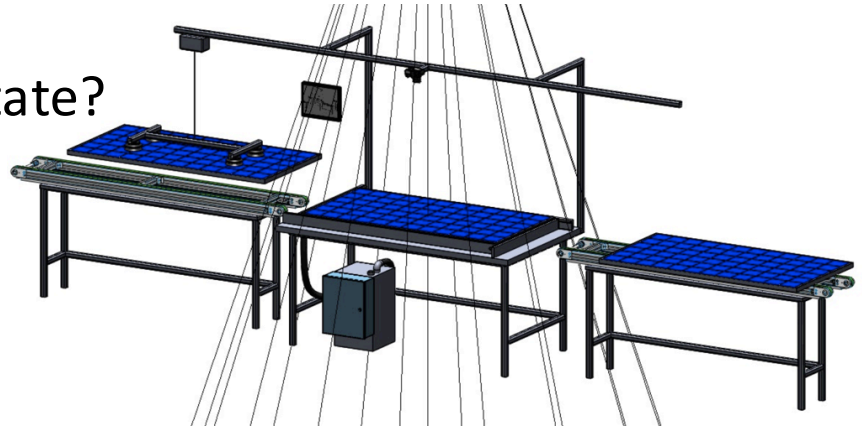




- > 80 MPa in center!
- Does not ”feel good” to the panel

LoadSpot-PRO concept

- Test every module in production line (30s takt time)
- EL & IV in bent and unbent states
  - Minimal pressure to mainly open pre-existing cracks (<800Pa)?
    - A few seconds vs weeks of environmental chamber time
  - Higher pressures to demonstrate whatever loads might be expected in the field?
    - Burn-in testing - Common in other industries (e.g. – PCB)
- Statistical process control to help optimize factory performance
- IV delta data can be provided to customers as demonstration of panel quality
  - Rate module Watts on degraded state?



Comparison of Loading Methods

BrightSpot Automation

Factor	Sand bags	Suction Cups	Air bladder	Vacuum/ Air Pressure
Static test	Manual Flip	Auto	Manual Flip	Auto
Cyclic test	No	Yes	One direction	Yes
Point loading	No	Yes	No	No
Test with racking	Top static	Yes	Top static	No
Simultaneous EL/IV	No	No	No	Yes
Quick QC /Burn-In	No	No	No	Yes

Conclusions

- Modeled cell stress under front side panel load
  - Important to not constrain the edge during testing
  - Potential for lower stress using Al mass in back rails rather than perimeter frames
  - Glass/glass module construction is vastly superior regarding cracking
- Demonstrated **LoadSpot** operation
  - Mechanical load testing with vacuum and air pressure
  - Satisfy IEC static and cyclic load testing definitions for panel certification
- IEC 61215 does not make sense regarding load testing
  - Any load test should be followed by environmental chamber testing to open up the cracks created
    - PVQAT sequence
    - Different load levels for different applications?
  - How many modules on the market would pass certification with such a requirement?
- EL images captured in the factory provide little confidence regarding future cracking and degradation in the field

Beyond certification testing

BrightSpot Automation

- EL/IV on panel under load to quickly quantify future impact of existing cracked cells once cracks open up in the field
  - Faster, cheaper, non-destructive alternative to environmental chamber testing
- Statistical process control of panel factory
- Burn-in testing: load modules in the factory to levels they will likely see in the field and quantify the potential impact of newly formed cracks
- Interaction between shading and cracked cells

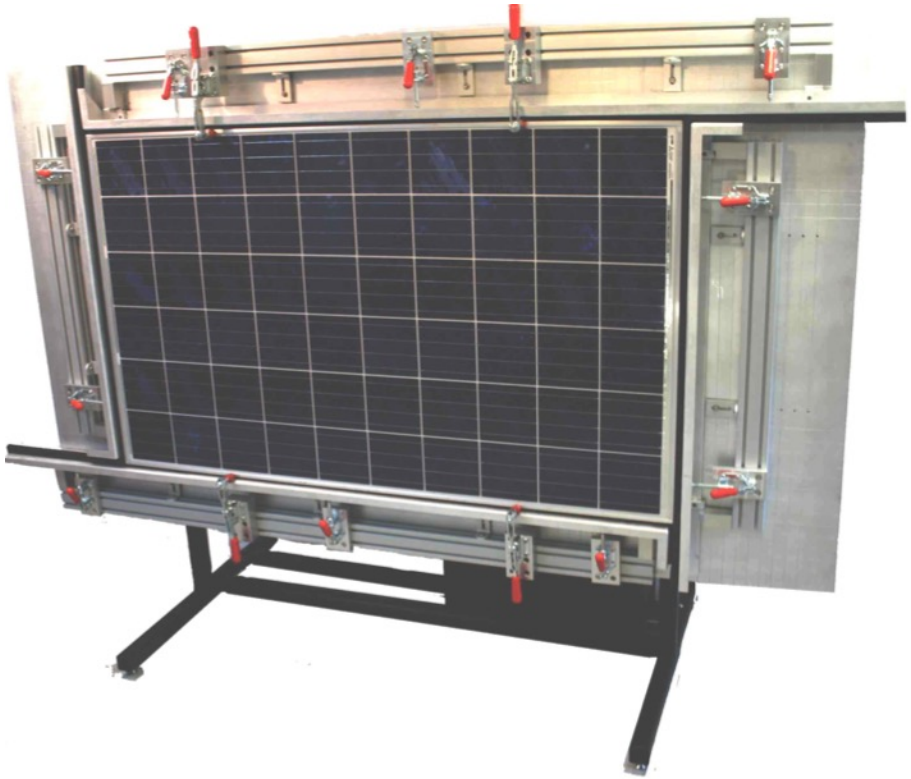
Next Steps

BrightSpot Automation

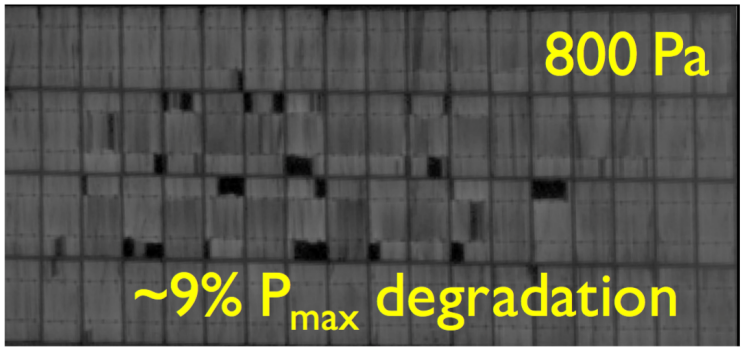
- Transfer the modeling from SolidWorks to Abacus and replace the silicon sheet with discrete cells
- New **LoadSpot** variations
  - **LoadSpot-PRO**: In-line QC on every panel in factory
  - **LoadSpot-Mobile**: Test panels prior to installation in field
  - **LoadSpot-Field**: Test installed panels
- Test panels at FSEC
  - Correlate crack opening test to environmental chamber degradation
  - Hubert.Seigneur@uspvmc.org
- More field studies needed tracking the evolution of cracked cells and power degradation

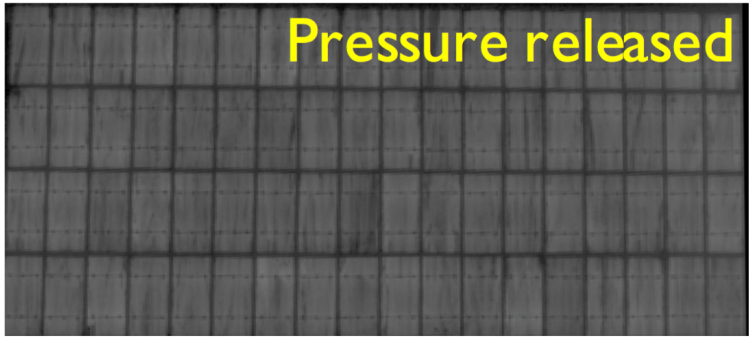
Thank you for your attention!

BrightSpot Automation



Predictive crack opening test





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