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Testing for Crack Susceptibility in c-Si Cells Using SMLT+DMLT Sequence

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Background

- This work, completed in early 2019, proposed a new sequence to test crack susceptibility for extended reliability testing that combined static mechanical loading (SMLT) with dynamic mechanical loading (DMLT), followed by temperature (TC50) and humidity cycling (HF10).

- Since this work was presented, the SMLT+DMLT sequence has been adopted by PVEL's recently updated PQP Program and is in the new drafts of both ANSI C450 and IEC 63209.

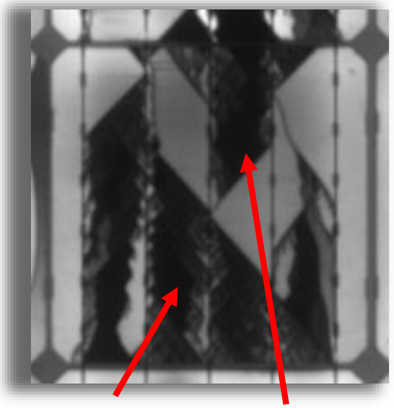
- This project was motivated by empirical lab evidence, which suggests that DMLT testing is effective as cracking cells, but is not effective at producing the type of electrically isolated cell regions which have been seen in fielded samples.

- Empirical lab evidence also suggests that the environmental chamber stresses after DMLT do not necessarily propagate or isolate cracks, but instead can cause independent degradation modes.

- This work showed that the SMLT+DMLT sequence was effective at both creating cracks and electrically isolating regions within cells like what has been seen in fielded modules that undergo high levels of mechanical stress.

Motivation

- Cell cracks in PV modules are considered to be problematic for several reasons:
  - Cell cracks can cause isolated power regions which result in power loss in the module.
  - Cell cracks can cause hot spot behavior due to uneven current flow through the active regions of the cell.
  - Cell cracks provide a path for moisture through the backsheet to the front of the cell surface, which can cause corrosion or “snail trails”, although this problem has been largely mitigated.



Electroluminescence image showing electrically isolated cell sections

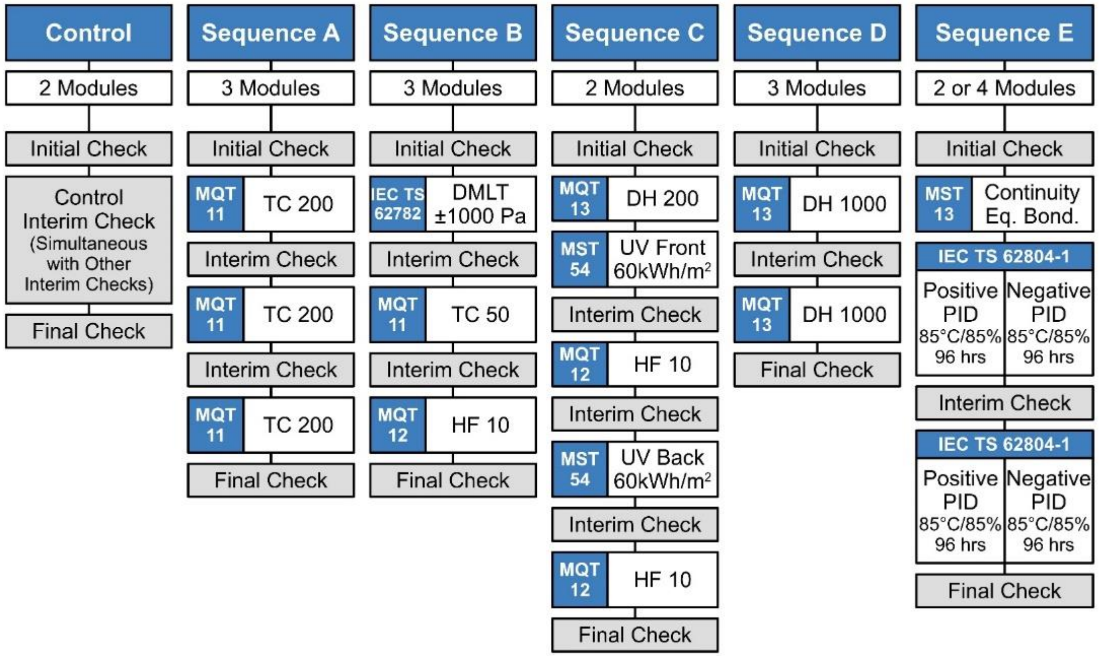
Infrared image showing hotspots on electrically isolated cell sections

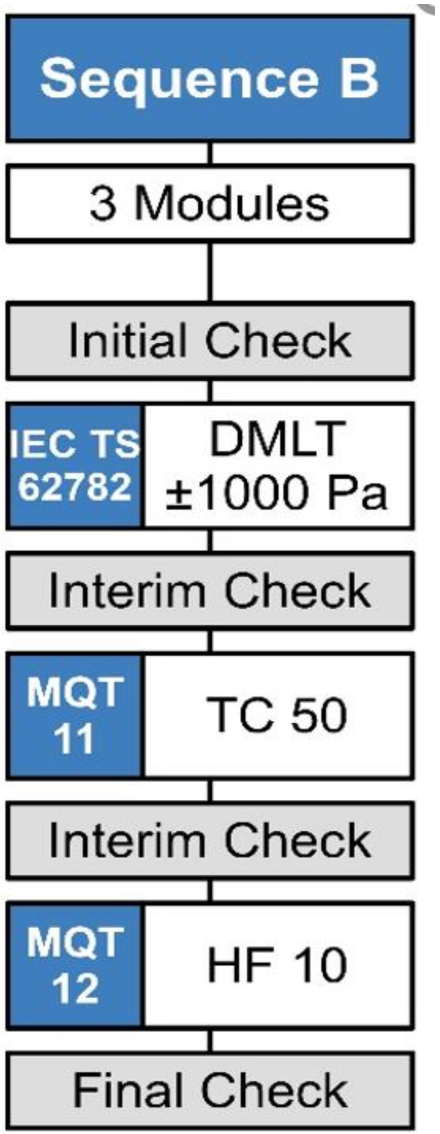
Visual and EL images show a snail trail tracing a crack

Motivation

- Currently, there is no standard test for crack susceptibility in PV modules.
- Reliability tests (CSA ANSI/C450, PVEL PQP, etc.) typically use DMLT (Dynamic Mechanical Load Testing) followed by environmental chamber stresses (TC50/HF10/HF20, etc.).
- Empirical lab evidence suggests that the DMLT testing, while it cracks cells, is not effective at producing electrically isolated cell regions which are sometimes seen in the field, and are problematic.
- Empirical lab evidence also suggests that the environmental chamber stresses after DMLT do not necessarily propagate or isolate cracks, but instead typically cause independent degradation modes.
- This project intends to investigate those observations.

Motivation – ANSI/CSA Seq B





- First public extended module testing protocol – published November, 2018.
- Sequence B based on NREL Qualification Plus - checks for crack susceptibility

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Design of Experiment

- Dynamic MLT = repeated minor loading events
  - Standardized with IEC TS 62782:2006.
  - Intended to mimic stresses encountered during installation and operation
  - Usually followed by TC50 and HF10 to “amplify” the mechanically induced cracks
  - DMLT: ±1000 Pa, 1000 cycles, 6 cycles/min per IEC TS 62782:2016
- Static MLT = major loading event
  - Has been a part of IEC 61215 from inception.
  - +/-2400 Pa corresponds to wind pressure of 130 km/hr with a safety factor of 3 for gusty winds (61215:2005)
  - Static MLT: (+2400 Pa for 1 hr, -2400 Pa for 1 hr) x3 per IEC 61215-2:2016
- During its lifetime, a PV module is likely to experience both major and minor loading events.

Design of Experiment

- **How will the results vary if we try different combinations of mechanical stresses?**

Leg 1 (Baseline)	Leg 2 (Static MLT)	Leg 3 (SMLT+DMLT)	Leg 4 (No MLT)
Stabilization	Stabilization	Stabilization	Stabilization
DMLT	Static MLT	Static MLT	TC50
TC50	TC50	DMLT	HF10
HF10	HF10	TC50	
		HF10	

Current C450 Seq B

- STC I-V and EL after each step.
- 2 module types (A and B), 2 samples per module type per leg

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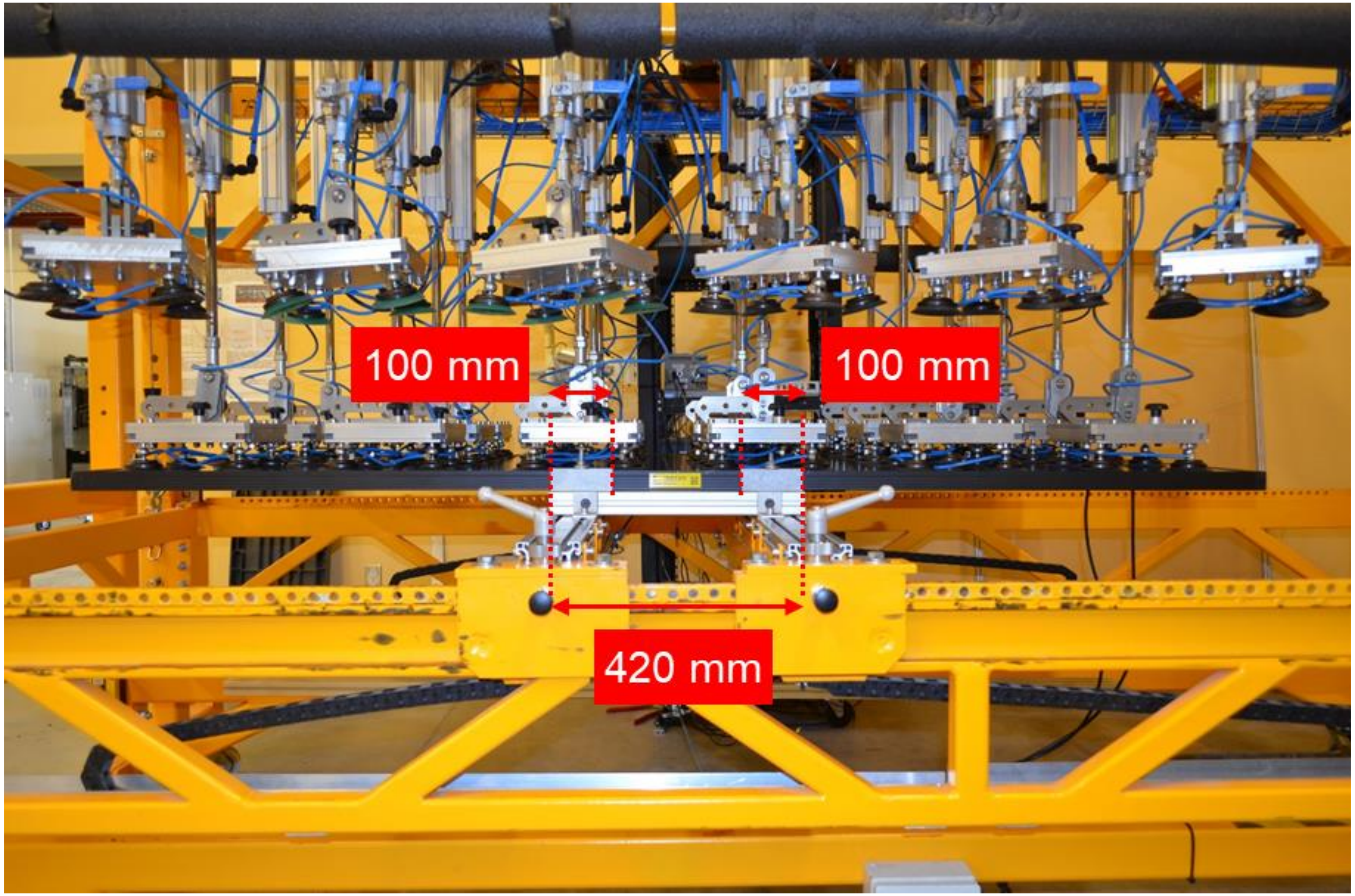
Dynamic MLT + Static MLT Setup

- We used a “center-clamping” setup that is more representative of single-axis-tracker installations.
- Our MLT machine pushes down and pulls up on the module with pneumatic cylinders and vacuum suction cups.



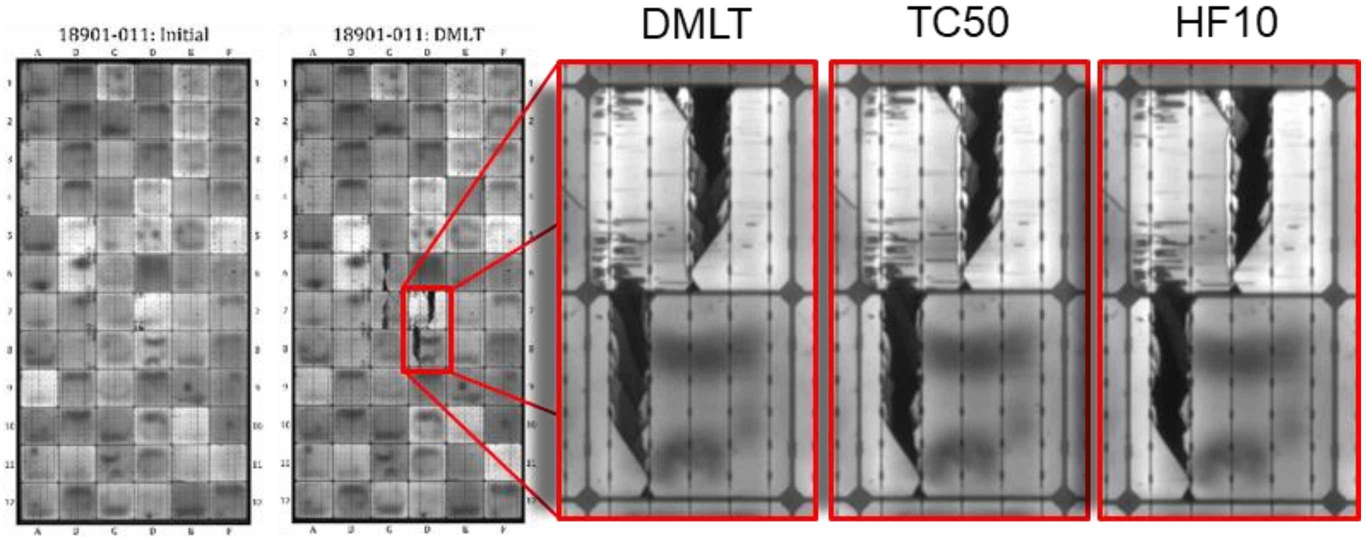
Tested Module Types

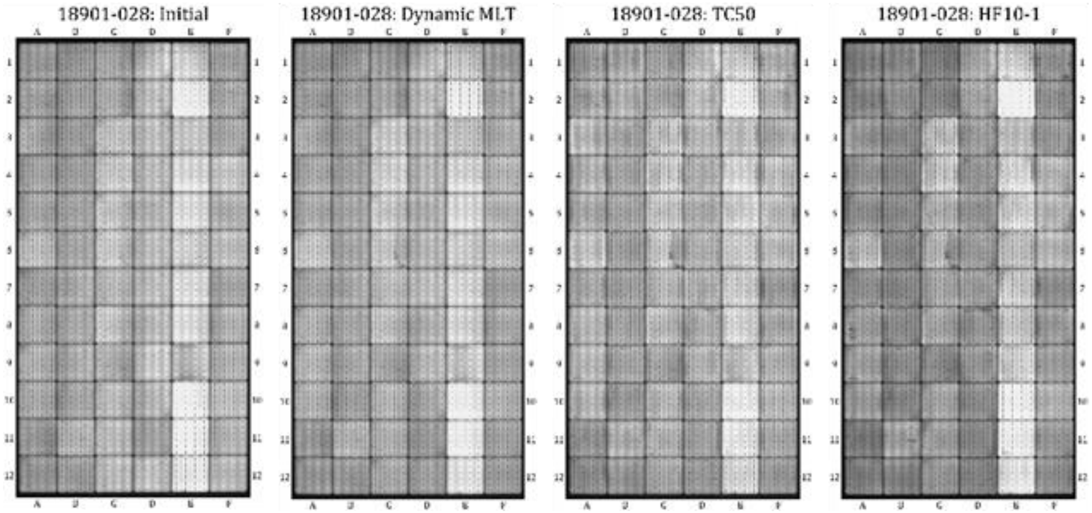
Module Type A	Module Type B
• Cell Type: 5BB Mono-PERC • Cell count: 72 • Frame Thickness: < 35 mm • Power Class: 350 W • Glass with Backsheet • Prone to cracking, per our experience	• Cell Type: 4BB Mono-PERC • Cell count: 72 • Frame Thickness: 40 mm • Power Class: 360 W • Glass with Backsheet

Center Point Deflection = 47 mm

Center Point Deflection = 32 mm

Leg 1 (Baseline - DMLT) – EL Results





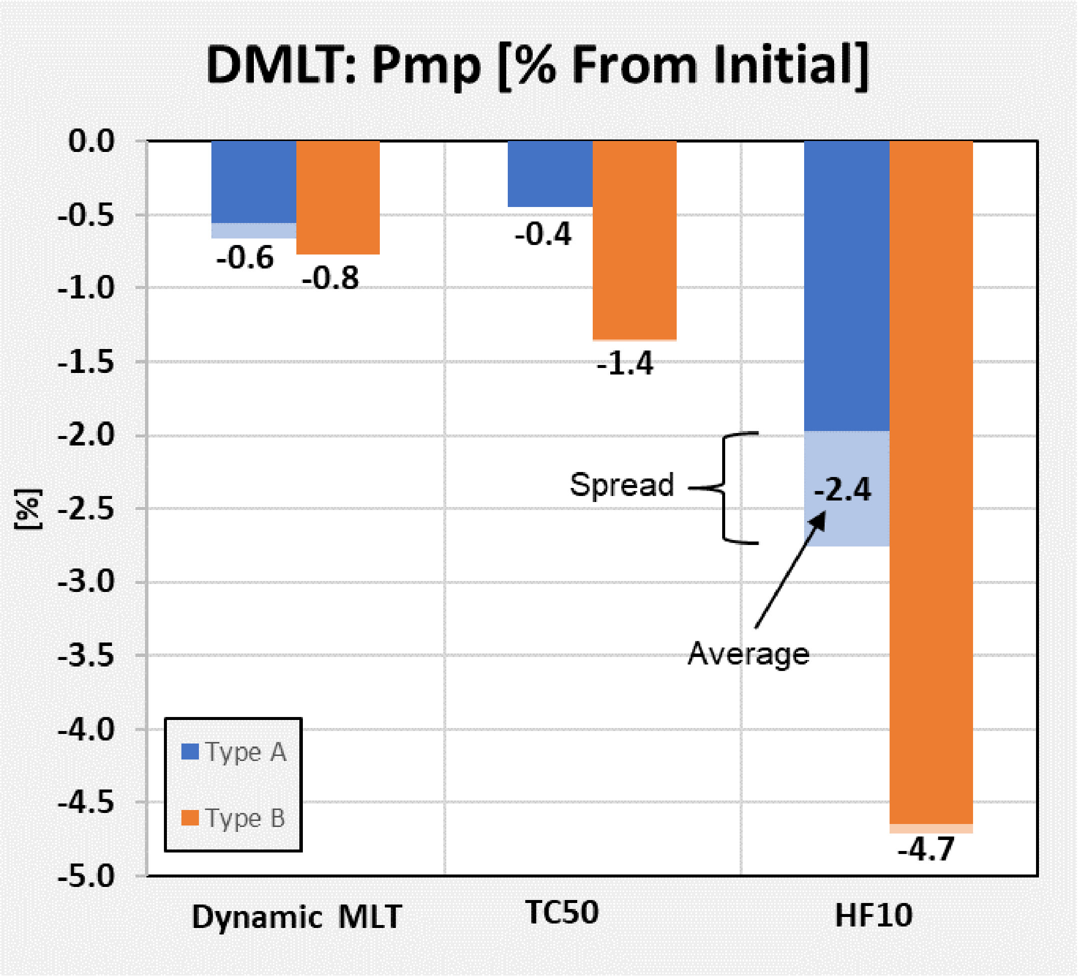
Type A (4-7 cracked cells post MLT)

- DMLT creates some bad cracks in the center.
- Some areas that are cracked become electrically isolated after DMLT.
- Electrical isolation is slightly enhanced by TC50 and HF10

Type B (2-3 cracked cells post MLT)

- DMLT caused virtually no cracking.
- Environmental stress enhances cell-to-cell mismatch

Leg 1 (Baseline DMLT) – Pmp Results



- Despite the difference in EL images, both module types show similar power losses after DMLT (< 1%).
- TC50 caused negligible power change on either type.
- HF10 creates significant power loss on Type B.
  - Type A: 1.6-2.4%
  - Type B: 3.4%

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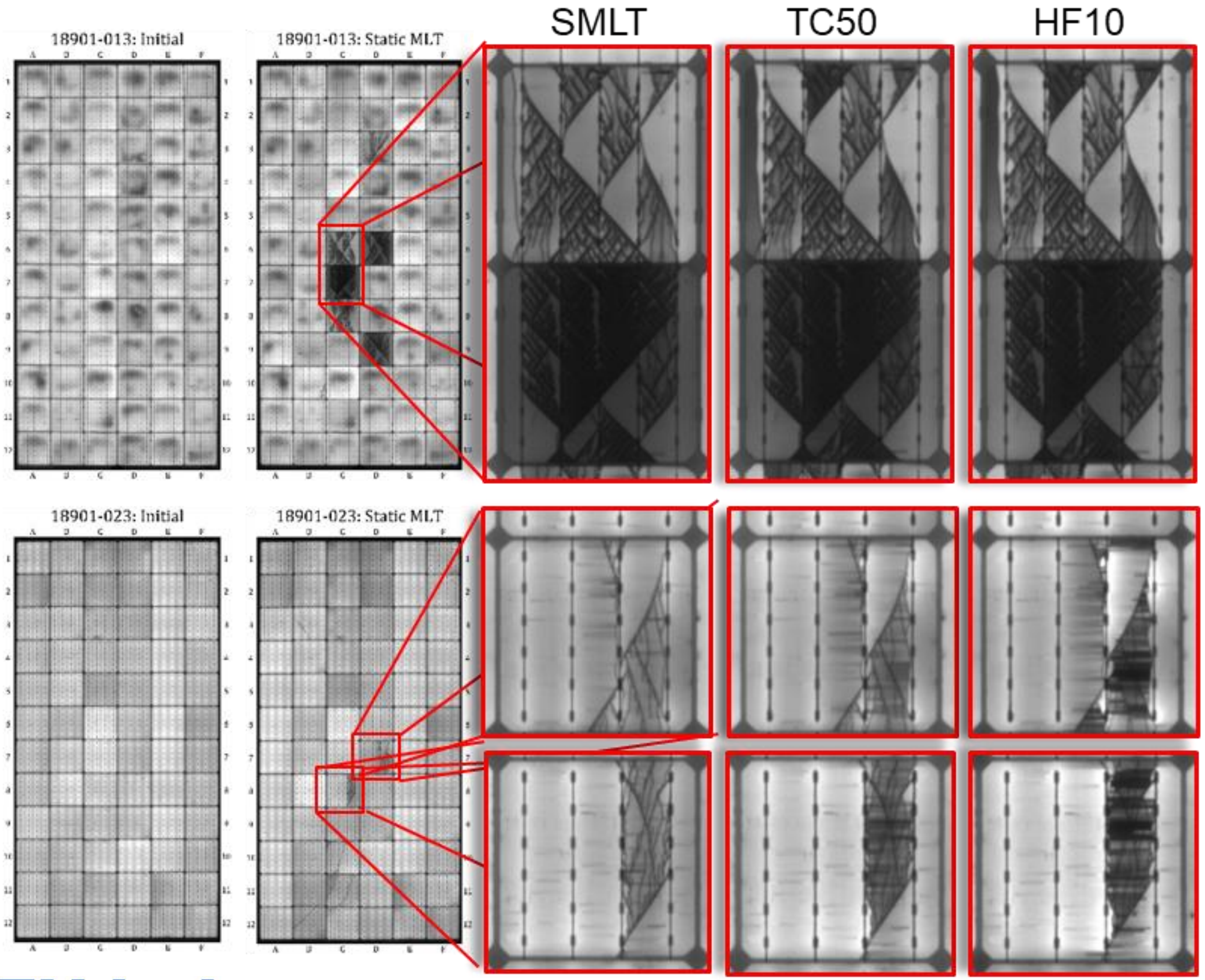
Leg 2 (Static MLT) – EL Results



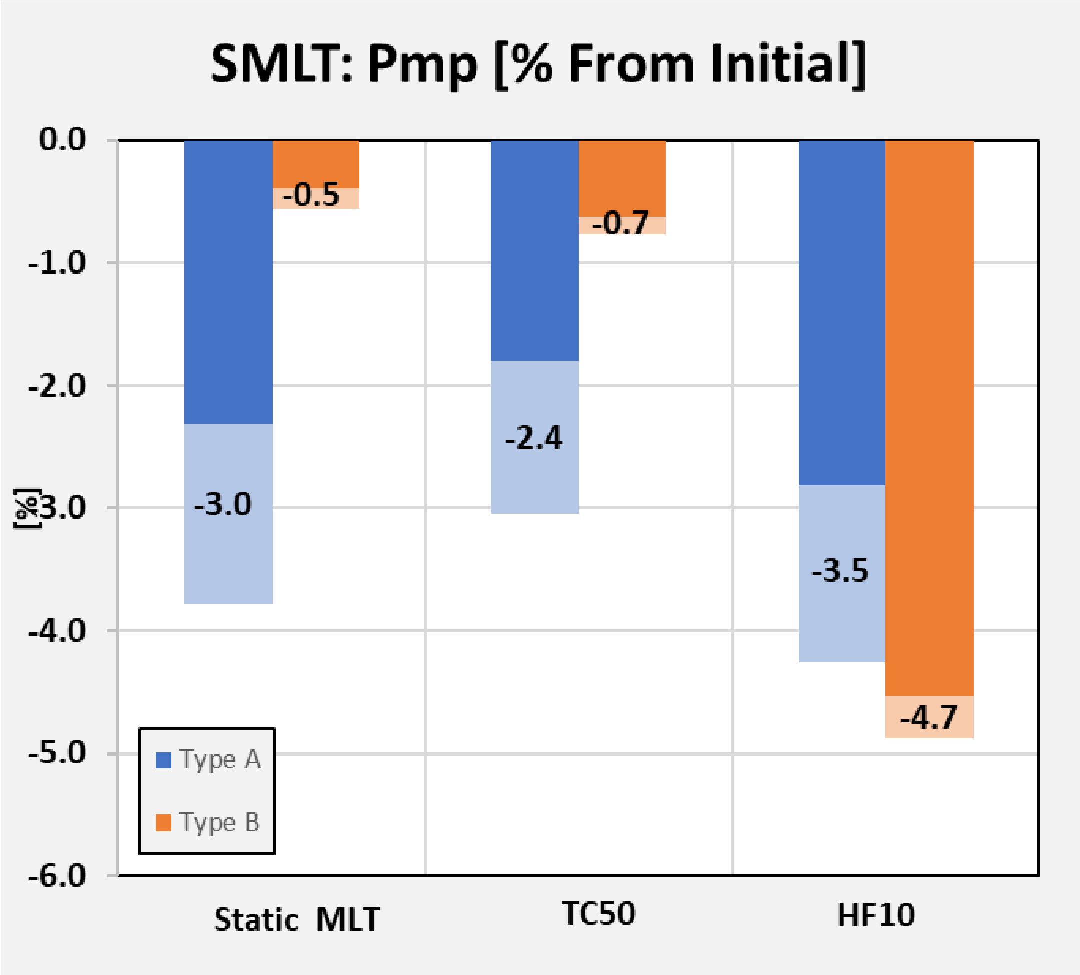
Type A (7-16 cracked cells)

- Static MLT creates more cracks than DMLT, but the broken pieces are initially still interconnected.
- Following chamber stress, some cracked portions become electrically isolated.

Type B (2-11 cracked cells)

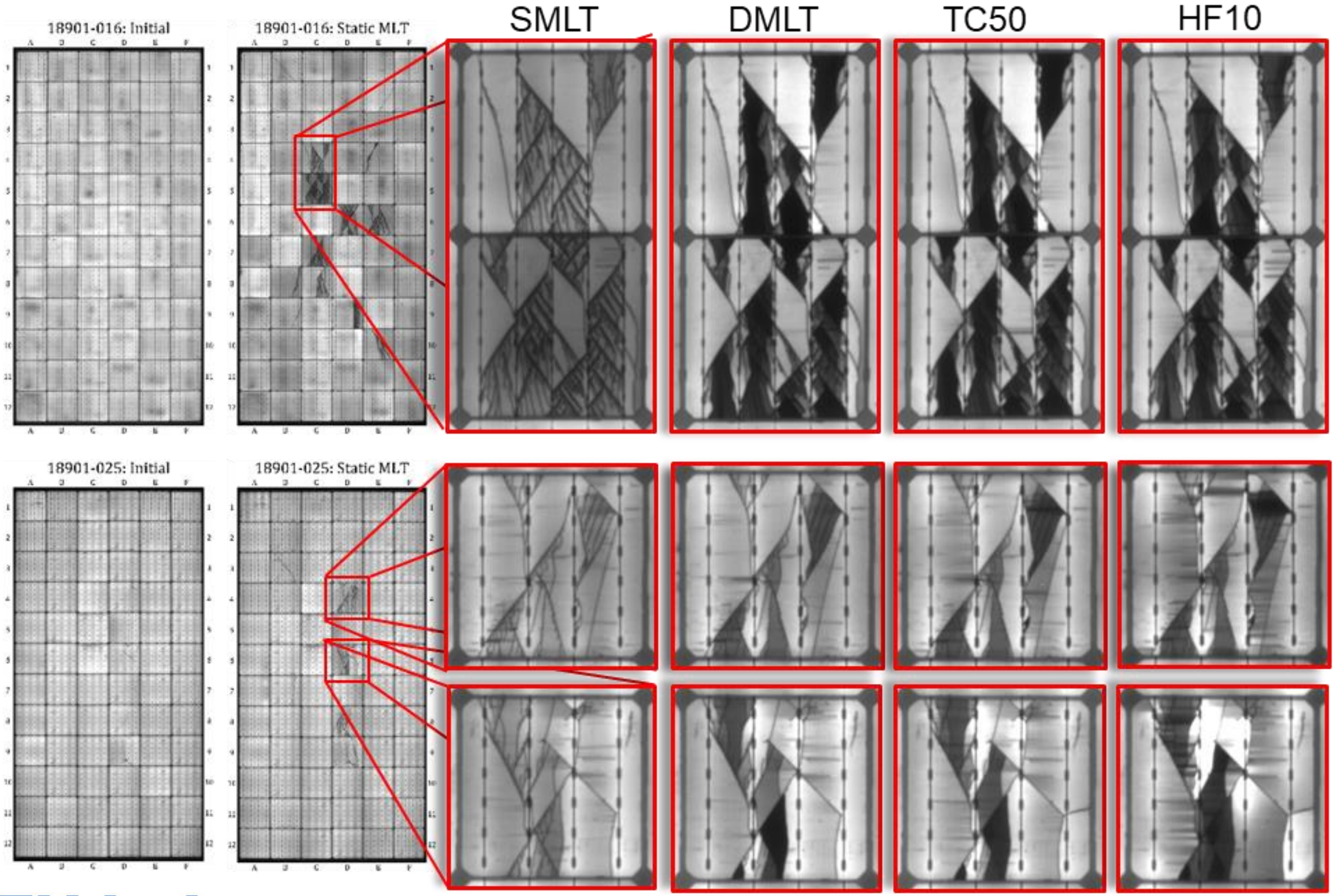
- Again, static MLT creates more cracks than DMLT, but still minor on this type.
- Electrical contact is retained after MLT.
- Chamber stress electrically isolates some of the cracked portions.

Leg 2 (Static MLT) – Pmp Results



- The increased cracking on Type A led to ~ -3% Pmp change following MLT.
- Type B showed negligible power change from mechanical stress.
- TC50 impact was negligible on both types.
- Type B degraded significantly following HF10, leading to similar total power losses for both types.
  - Type A: 1.0-1.2%
  - Type B: 4.0%

Leg 3 (Static + Dynamic MLT) – EL Results



Type A (12-13 cracked cells)

- SMLT creates non-isolated cracks; DMLT isolates them.
- Little impact from follow-up chamber stress

Type B (7-11 cracked cells)

- Less cracked cells
- Slightly less isolation from DMLT, but still significant isolation occurs
- Further isolation resulted from environmental testing.

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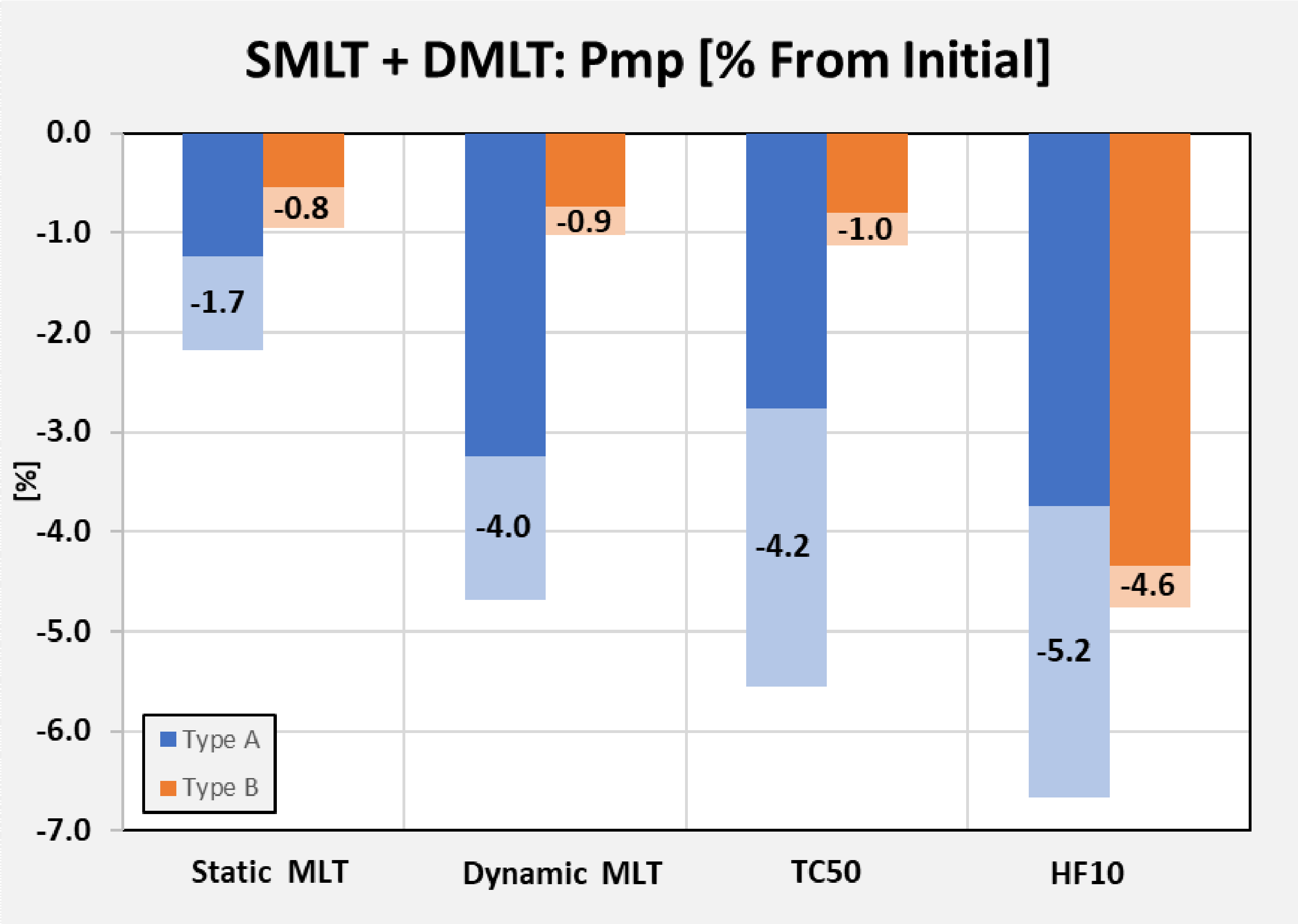
Leg 3 (Static + Dynamic MLT) – Pmp Results



- Type A showed 3-5% power loss following SMLT/DMLT.
- Type B showed 1% power loss following SMLT/DMLT.
- TC50 impact was negligible
- The final power loss was similar between types because Type B degraded more from HF10.
- The incremental degradation from HF10 was:
  - Type A: 1.0%
  - Type B: 3.6%

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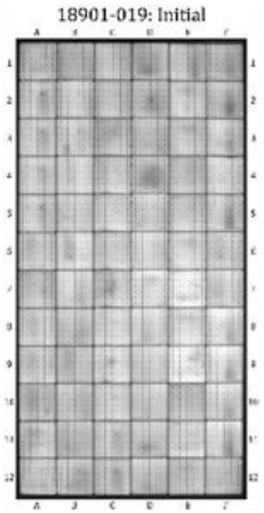
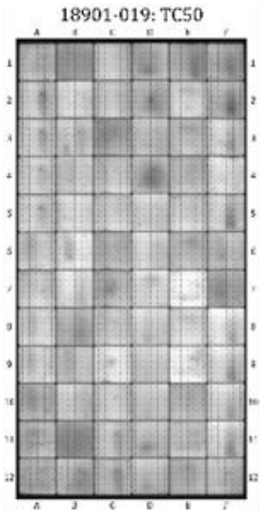
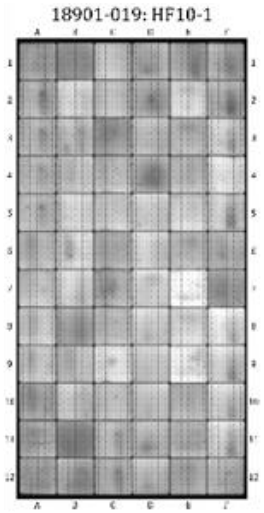
Leg 4 (No MLT) – EL Results

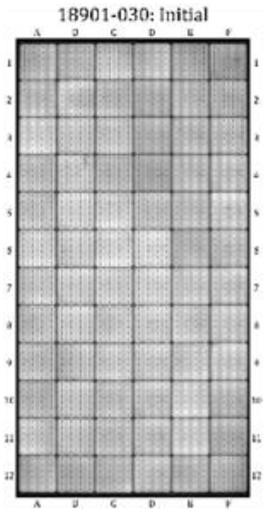


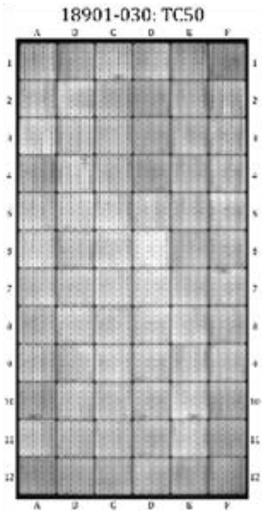


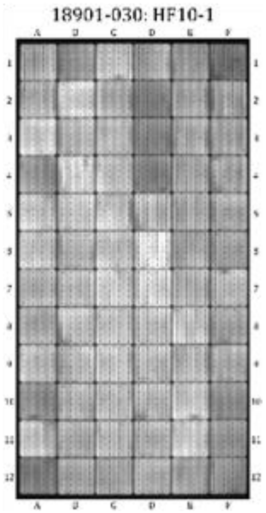


Type A

- No visible crack formation
- Same slight increase in cell mismatch



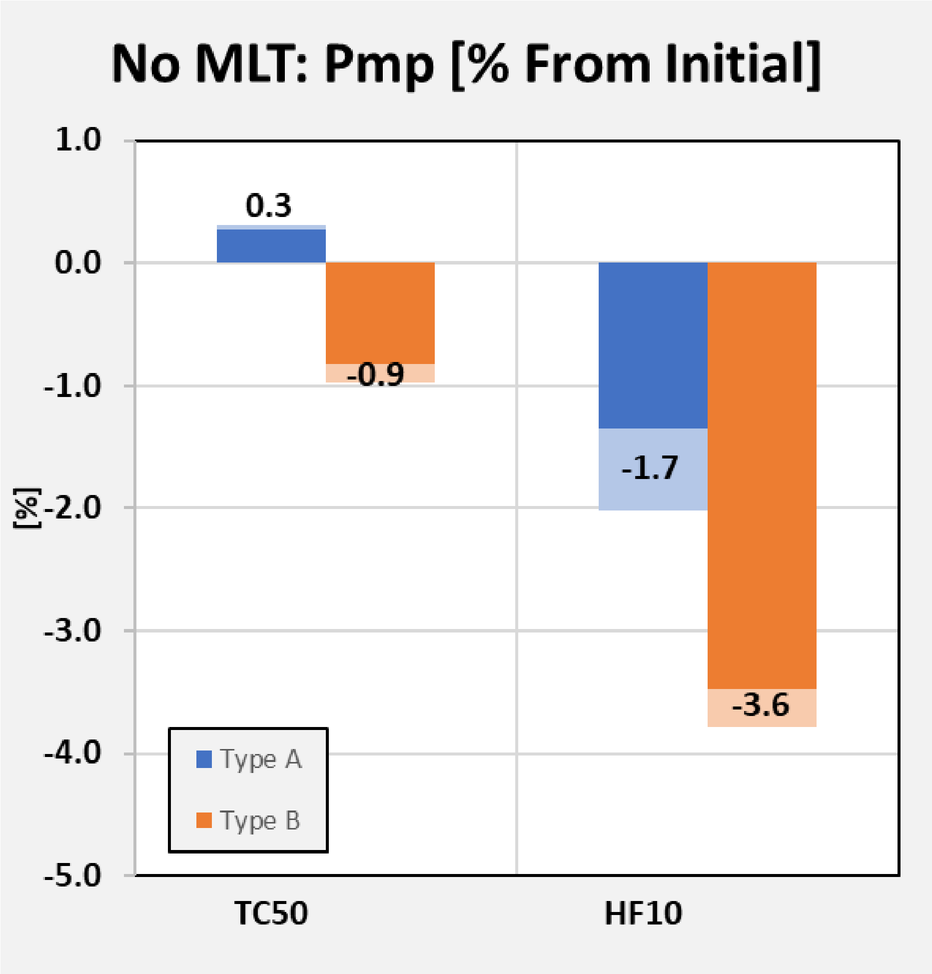




Type B

- No visible crack formation
- Same slight increase in cell mismatch

Leg 4 (No MLT) – Pmp Results



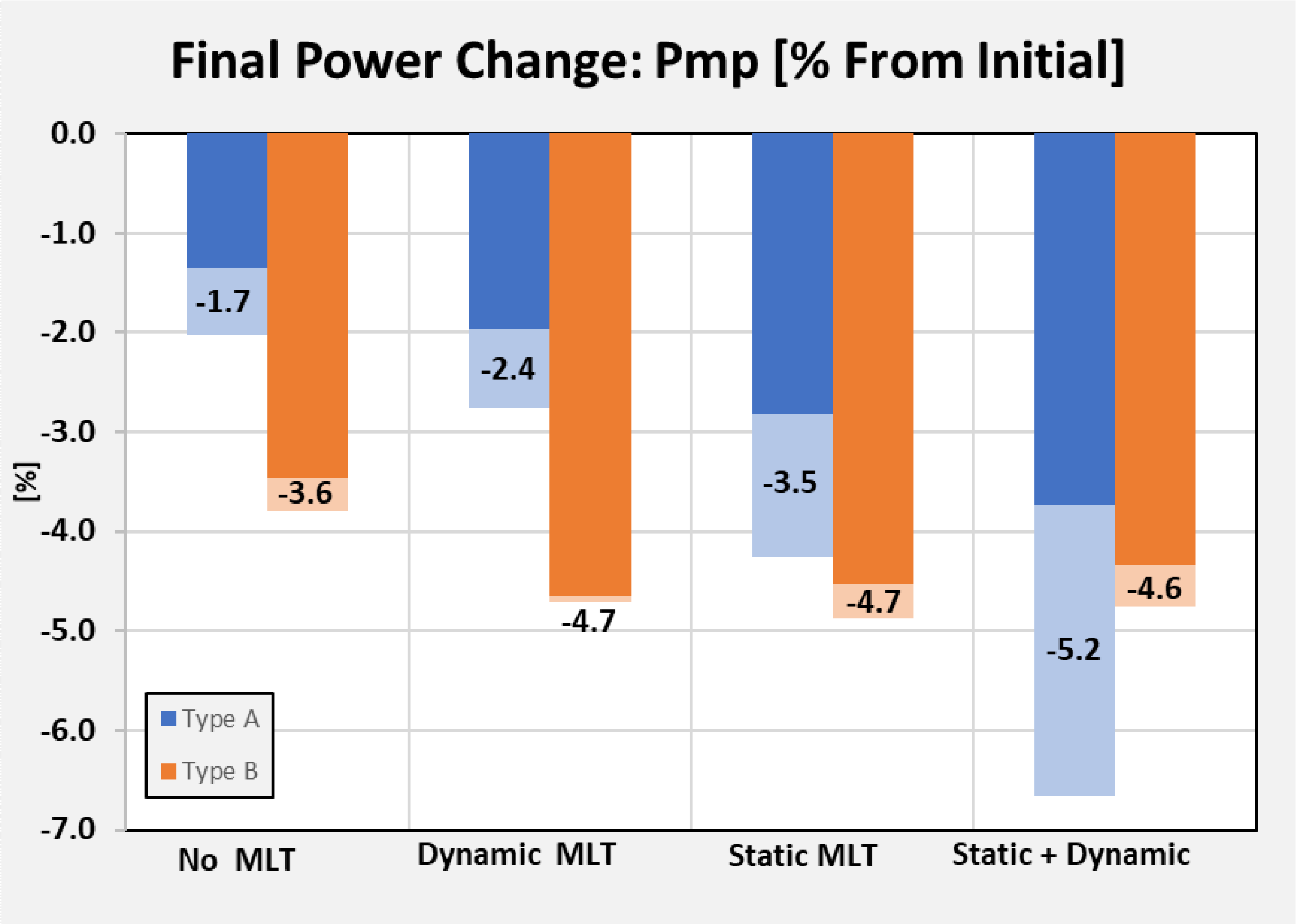
- TC50 showed negligible ΔPmp
- Type B modules degraded more significantly from HF10 stress than the Type A modules.
  - Type A: 1.6-2.3%
  - Type B: 2.6-2.8% series

Type	Isc [%]	Voc [%]	Imp [%]	Vmp [%]
A	-0.94	-0.17	-1.29	-0.40
B	-1.96	-0.37	-2.11	-1.56

Type	FF [%]	R-ser [%]
A	-0.57	**7.31**
B	-1.34	**17.60**

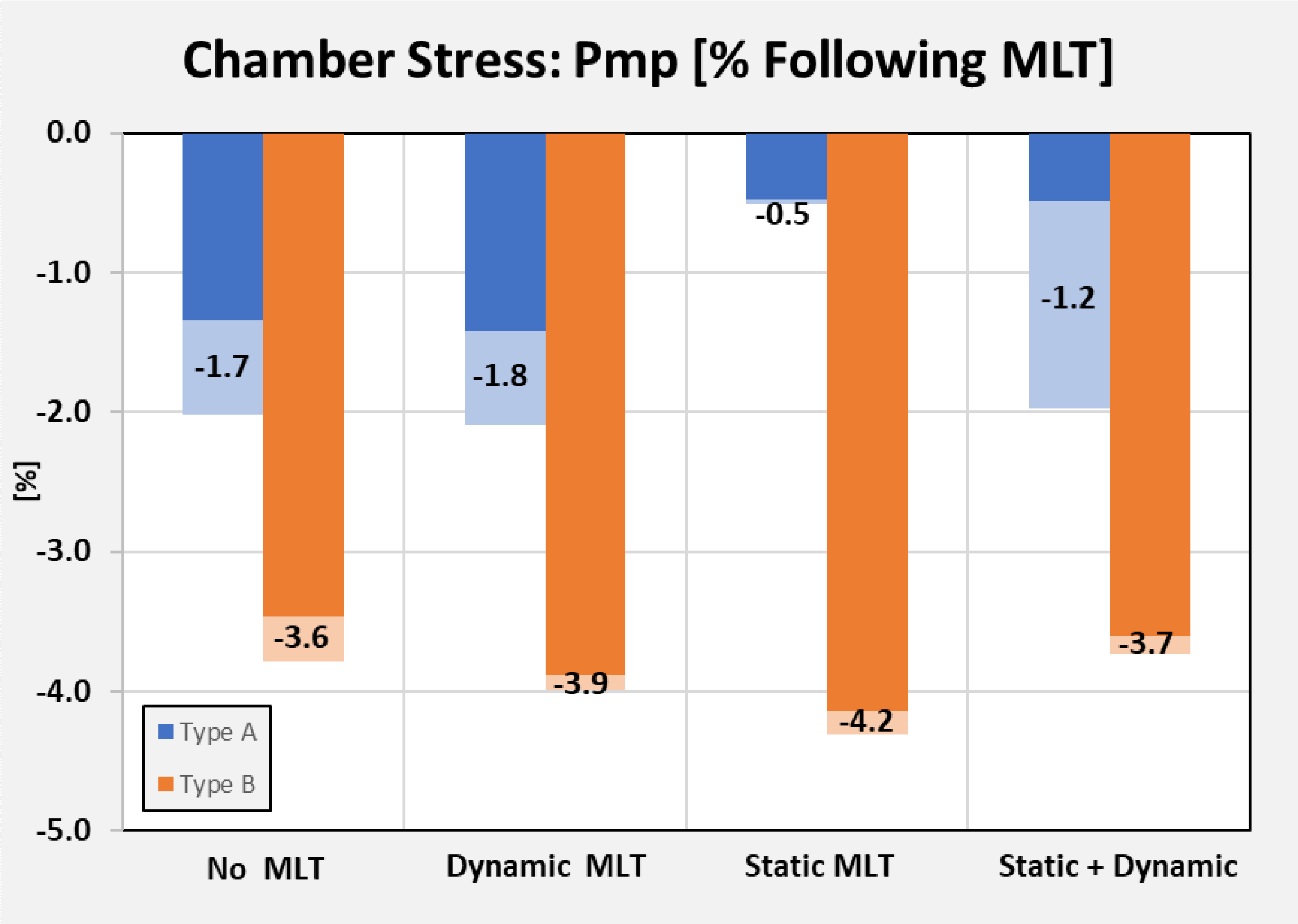
- Type B modules may have weaker solder bonds or easily degradable AR coating

Final Pmp Change of All Legs



- Type A, being more susceptible to cracking, exhibited increased power loss with increased mechanical stress.
- Type B, being more robust, incurred the same ~ 1.0% Pmp drop with all mechanical stresses.
- The remaining Pmp drop of 3.6-3.7% was mostly due to HF10 inducing non-crack related failure modes.

Pmp Change from Chamber Stress



- Type A exhibited an average Pmp change of -1.3% resulting from chamber stress.
- Pmp on Type A increased following TC50 on the SMLT leg.
  - TC50 may “heal” non-isolated cracks.
- Type B exhibited an average Pmp change of -3.9 % resulting from chamber stress.

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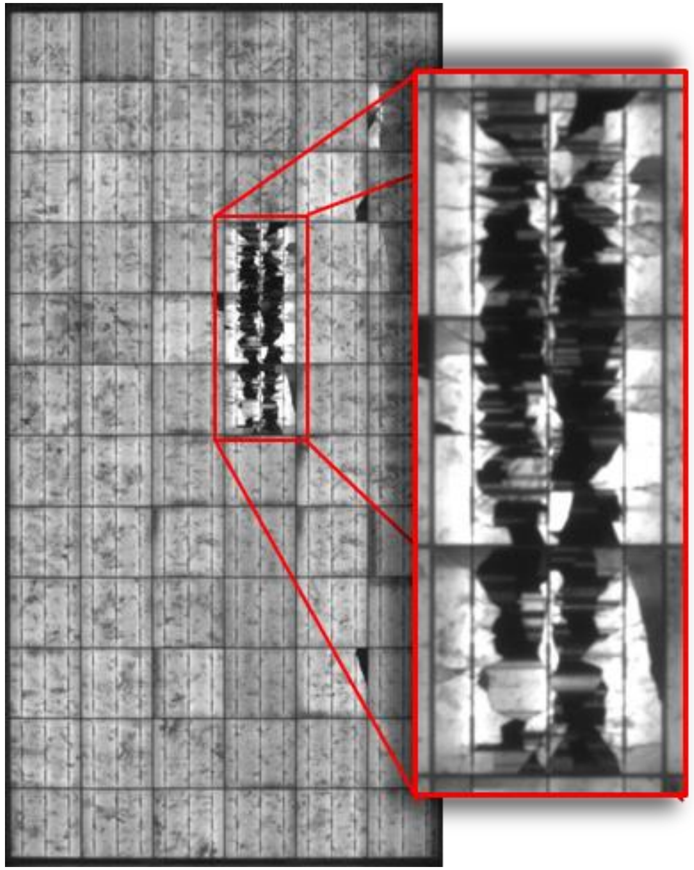
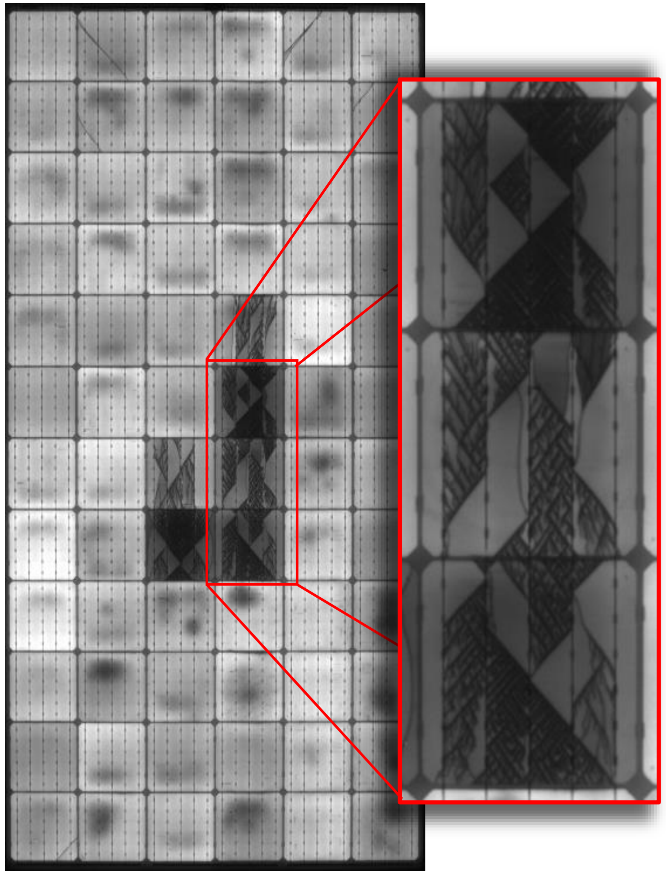
Comparison with Fielded Modules

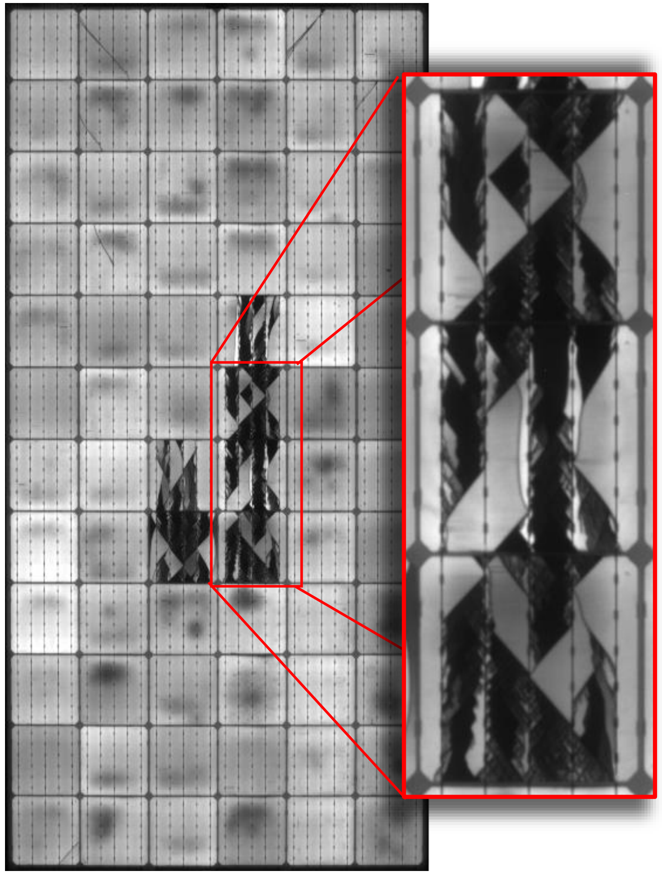
Fielded Module



SMLT



SMLT + DMLT



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Conclusions

- This study has a very small sample size but confirms empirical lab testing observations.
- Neither DMLT or SMLT alone appears to be very effective at producing electrically isolated cell regions in PV modules.
- SMLT+DMLT appears to be an effective method of producing isolated cell regions in PV modules.
- Typically used environmental stresses (TC50/HF10/HF20, etc.) may not propagate cracks or isolate cell regions, but may instead activate independent module degradation modes such as solder bond or AR coating degradation.
- Further work may be needed on cell crack susceptibility test legs in extended module testing protocols.

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Thank you.

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