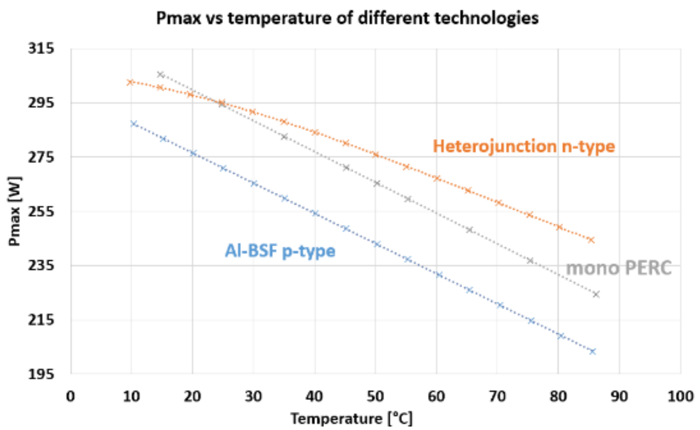
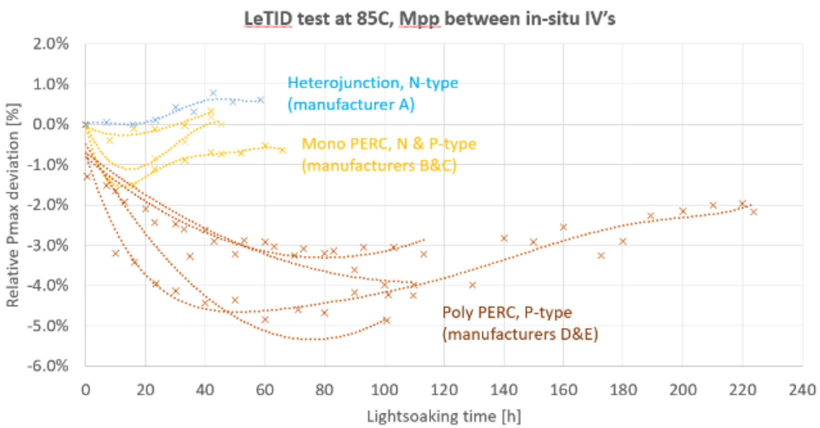
Temperature coefficients and LeTID of bifacial PV modules





Thank you for reading this whitepaper & we appreciate your feedback

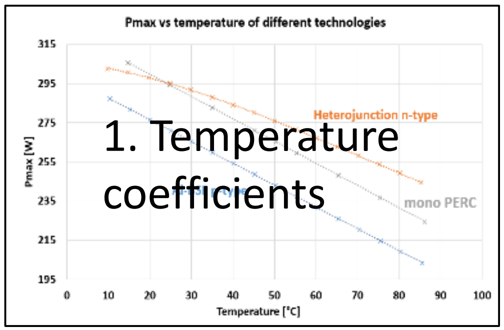
Our whitepapers are about sharing our knowledge with you.

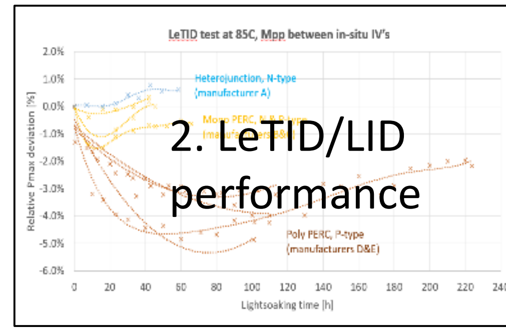
We would like to start a dialogue on continuous improvement on both sides.

We need your feedback, so we can make things better!

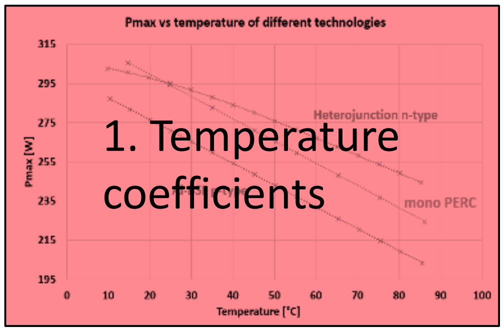
You can contact us at: contact@eternalsun.com or +31 (0)15-7440161

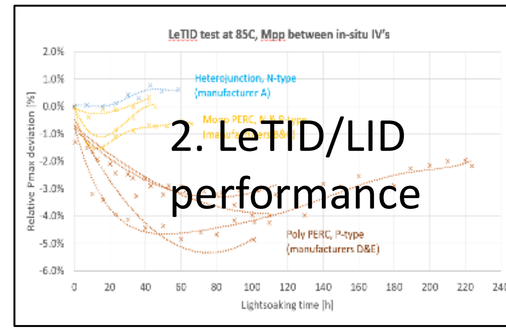
Two topics with Yield impact for Bifacial PV





Two topics with Yield impact for Bifacial PV

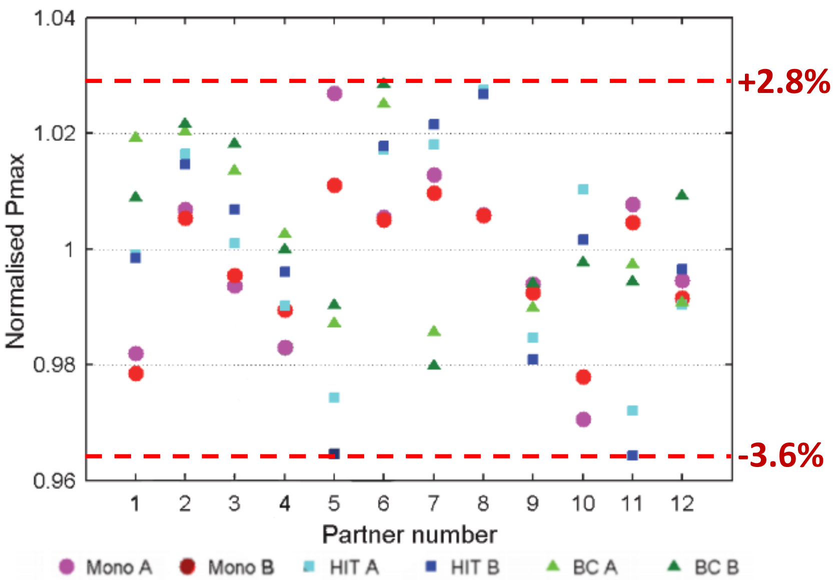




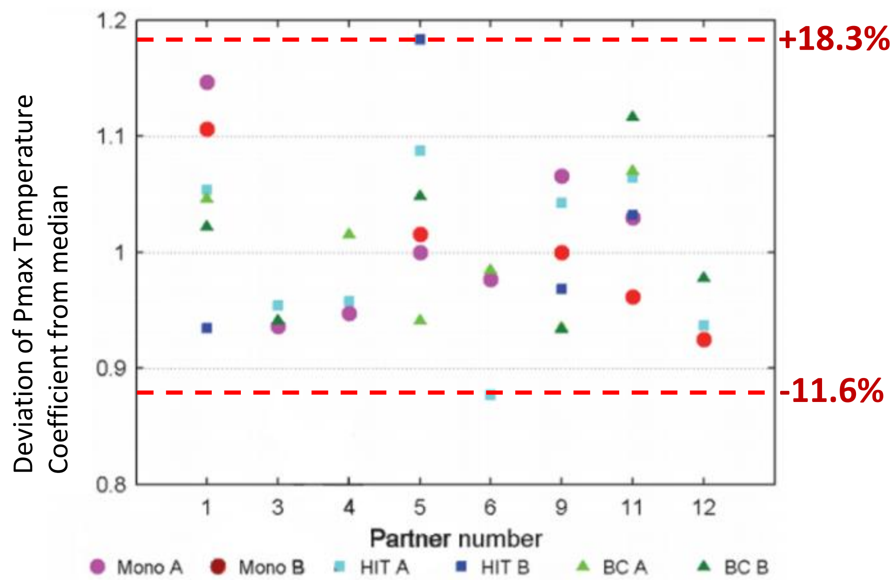
Temperature coefficients are a big challenge for the PV industry

Round robin between 12 leading laboratories:

P_{max} accuracy constantly improving



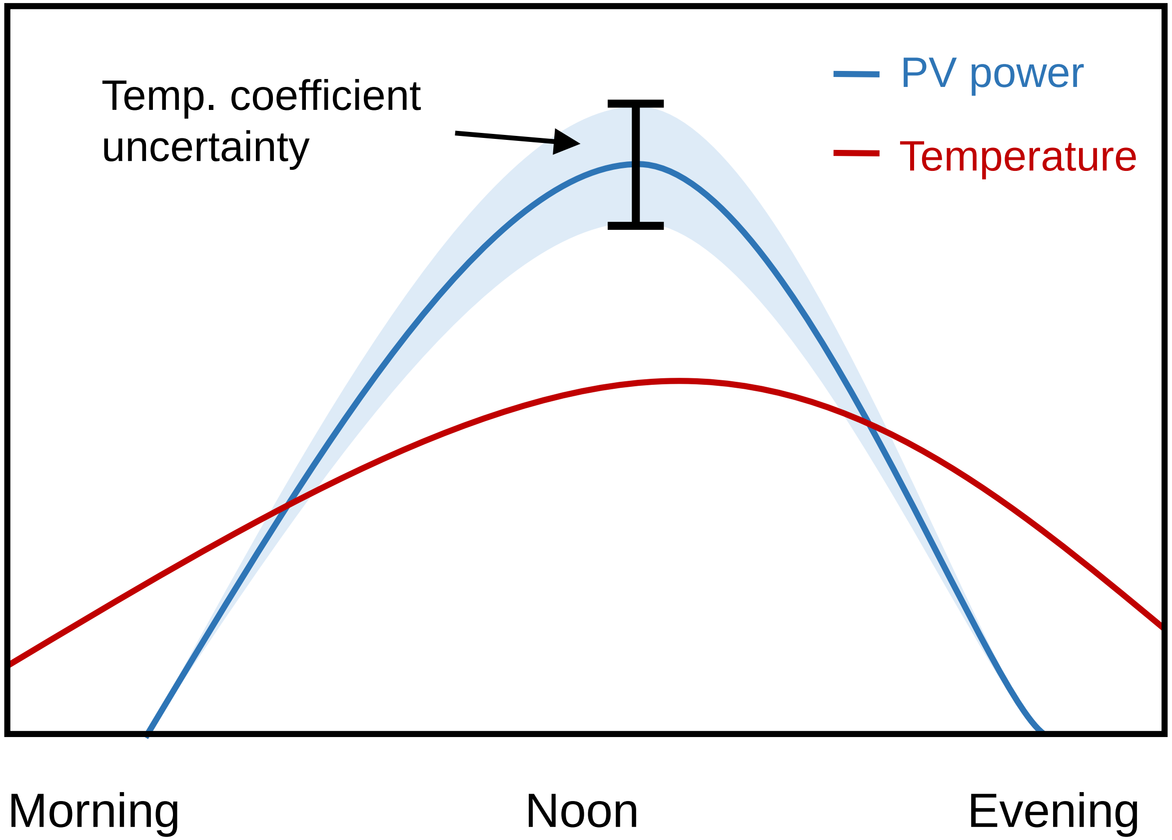
Temp coefficient accuracy has been forgotten



Typical tempco measurement uncertainties **OVER** 10%

[1] MIHAYLOV, B.V. ... et al, 2014. Results of the Sophia module intercomparison part-1: STC, low irradiance conditions and temperature coefficients - C-Si technologies

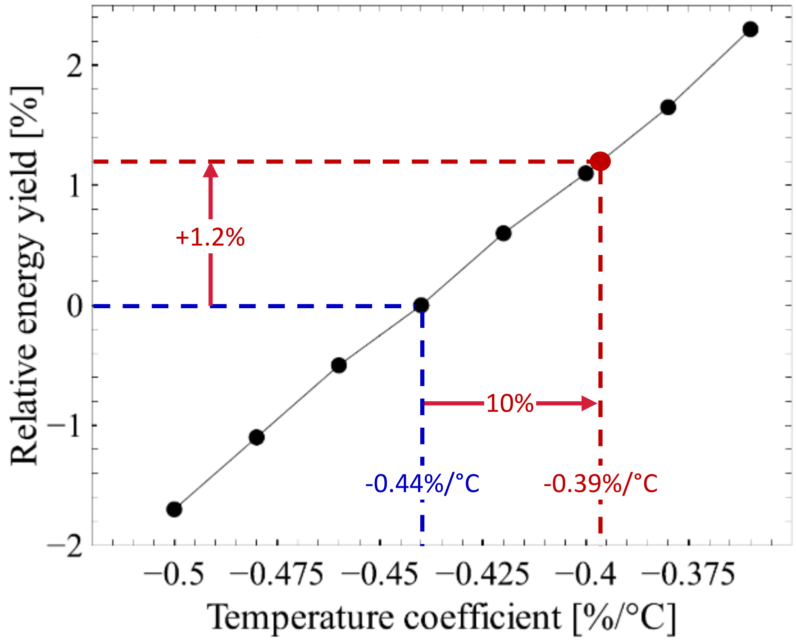
This uncertainty gets little attention, but impact can be significant



In sunbelt area's with high operating temperatures, the impact is largests

A 10% difference in temperature coefficient equates to a >1% difference in energy yield

The following figure shows the relationship between temperature coefficient and relative energy yield for the specified location (Phoenix, USA) [2]:



10% difference in temperature coefficient = 1.2% difference in energy yield for this PV plant location

Image adjusted from : [2] Yang Yang, YingBin Zhang…Pierre J. Verlinden, 2014. Understanding the uncertainties in the measurement of temperature coefficients of Si PV modules – PVSyst modelling of energy yield with varying temperature coefficient in Phoenix, USA climatic conditions

Our Goal:

Reduce T.C. measurement uncertainty from >10% to <5%, for all PV technologies

Outline

Illuminati
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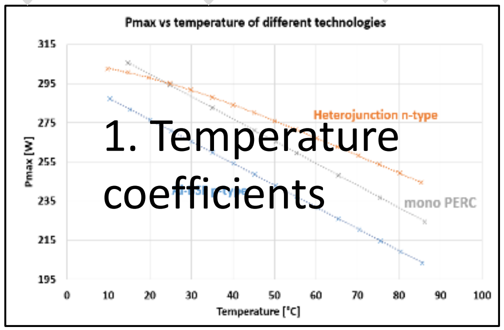
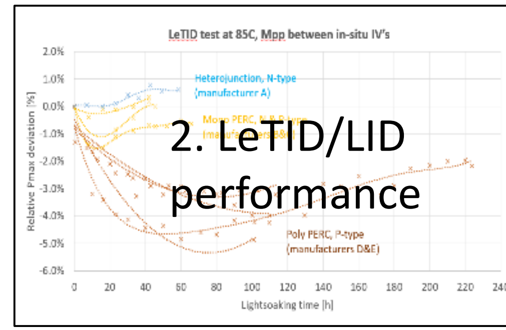
Temperat
ure

Procedure



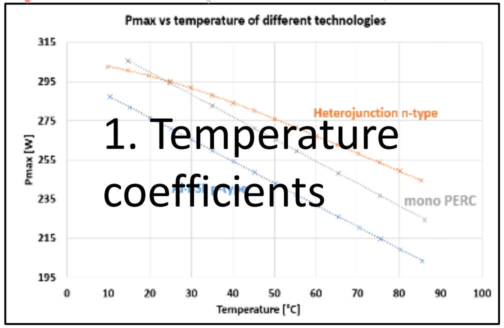


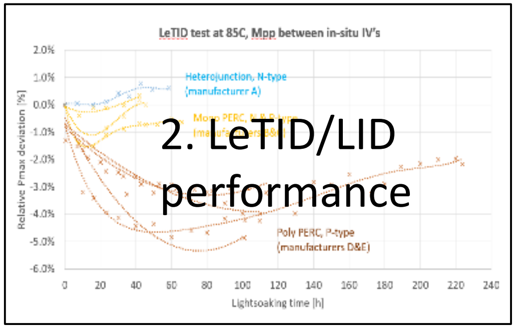
Outline

Illumination

Temperature

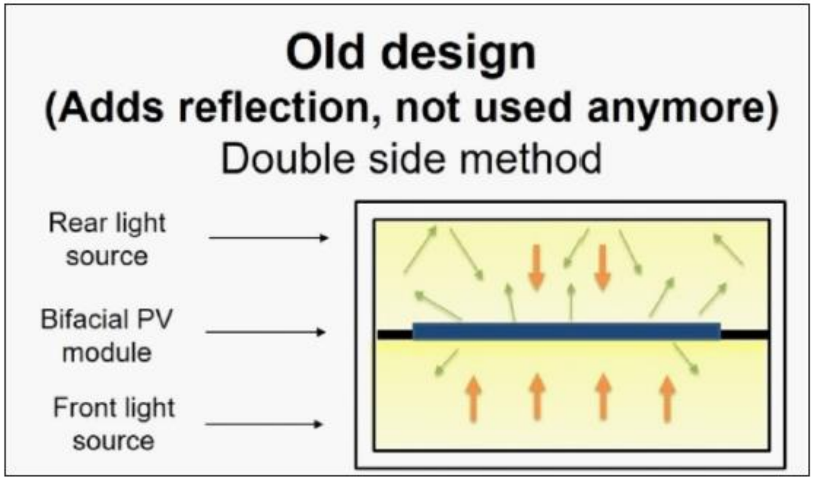
Procedure

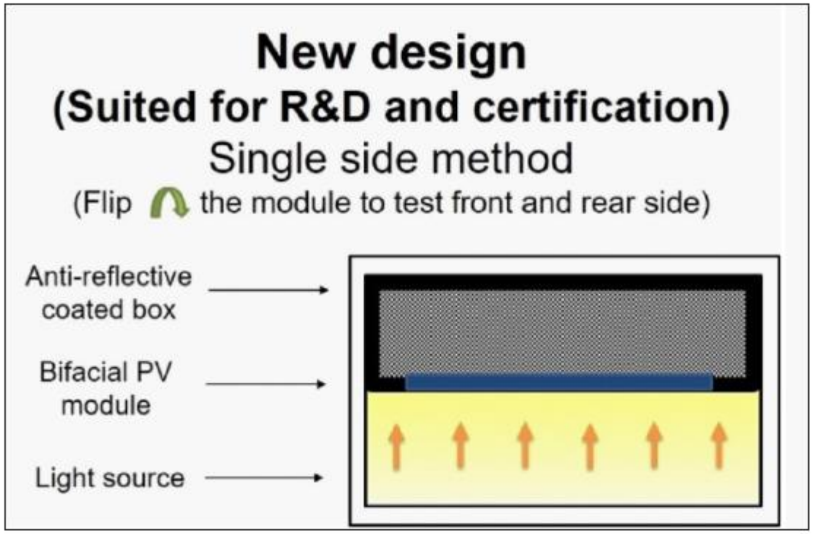




The single side and flip method is now regarded as most accurate

Illuminati
on



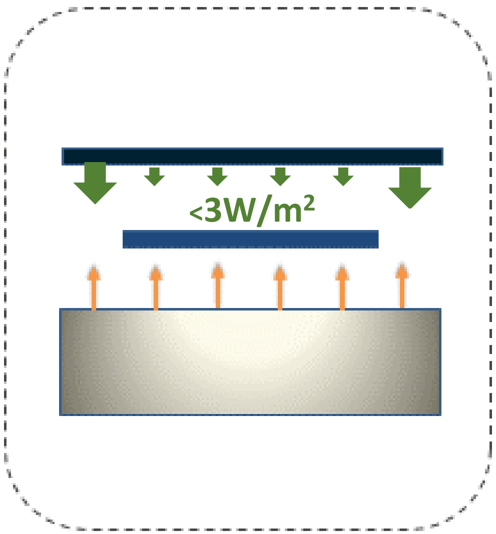


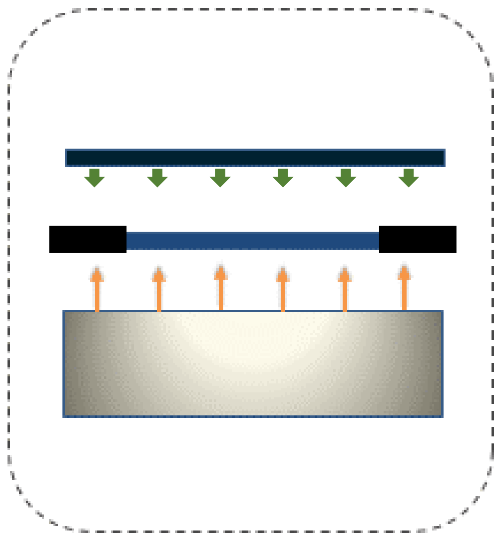
Bifacial measurements in the temperature controlled lab flasher: very low rear irradiance

Illumination

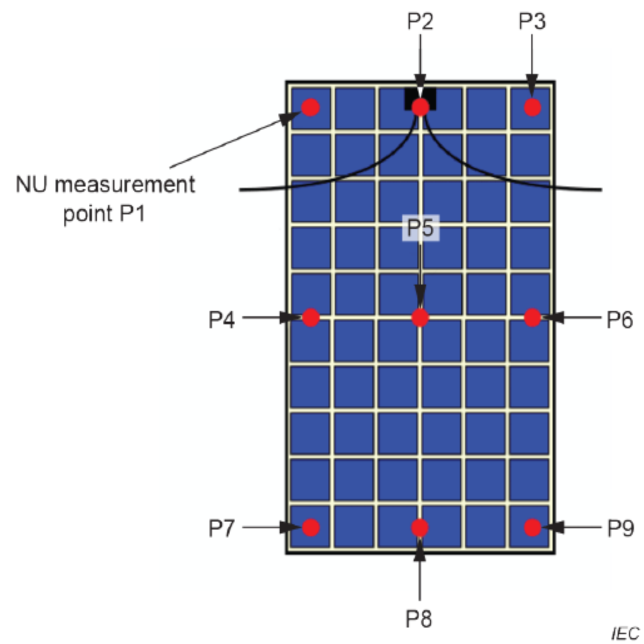
Method:
1. Temperature box special black paint
2. Black mask around module

IEC requirement: ensure rear side irradiance < 3W/m^2





Confirm: measure irradiance at 9 points on PV module



IEC 60904-1-2

Result: on all 9 points rear side irradiance < 3W/m^2

Illumination

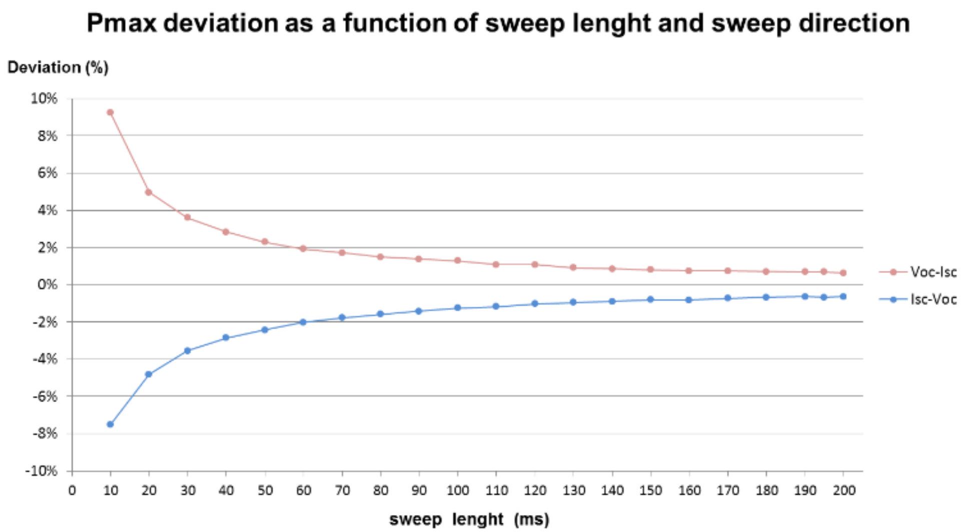
Position on module rear	Voltage measured [mV]	Irradiance equivalent [W/m^2]
	95.35	1000
P1	0.215	2.25
P2	0.192	2.01
P3	0.247	**2.59**
P4	0.144	1.51
P5	0.108	1.13
P6	0.157	1.65
P7	0.161	1.69
P8	0.169	1.77
P9	0.176	1.85

The temperature box is suitable for bifacial module testing according to IEC 60904-1-2 in combination with module mask

Pulsewidth: HJT modules require a pulse up to 300 ms

Illumination

HJT: 100-300 ms

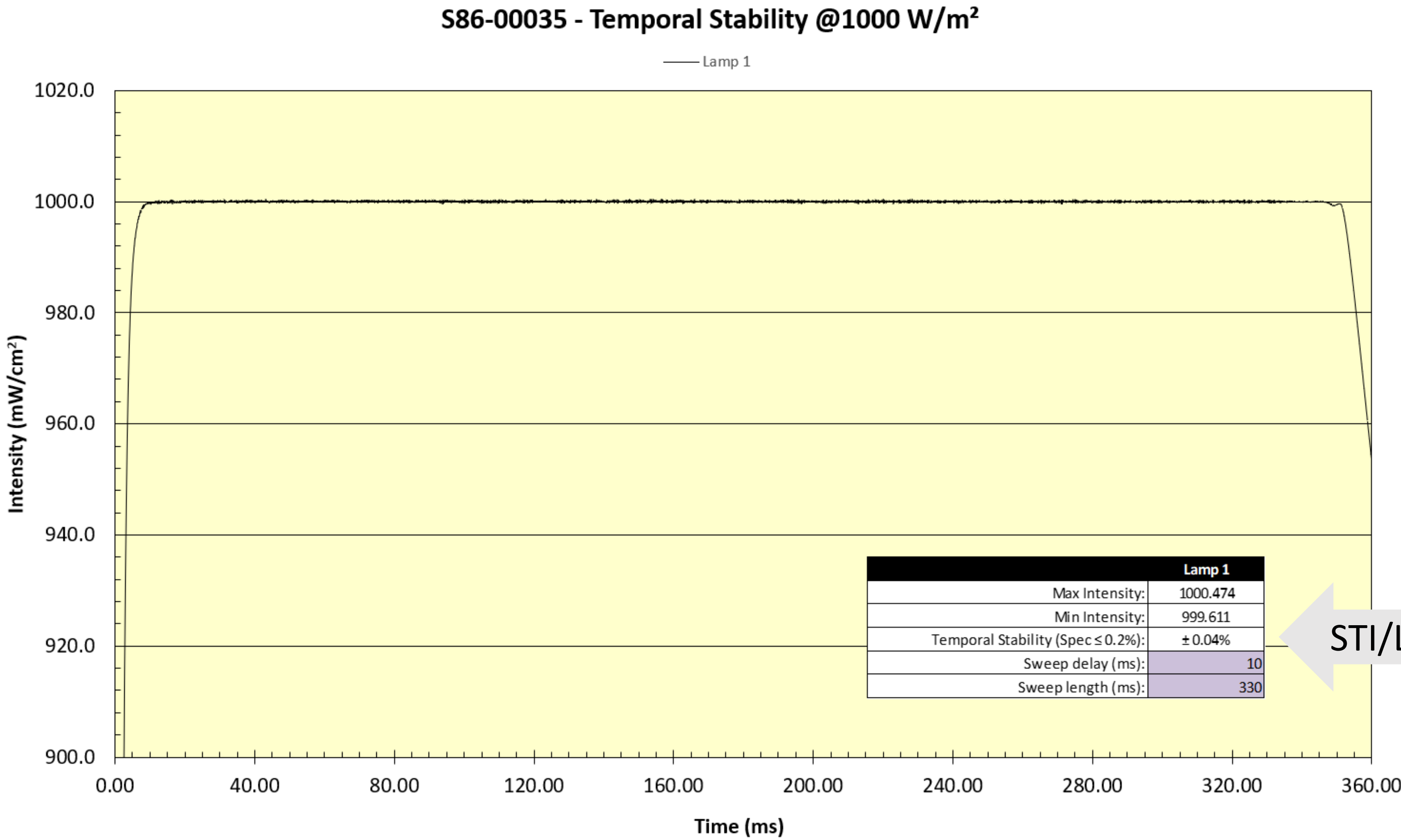


- *Every cell V_{oc} increase of 18mV roughly doubles the carrier concentration, which causes a doubled sweep time effect [2]*
- *More cells in series (e.g. 60 to 72 cells) reduces the string capacitance*
- *Multiflash can be applied in combination with Single Long pulse*

[1] Source: Based on 5600 SLP sweep time sequence measurement of PERC module (2016)
[2] Source: Smets et al., Solar Energy: the physics and engineering of photovoltaic conversion technologies and systems (2016)

Pulsewidth: a stable single long pulse enables lowest uncertainty on high efficiency PV technologies

Illumination

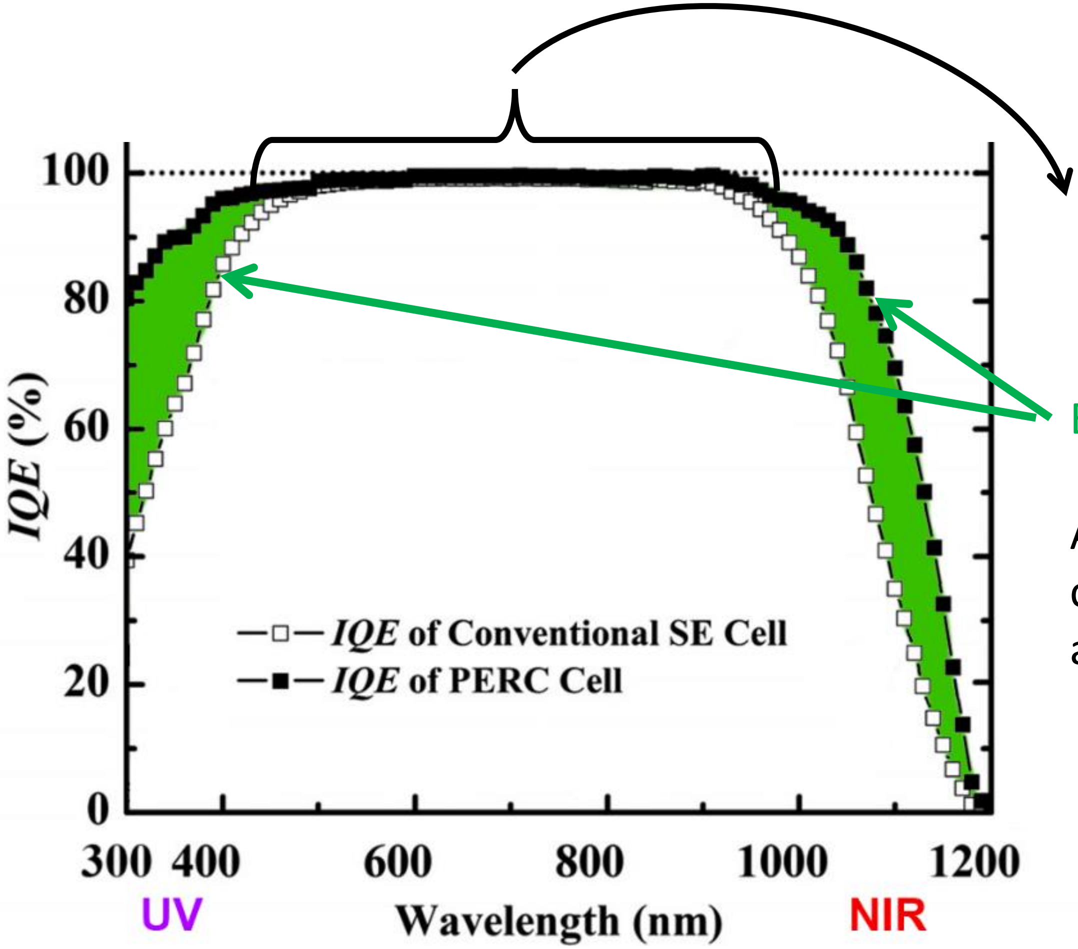


	Lamp 1
Max Intensity:	1000.474
Min Intensity:	999.611
Temporal Stability (Spec ≤ 0.2%):	± 0.04%
Sweep delay (ms):	10
Sweep length (ms):	330

STI/LTI

Spectrum: a wide, 300-1200 nm spectrum is critical for T.C. measurement on high efficiency cell technology

Illumination



The quantum efficiency of solar cells between 400-1000nm is already at 100%

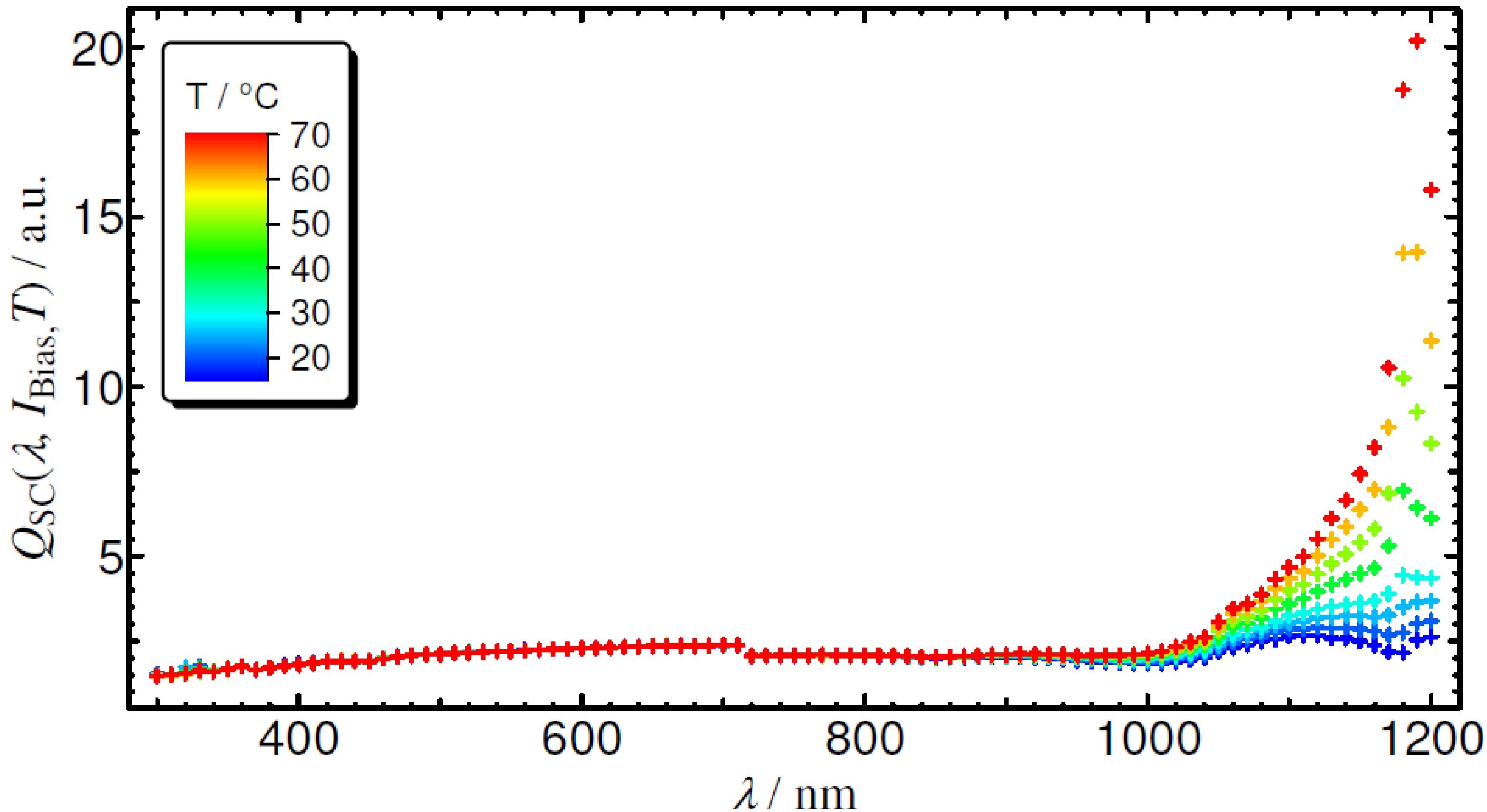
Efficiency gains PERC/Topcon/HJT

All efficiency improvements in new cells MUST occur in the 300-400nm and 1000-1200nm range

Image adjusted from: Zhang *et al.*: 335-W World-record p-type monocrystalline module IEEE journal of photovoltaics, VOL. 6, NO. 1 (2016)

Spectrum: when temperature increases, QE changes in 1000-1200 nm

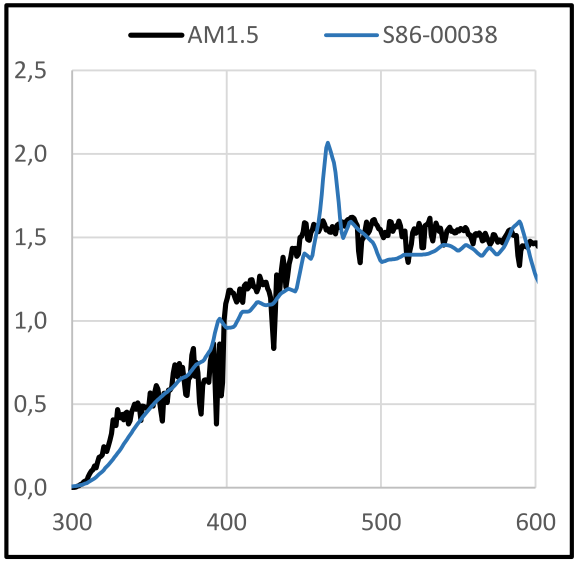
Illumination



Source: PTB Photoclass

Spectral coverage of >99% in 300-1200 nm of Eternalsun Spires 5100 & 5600 SLP Flashers enable the lowest uncertainty

Illumination



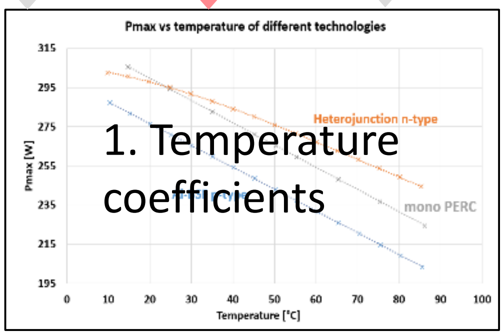
AM1.5G		Spire Flasher solar simulator				Results
nm	Value	nm	Value	Midpoint	Value	SPC 99.31%
300.0	0.0010	300	0.005	300.5	0.0052	
300.5	0.0012	301	0.006	301.5	0.0059	
301.0	0.0019	302	0.006	302.5	0.0066	SPD 34.65%
301.5	0.0027	303	0.007	303.5	0.0072	
302.0	0.0029	304	0.008	304.5	0.0079	
302.5	0.0043	305	0.008	305.5	0.0092	
303.0	0.0071	306	0.010	306.5	0.0110	
303.5	0.0090	307	0.012	307.5	0.0128	
304.0	0.0095	308	0.014	308.5	0.0146	
304.5	0.0120	309	0.016	309.5	0.0164	
305.0	0.0165	310	0.017	310.5	0.0190	

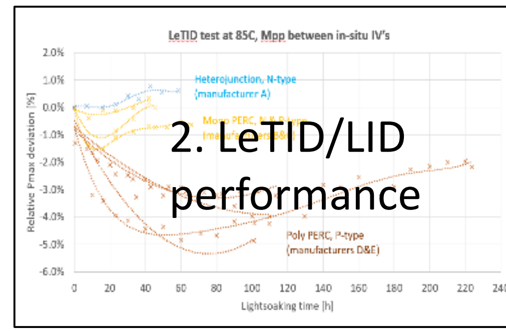
IEC 60904-9 Edition 3

Eternalsun Spire flashers have spectrum coverage starting at 300nm. This is critical for accurately measuring high efficiency technologies

Outline

Illumination | Temperature | Procedure





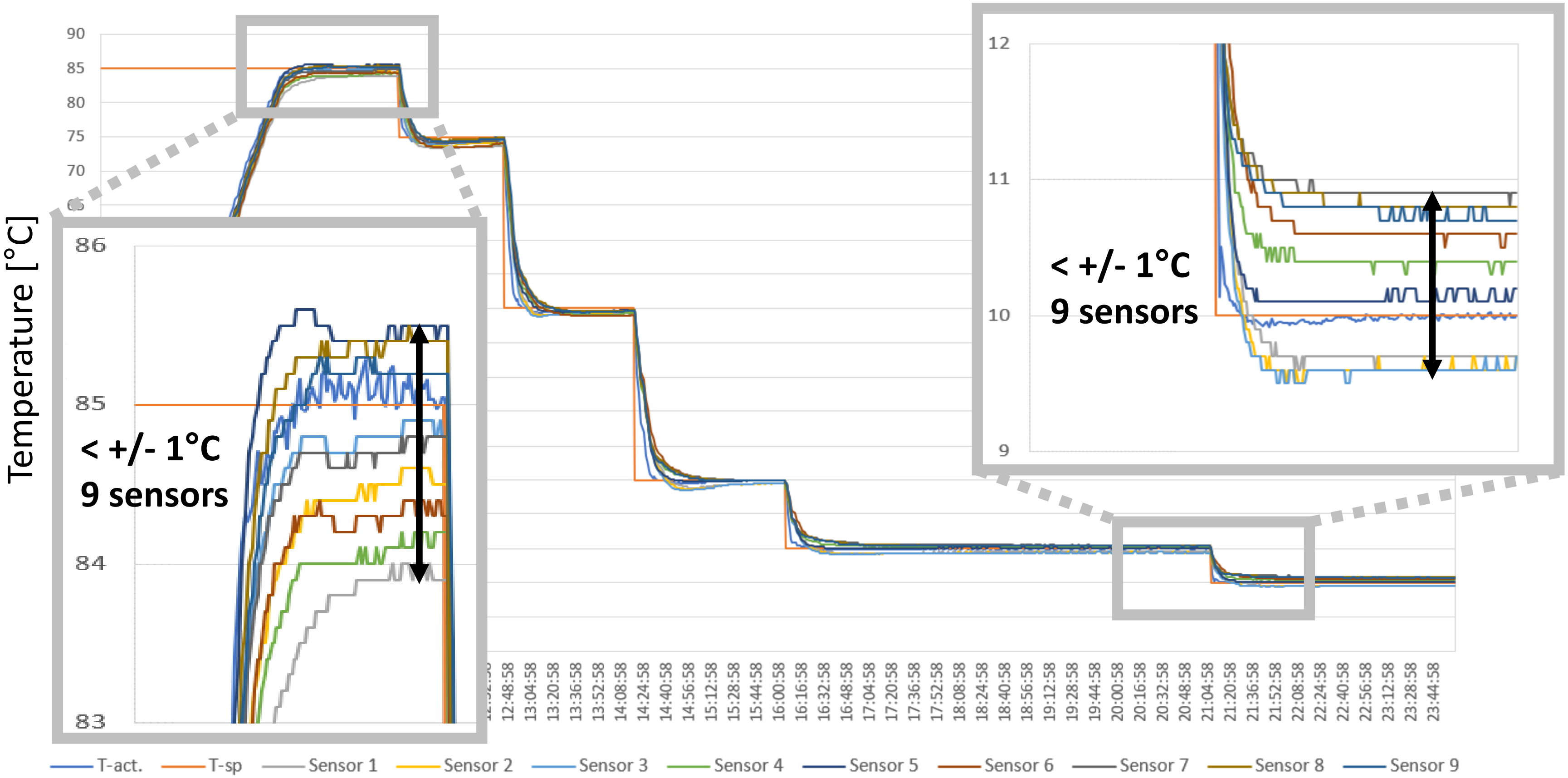
Temperature control box added to flasher:

- Heating and cooling from 15 C to 85 C
- Temperature control chamber moves down to fully enclose PV module for accurate temperature control

Temperature control: temperature uniformity directly affects uncertainty

Temperat
ure

Any temperature difference between individual cells in the module causes an error in the coefficient

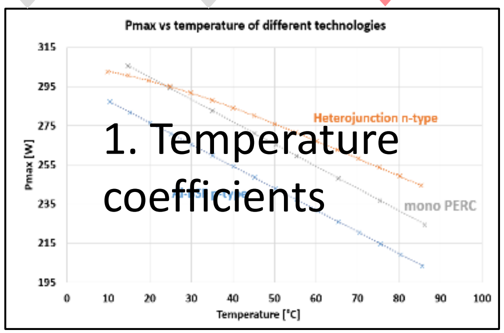


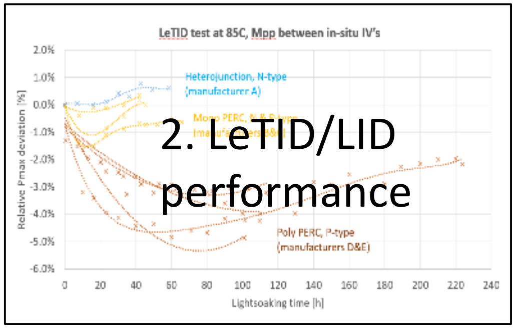
Outline

Illumination

Temperature

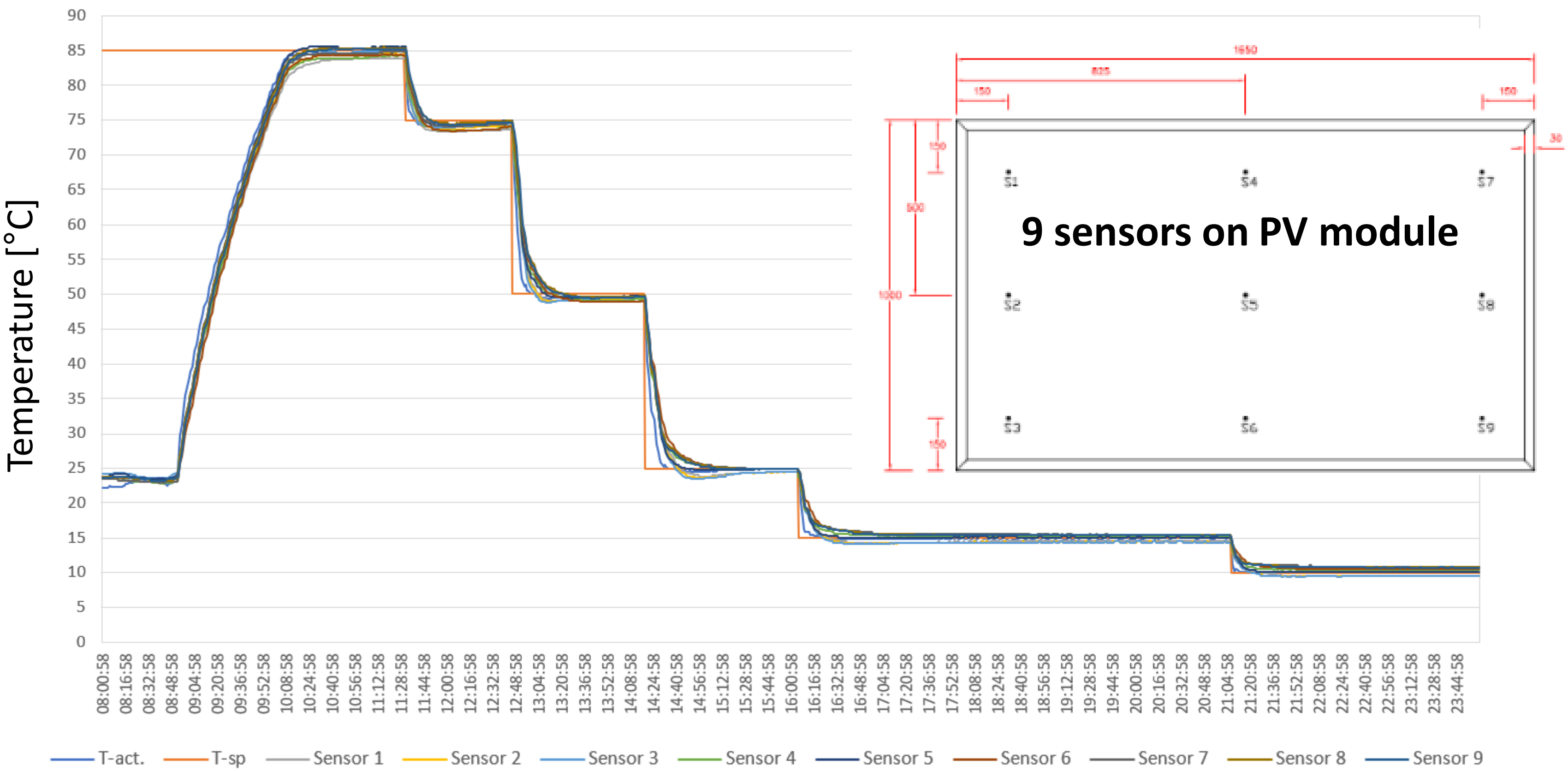
Procedure





The “stable temperatures/dwell” method reduces uncertainty and is therefore recommended by IEC

Procedure



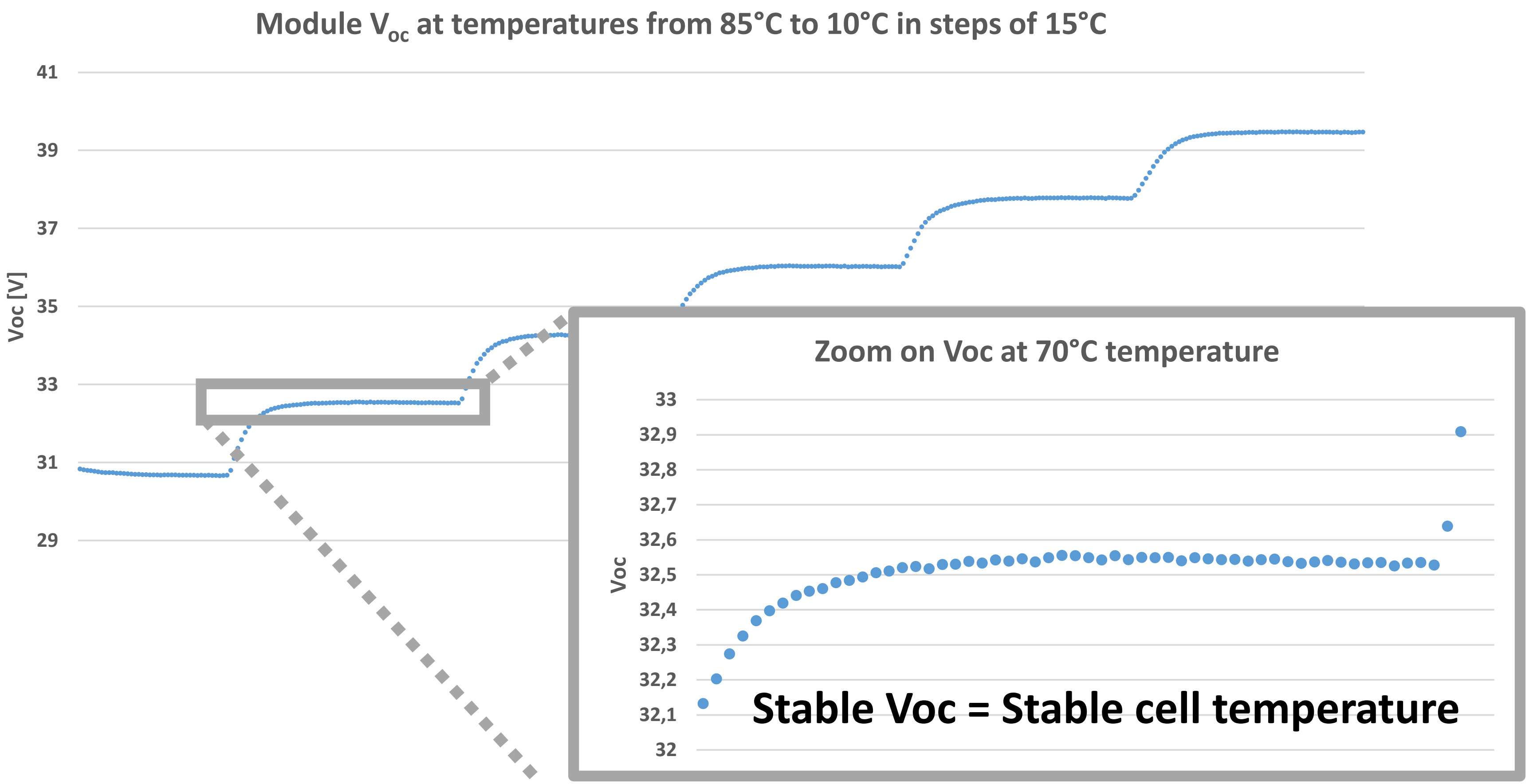
IEC 61215 2016

“At each temperature level of interest, the module temperature should be **stable**”

True cell temperature stability is ensured by continuously monitoring Voc

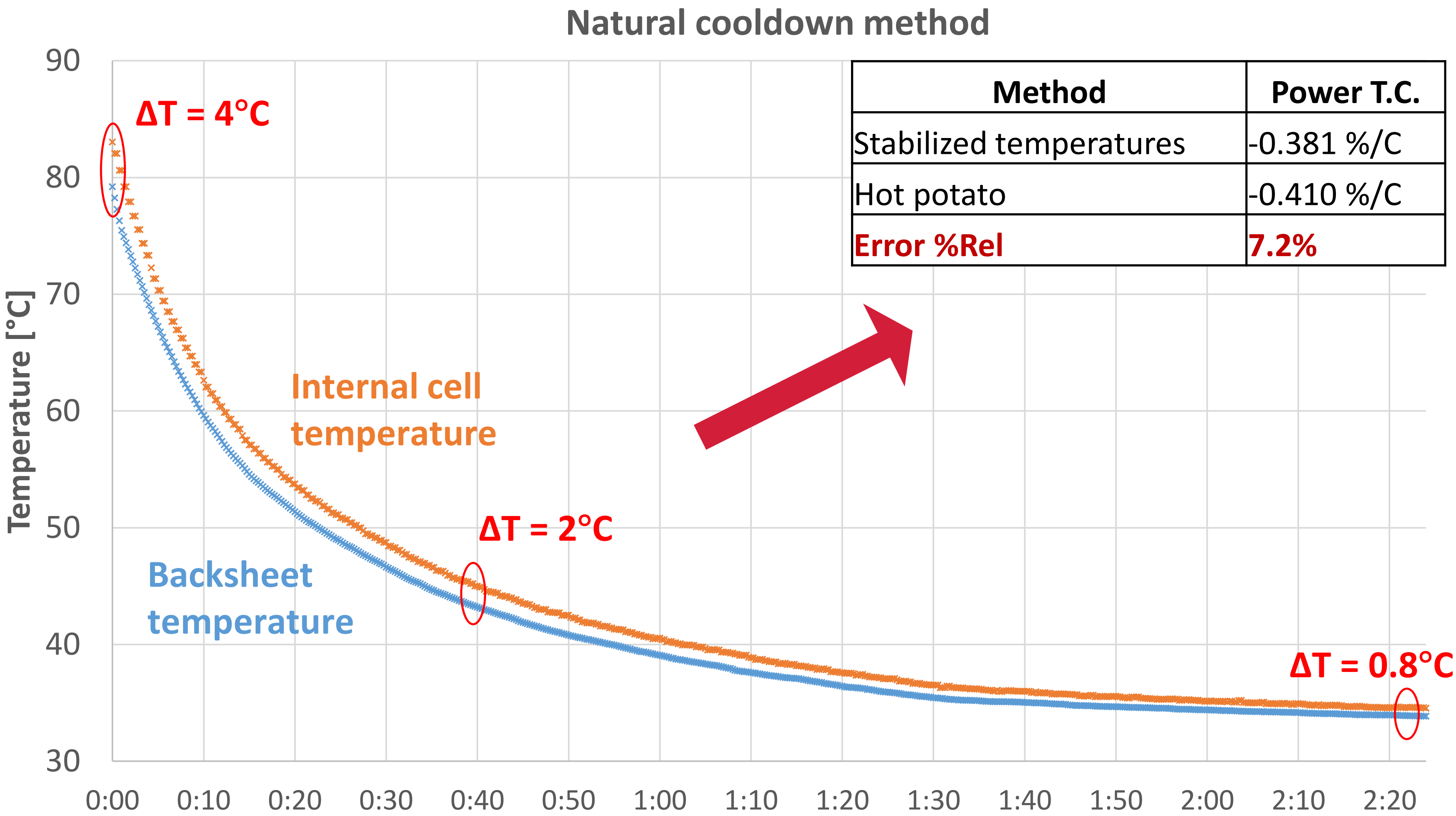
Procedure

IV performance is determined by the true, internal solar cell temperature, which often differs from the temperature of the backside of the module that is measured.



The error caused by measurement during natural cooldown can be up to 7%

Procedure



Method	Power T.C.
Stabilized temperatures	-0.381 %/C
Hot potato	-0.410 %/C
Error %Rel	**7.2%**

Outline

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Temperat ure

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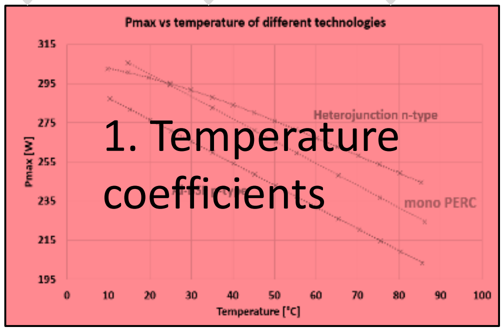
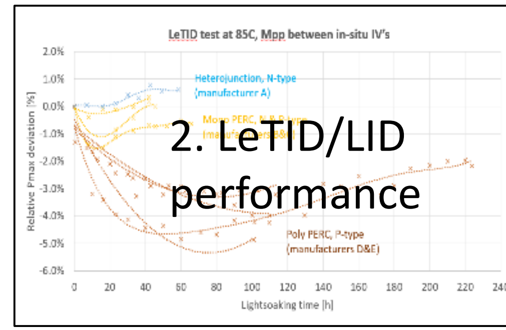
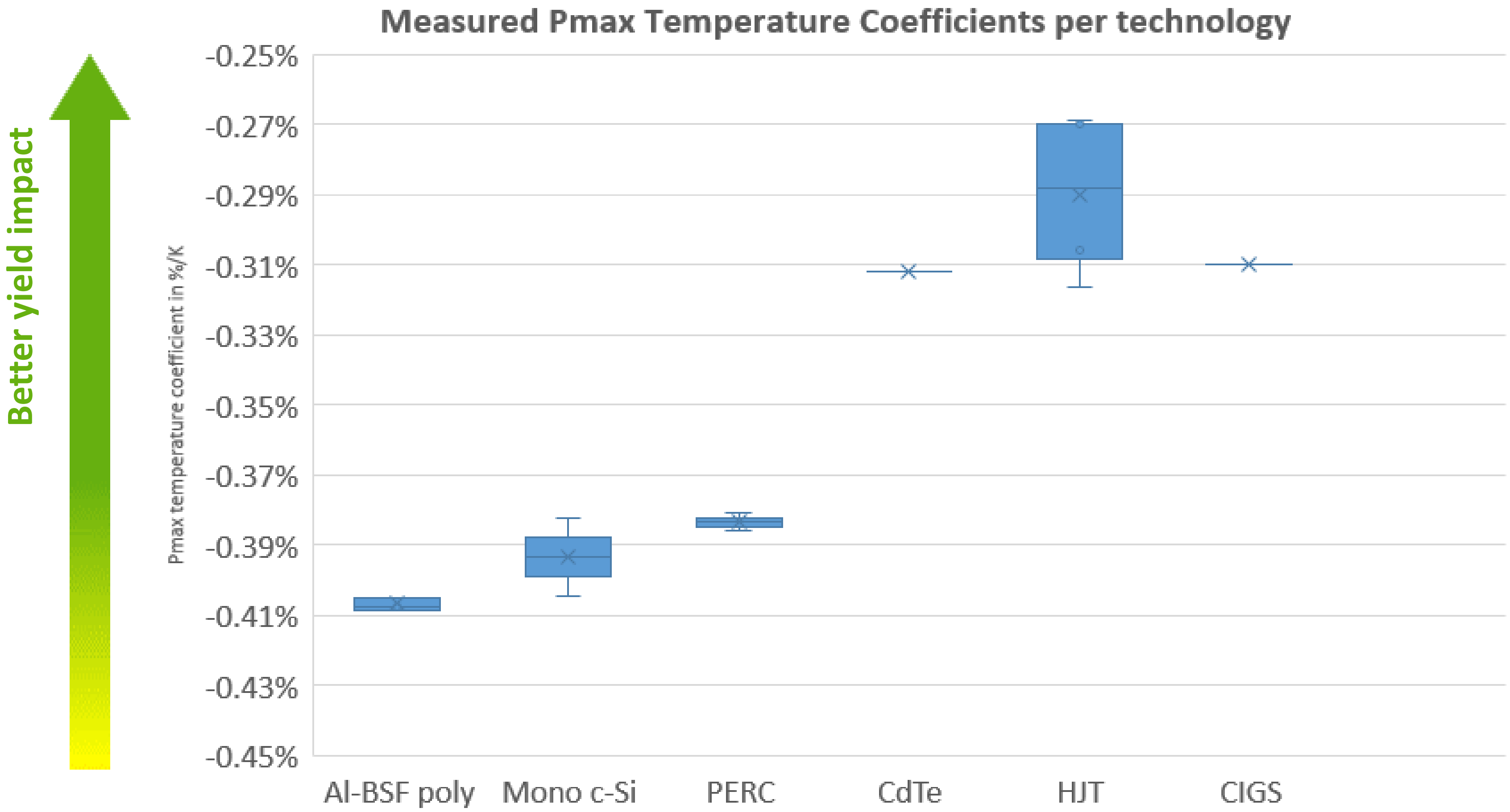


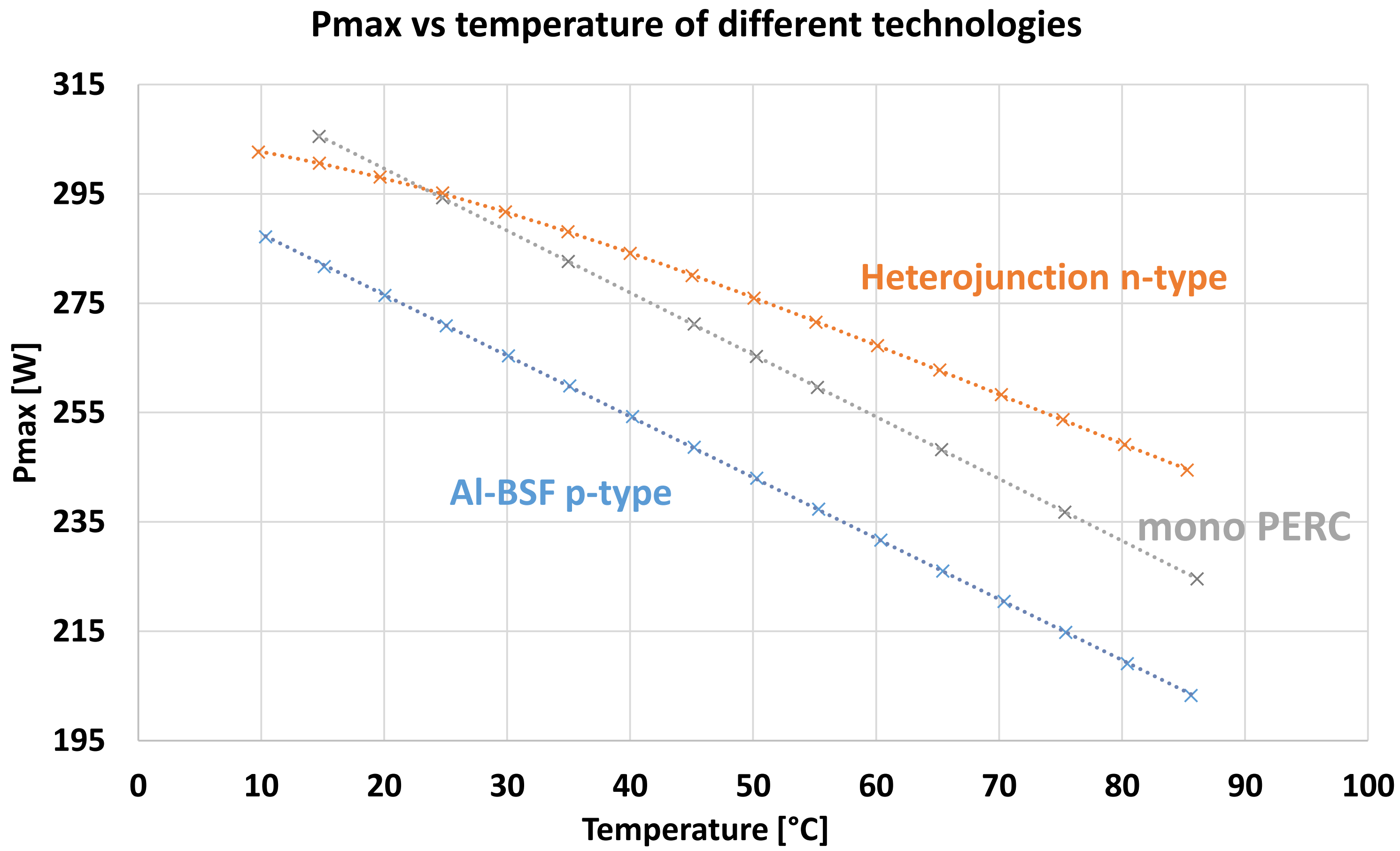


Results: significant differences between PV technologies



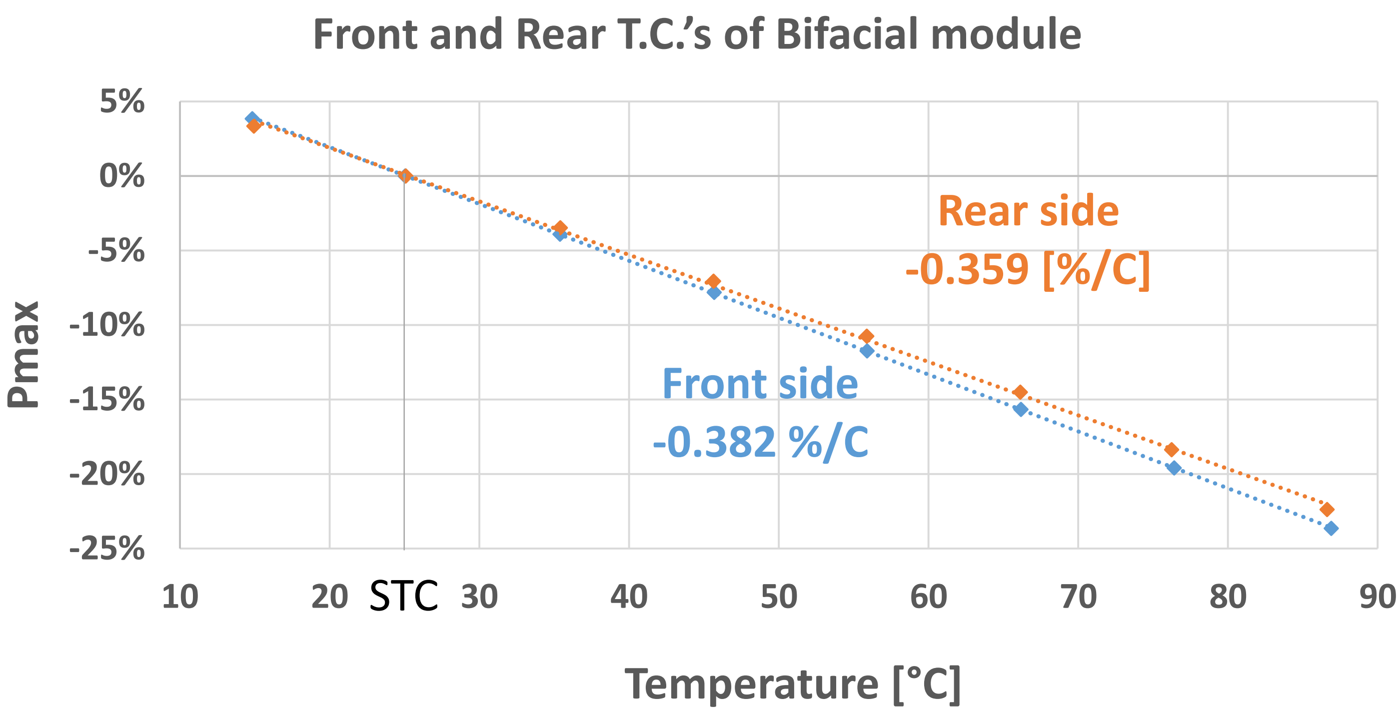
Source: Eternalsun Spire temperature coefficients study on 20 different PV modules, using Temperature Controlled Lab Flasher and HPLS for CdTe

Results: behavior is not always linear and the T.C. dependent on the range of interest



Source: Eternalsun Spire temperature coefficients study on 11 different PV modules, using Temperature Controlled Lab Flasher

Results: front and rear temperature coefficients can differ significantly



	γ - Pmax	δ - FF	β - Voc	α - Isc
Front side	-0.382 %/°C	-0.136 %/°C	-0.285 %/°C	0.028 %/°C
Rear side	-0.359 %/°C	-0.123 %/°C	-0.290 %/°C	0.039 %/°C
Deviation	**6%**	10%	-2%	-39%

Outline

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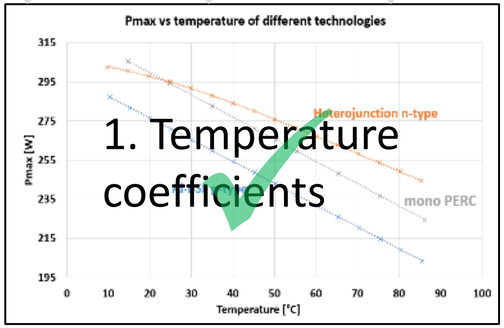
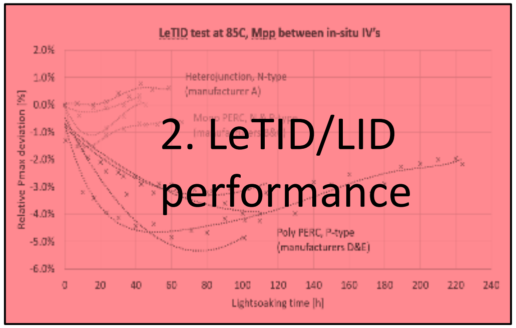
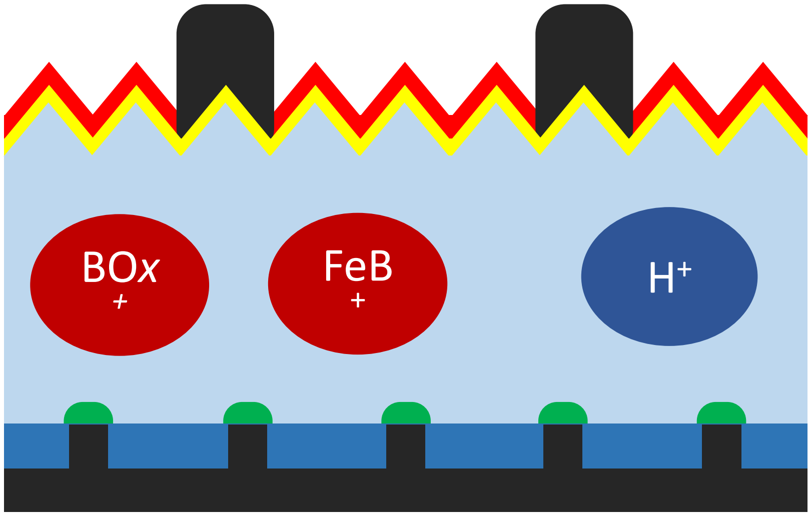




LeTID & LID: the difference



	LID	LeTID
Expected cause	Boron-Oxygen complexes or metal defects	Diffusing (moving) Hydrogen
Mitigation	Add hydrogen	Less hydrogen or temperature treatment
Timescale of effect	10-20 hours	50-500 hours
Temperatures	25-50 °C	60-90 °C
Potential extent of effect	0-3% reported c-Si modules	0-8% reported c-Si modules (commercial)

[1] Chan, Catherine et al. (2017). Modulation of Carrier-Induced Defect Kinetics in Multi-Crystalline Silicon PERC Cells Through Dark Annealing. Solar RRL
[2] Wenham, Stuart (2016). UNSW Advanced Hydrogenation. SPREE Alumni Event presentation. 8th December, 2016

Outline

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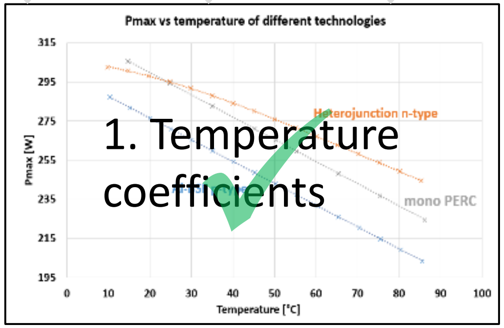
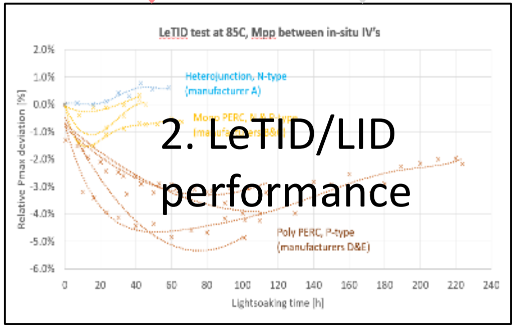
Setup

Procedure



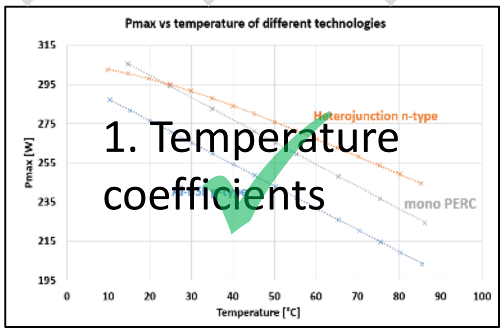


Setup used for LeTID study

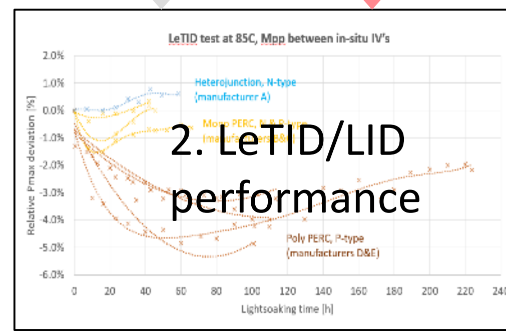
- 1 sun Class AAA+ illumination
- 300 to 1200 nm spectrum
- 2 modules simultaneously
- 20 °C to 100 °C module temperature
- In-situ IV measurements
- Custom IV setpoints (e.g. Mpp) between IV

Outline

Illumination | Temperature | Procedure

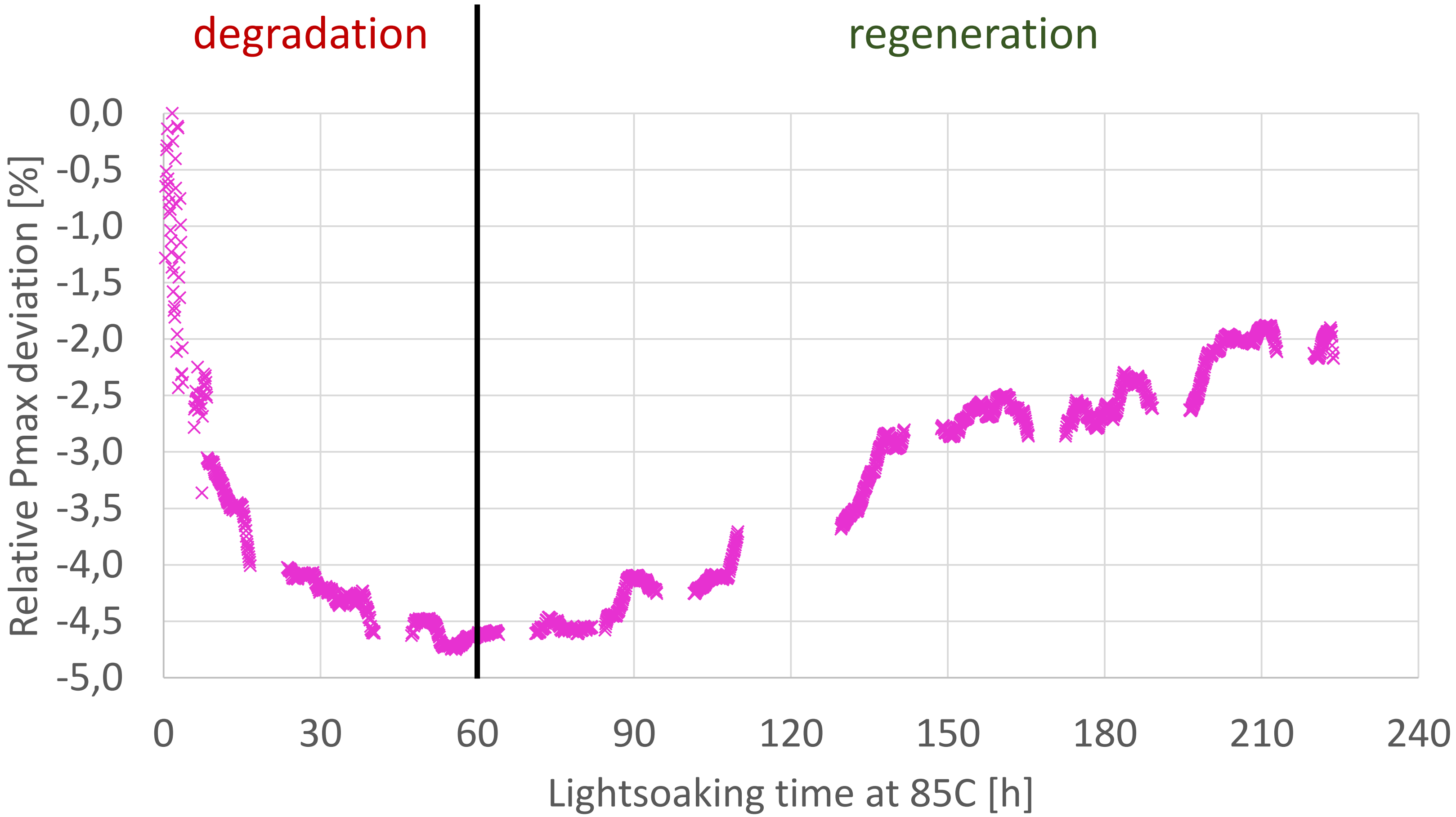


Setup | Procedure



Procedure: 85C, Module in Mpp between In-situ IV’s

Procedure



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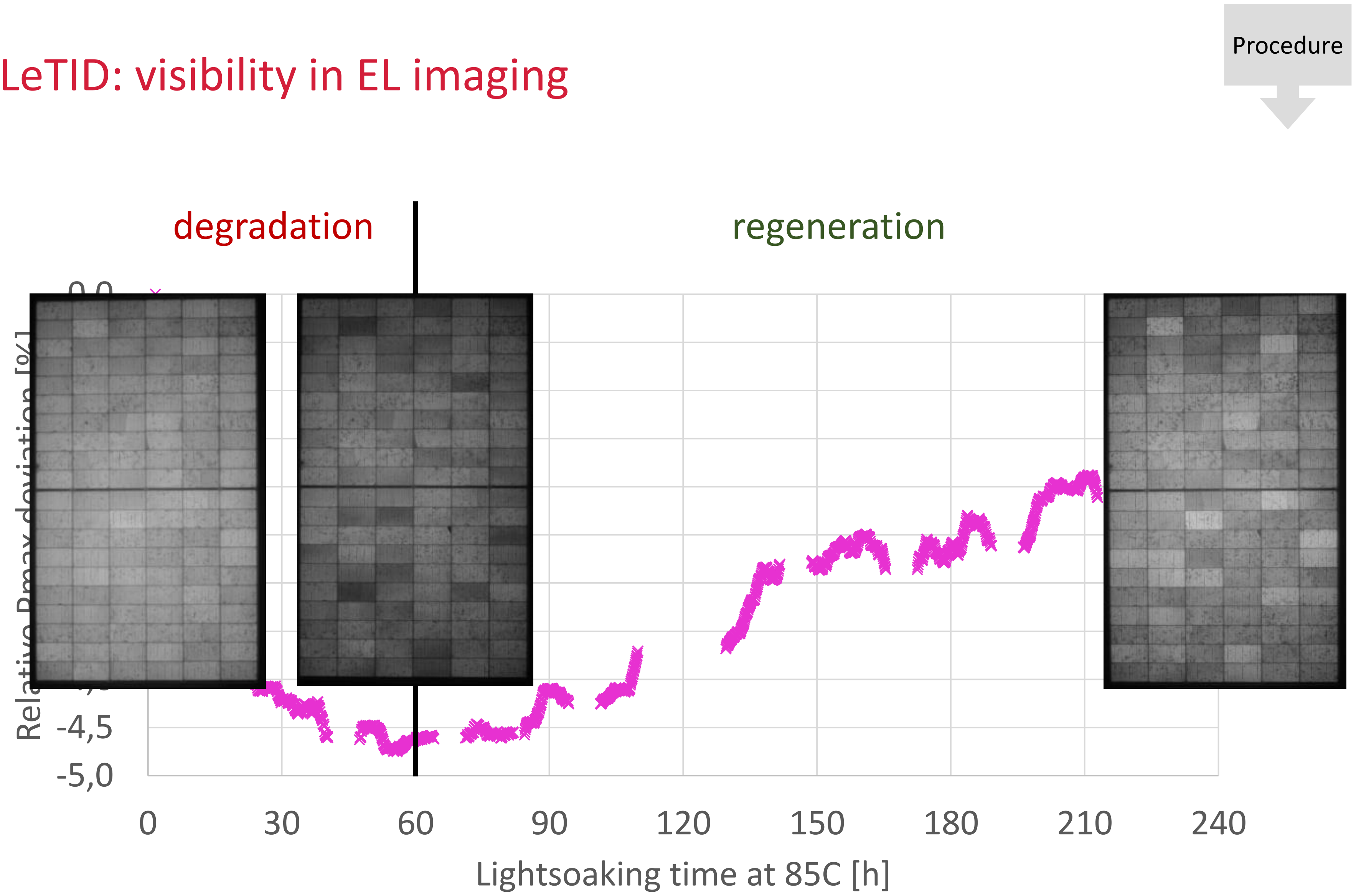
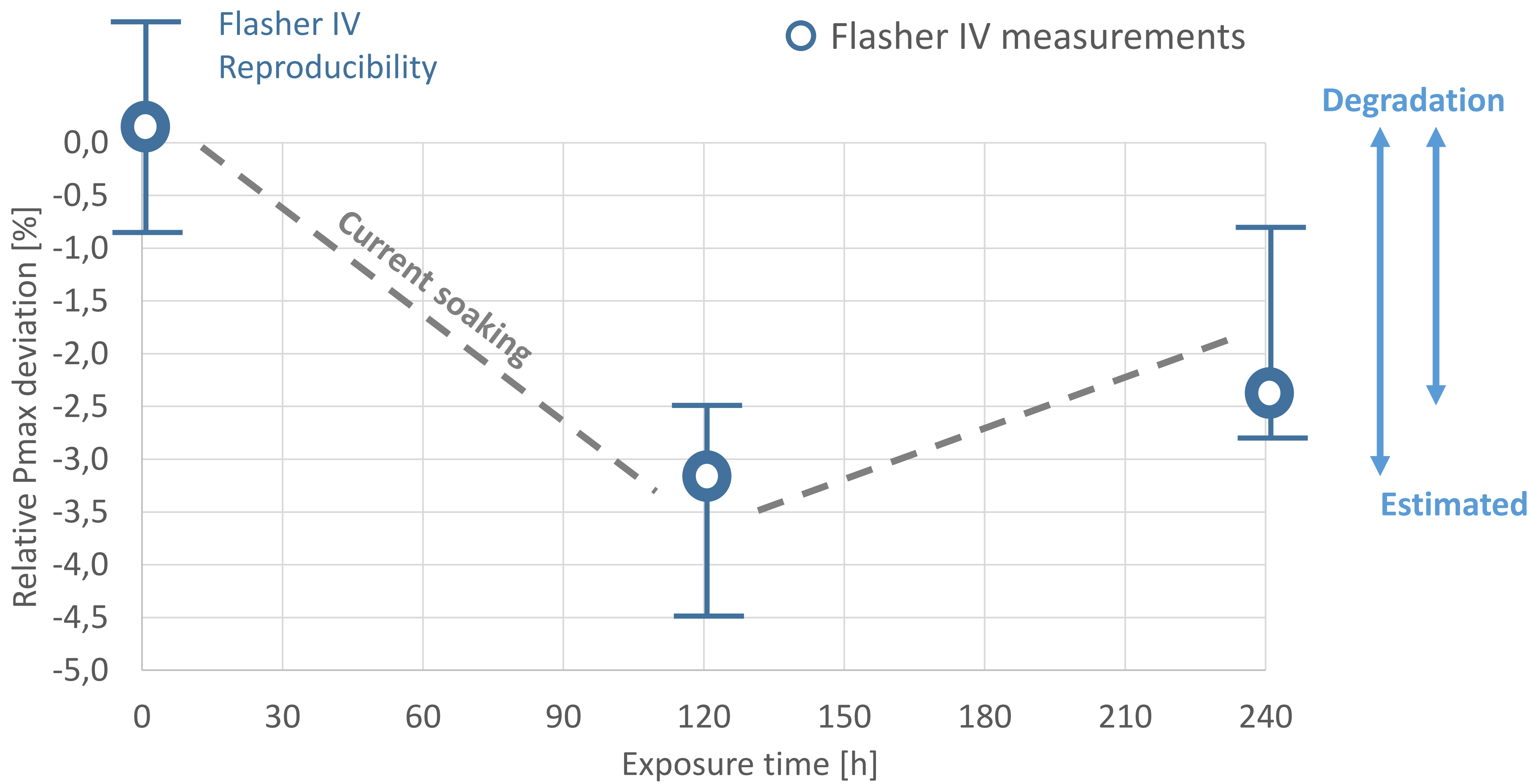
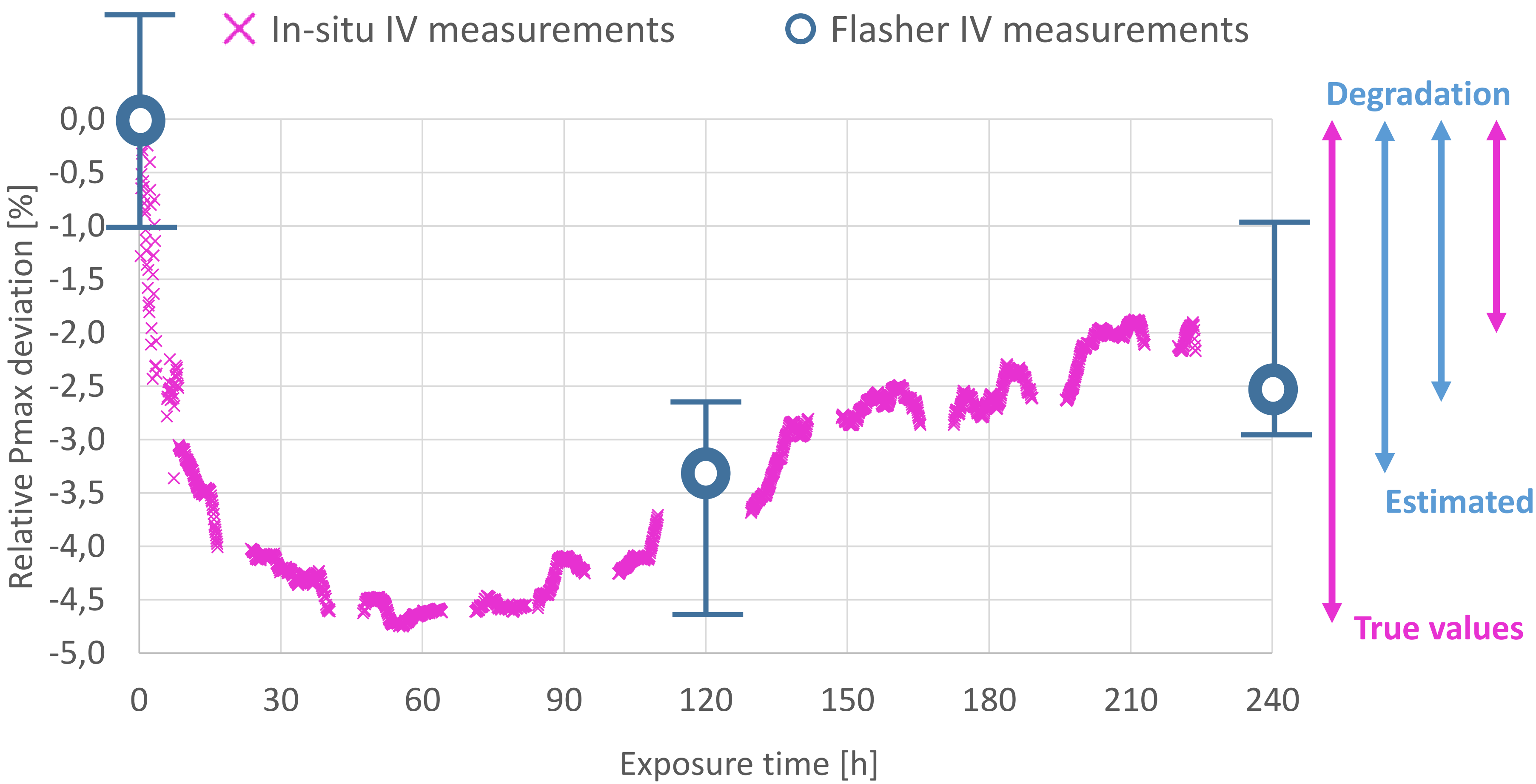
LeTID: visibility in EL imaging



Alternative procedure: current soaking and interval IV flashing



Procedure: Benefit of in-situ IV vs current soaking and flashing



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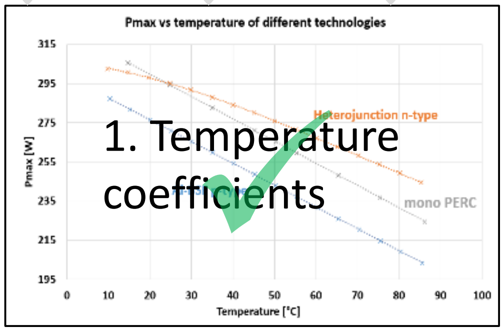
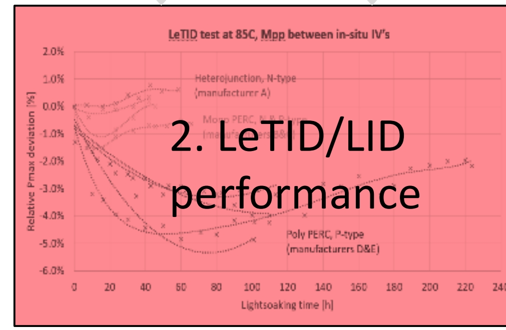
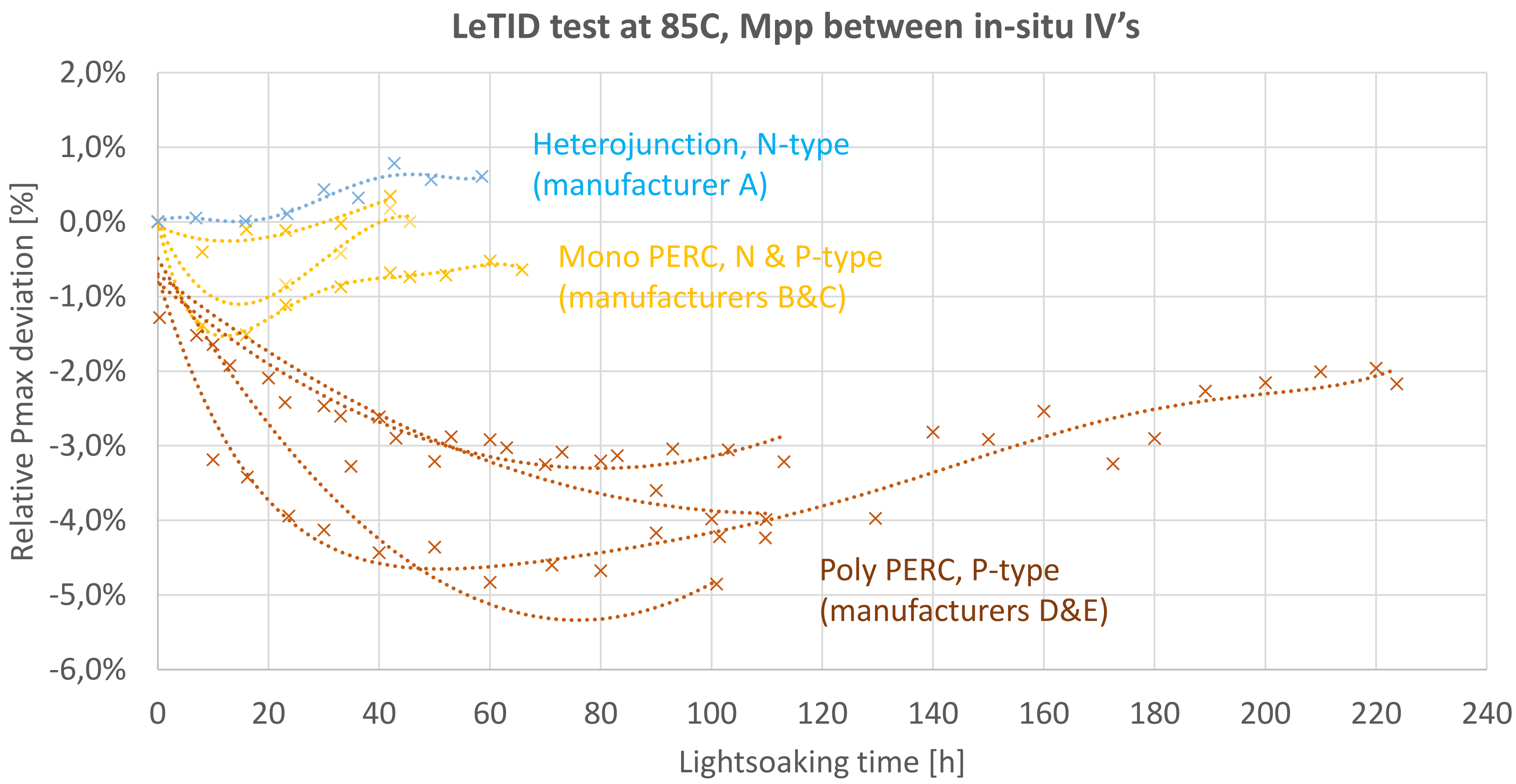


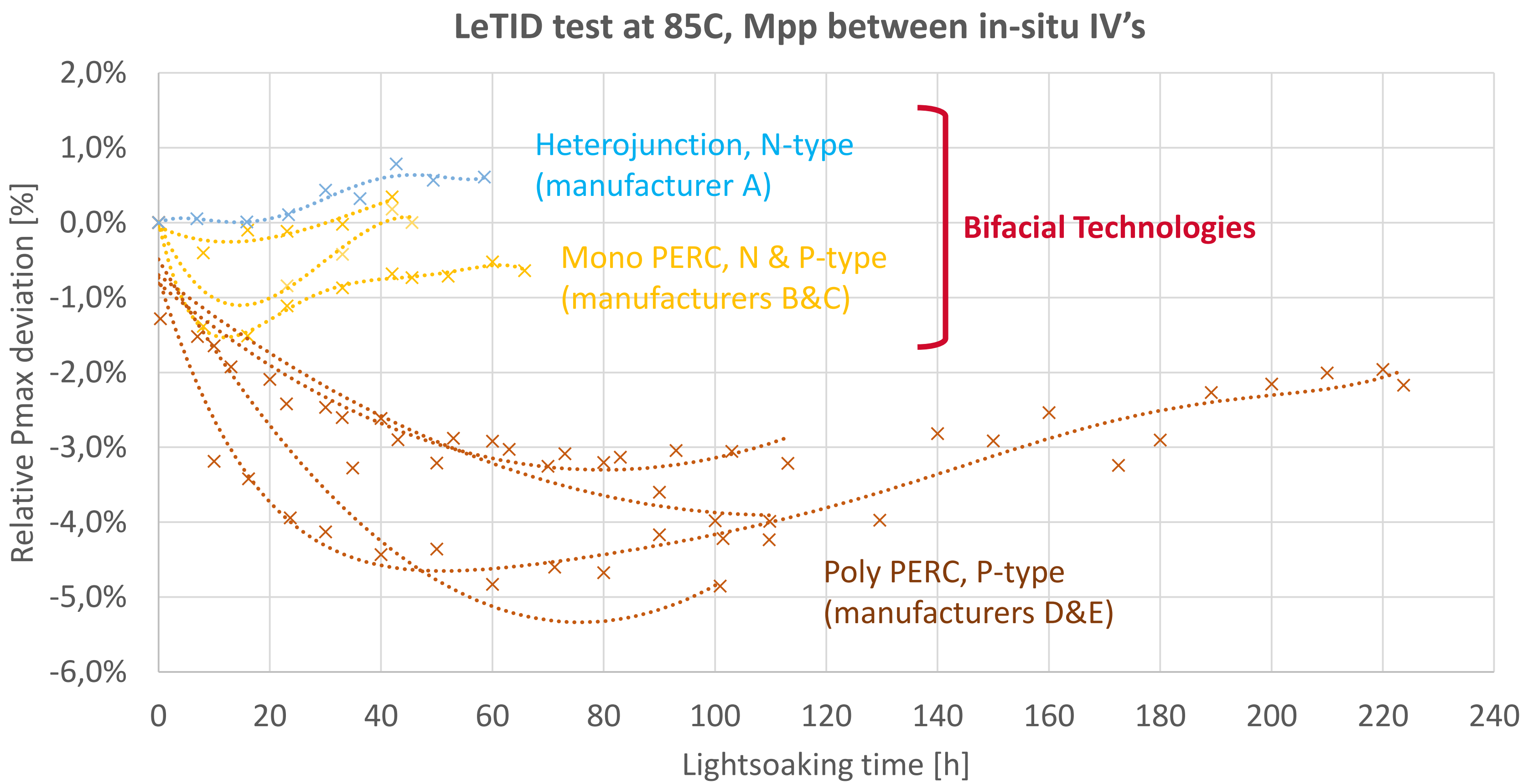


LeTID Results



Source: Eternalsun Spire LeTID study on 14 different PV modules, using High Performance Light Soaker

LeTID Results

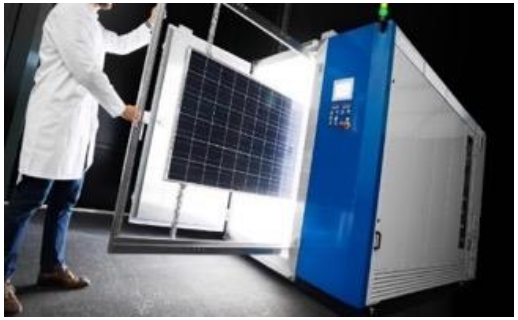


Source: Eternalsun Spire LeTID study on 14 different PV modules, using High Performance Light Soaker

Thank you!

Providing high-end solar testing application knowledge, technology & services

eternal sun



Steady State AAA+ Sun Simulators
Integrated in Climate Chambers

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A+A+A+ 270ms Sun Simulators
Advanced Temperature control

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Rotterdam harbour warehouse