Sensitivities of I-V Parameters in c-Si PV Modules to Hygrothermal Stress

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Introduction & Procedures

Backgrounds

Hygrothermal Stress Test in IEC 61215: 10.13 Damp Heat Test

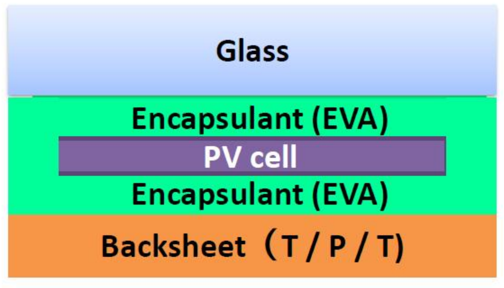
"To determine the ability of the module to withstand the effects of long-term penetration of humidity"

Long-term penetration of humidity (moisture Ingress) induced the power-loss of PV modules by corrosion, delamination, loss of elasticity / adhesion in polymer materials, discoloration, and other failure modes.

To accelerate this testing, we attempt to clarify the failure mechanisms of c-Si PV modules using the recent module components, under the several hygrothermal-stress conditions.

c-Si PV Mini-Module

Mini-Module Architecture



No Frame / No Edge Seal

= practically "No Guard" to Moisture Ingress

Mini-Module (1 cell)

Experimented Hygrothermal Conditions

Conditions	Temp. (°C)	Humidity (% RH)	Equipment
Damp Heat (85/85)	85	85	ESPEC: PL-2KP
Damp Heat (95/95)	95	95	ESPEC: PL-2KP
HAST (105/100)	105	100 (Unsaturated)	ESPEC: EHS-221
HAST (120/100)	120	100 (Unsaturated)	ESPEC: EHS-221

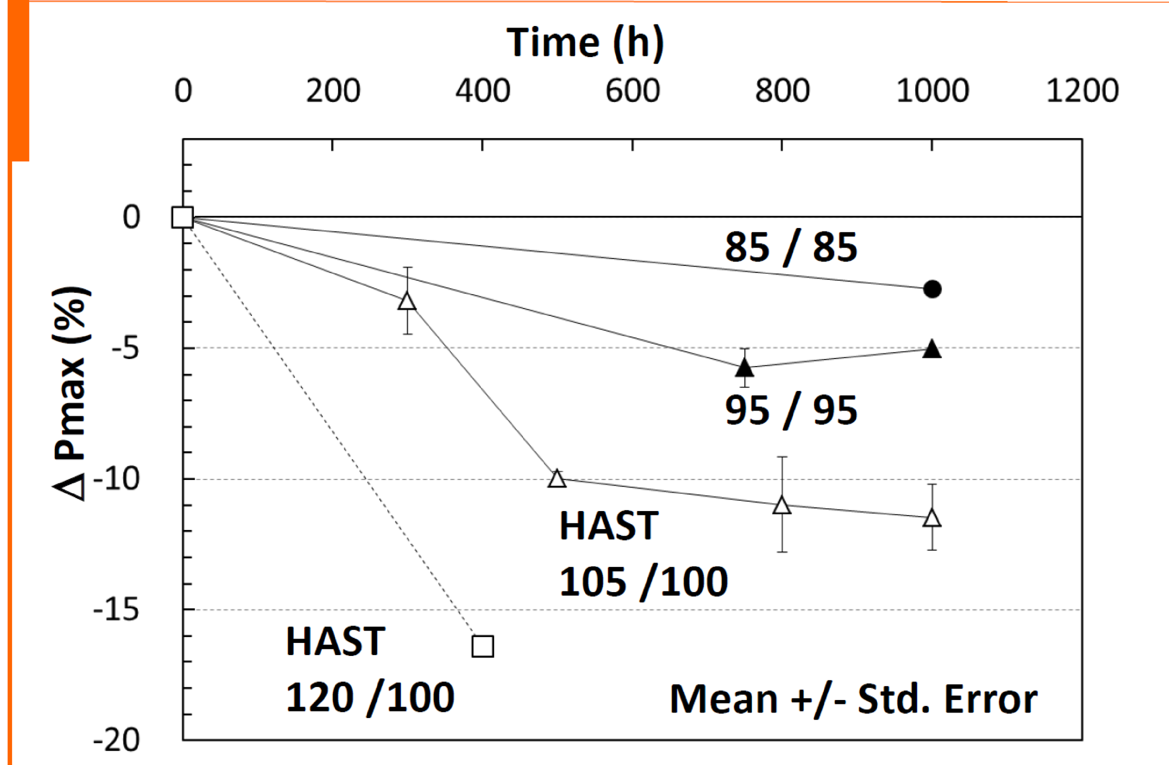
Equipment:
http://www.espec.co.jp/english/products/products01.html
http://www.espec.com/na/applications/solar/

Summary

1. Along with the elevation of hygrothermal stress, Pmax of c-Si PV mini-module was decreased **[Panel 1]**.
2. The reduction of Pmax with elevation of the hygrothermal stress almost correlated with that of FF, but not those of Voc and Isc **[Panel 3]**. Especially, the extreme reduction of Isc (which was observed in the long- term damp heat test) was not detected in our experimental conditions (up to 1,000 h) **[Panel 2]**.
3. By the breakdown of FF reduction to the changes of shunt resistance (Rsh) and series resistance (Rs) **[Panel 4]**, it is confirmed that, in the whole stress conditions, the sensitivity of Rsh-LP (Rsh like parameter = Ipm/Isc) to the change of hygrothermal stress was about 2.5-folds against that of Rs-LP (Rs like parameter = Vpm/Voc) **[Panel 5, 6, 7]**.

   However, in the low-stress conditions, the reduction of Rs-LP was about 2.5-folds against that of Rsh-LP **[Panel 5, 6, 7]**. The reduction of Rs-LP in the high-stress conditions was maintained virtually constant, although Rsh-LP was decreased with the applied stresses **[Panel 5,6, 7]**. These results suggest that the failure modes differ between in the low- and high-stress conditions **[Panel 8]**.
4. HAST (120 °C/100% RH) induced the drastic failure which was not observed in the other conditions **[Panel 9,10]**.

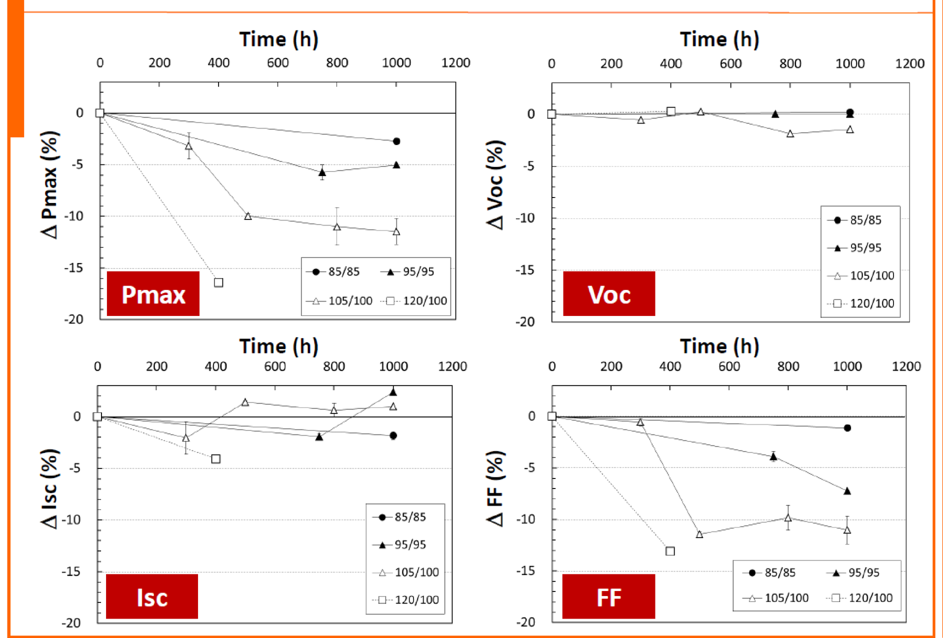
Power Loss with Hygrothermal Stress — Panel 1



Experimental Results

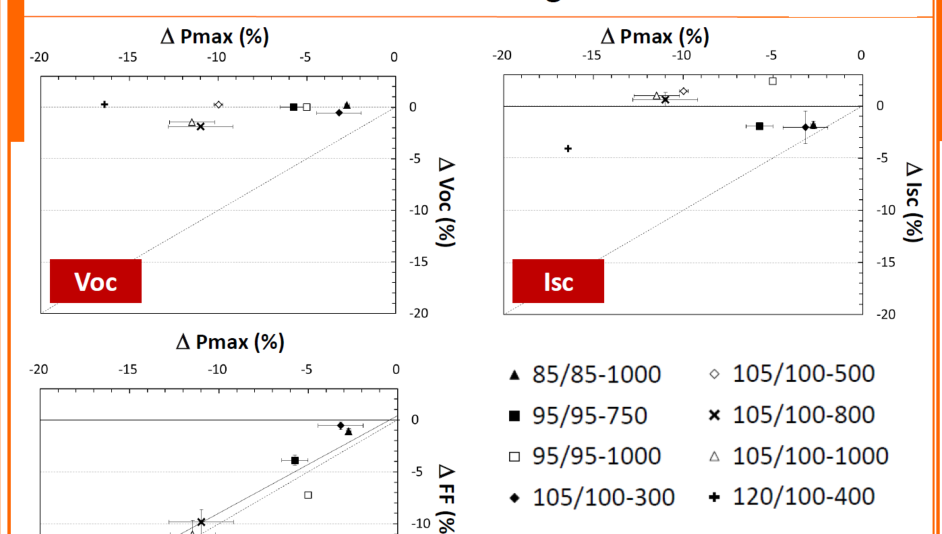
Panel 2

Effect of Hygrothermal Stress on I-V Parameters



Panel 3

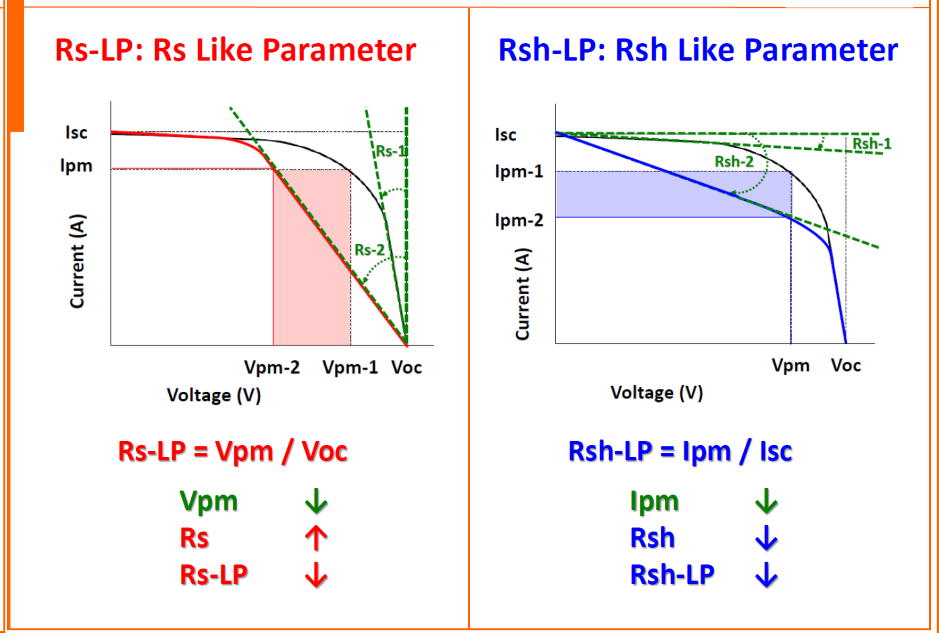
Correlation of I-V Parameter Changes with Power Loss



Δ Pmax = 0.938 Δ FF + 0.410 (R = 0.921)

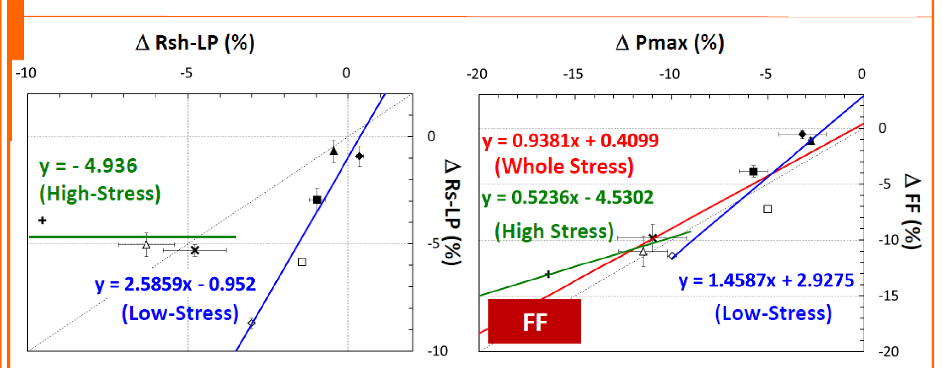
Panel 4

Rs-Like Parameter (Rs-LP) & Rsh-Like Parameter (Rsh-LP)



Panel 5

Correlation between Rsh-LP and Rs-LP

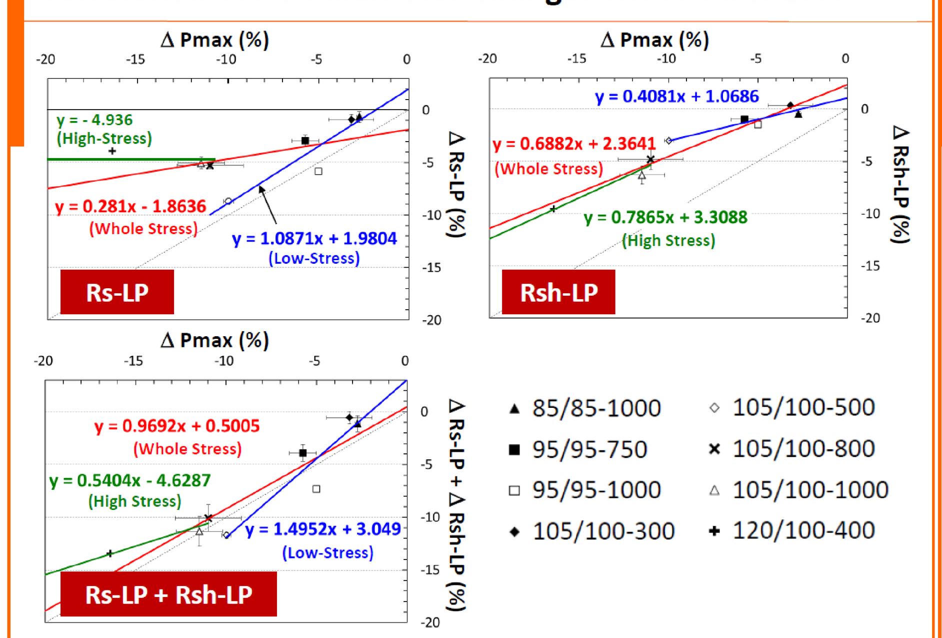


Low-Stress Condition:
(85/85-1000, 95/95-750, 95/95-1000, 105/100-300, 105/100-500)
The reduction of Rs-LP was about 2.5-folds against that of Rsh-LP.

High-Stress Condition:
(105/100-800, 105/100-1000, 120/100-400)
The reduction of Rs-LP was maintained virtually constant.

Panel 6

Correlation of I-V Parameter Changes with Power Loss



Panel 7

Correlation of I-V Parameter Changes with Power Loss (Δ Pmax)

Stress Condition	Independent Variables	Slope	Intercept	Correlation Coeff. (R)
Whole	Δ FF	0.938	0.410	0.921
	Δ Rs-LP	0.281	-1.864	0.504
	Δ Rsh-LP	0.688	2.364	0.970
	Δ Rs-LP + Δ Rsh-LP	0.969	0.501	0.923
Low-Stress	Δ FF	1.459	2.928	0.925
	Δ Rs-LP	1.087	1.980	0.912
	Δ Rsh-LP	0.408	1.069	0.932
	Δ Rs-LP + Δ Rsh-LP	1.500	3.049	0.926
High-Stress	Δ FF	0.524	-4.530	0.958
	Δ Rs-LP	0 (-0.246)	-4.936 (-7.938)	- (0.996)
	Δ Rsh-LP	0.787	3.309	0.972
	Δ Rs-LP + Δ Rsh-LP	0.540	-4.629	0.955

Panel 8

Correlation of I-V Parameter Changes with Power Loss (Δ Pmax)

Whole Stress Condition:

The sensitivity of Rsh-LP to the change of hygrothermal stress was about 2.5-folds against that of Rs-LP.
However, ΔRs-LP did not correlated with Δ Pmax.

Low-Stress Condition:

Δ Pmax was dominantly decreased by the reduction of Δ Rs-LP.
Δ Rsh-LP also contributed to the reduction of Pmax (about 30%).
By the partitioning of stress conditions, Δ Rs-LP and Δ Rsh-LP sufficiently correlated with Δ Pmax.

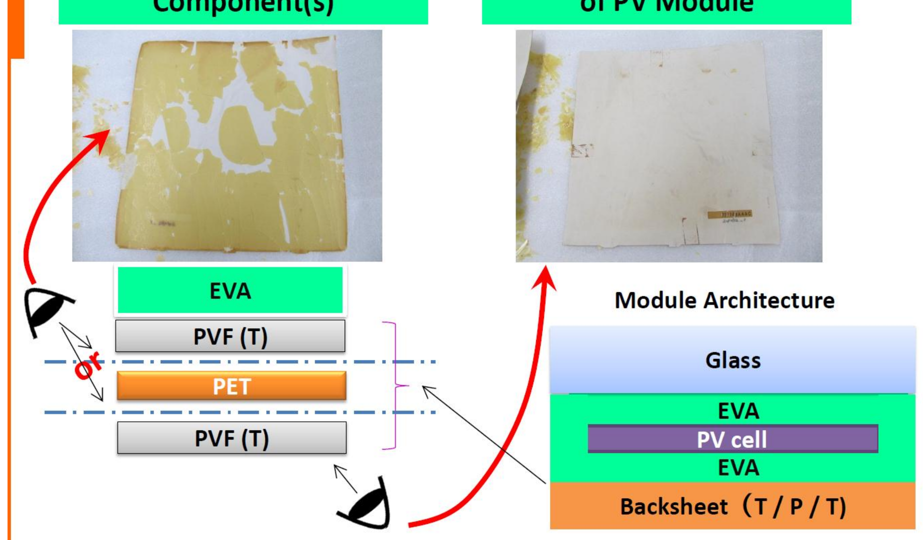
High-Stress Condition:

Δ Pmax was dominantly decreased by the reduction of Δ Rsh-LP.
Δ Rs-LP did not contribute to the reduction of Pmax, although the reduction of Pmax depended on the reduction of Δ Rsh-LP.
The combination of Δ Rs-LP and Δ Rsh-LP also completely correlated with Δ Pmax.

Panel 9

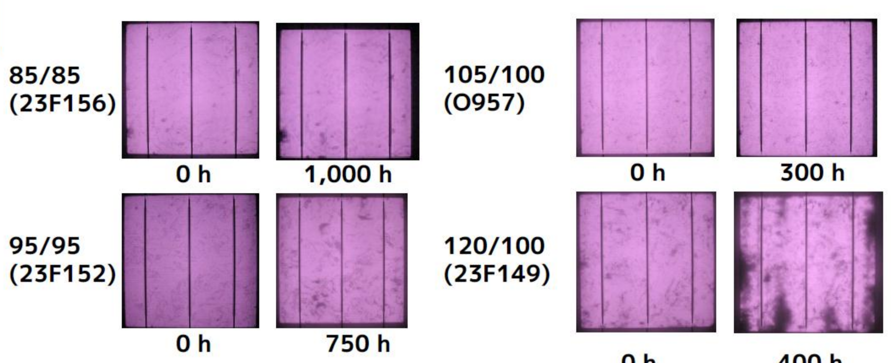
Artificial Degradation in HAST: 120 / 100 (200 h)

Delamination of Backsheet Component(s) | View from Backside of PV Module



Panel 10

EL Image

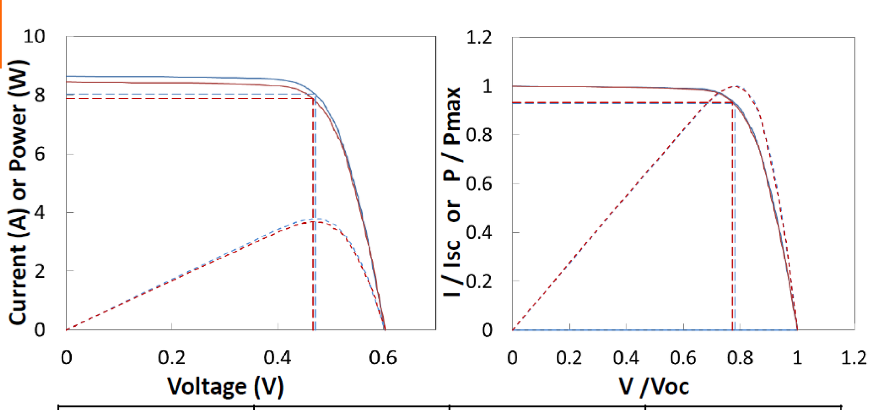


Except in the HAST condition (120 / 100), the defect in EL images was not detected in all cases.

Appendix 1

I-V Characteristics in PV Mini-Module

85℃ / 85% RH (— : Initial, — : 1,000 h)

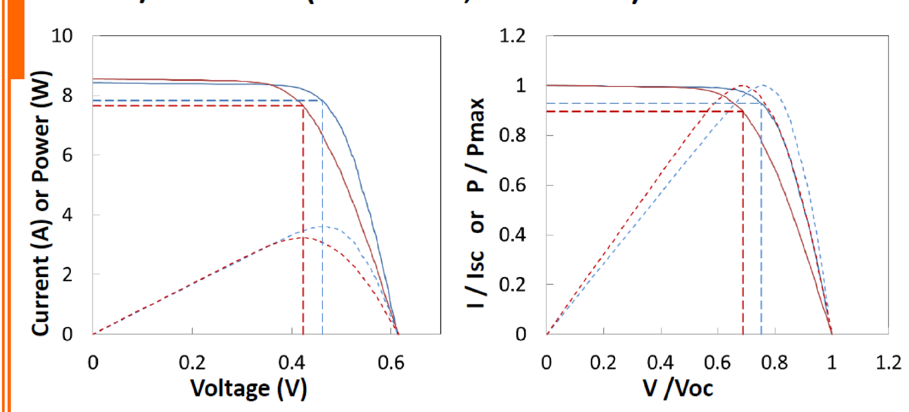


Δ Pmax	- 2.70 %	Δ Vpm	- 1.04 %
Δ Voc	0.19 %	Δ Ipm	- 1.69 %
Δ Isc	- 2.27 %	Δ Rs-LP	- 1.22 %
Δ FF	- 0.64 %	Δ Rsh-LP	0.59%

Appendix 2

I-V Characteristics in PV Mini-Module

105℃ / 100% RH (— : Initial, — : 500 h)

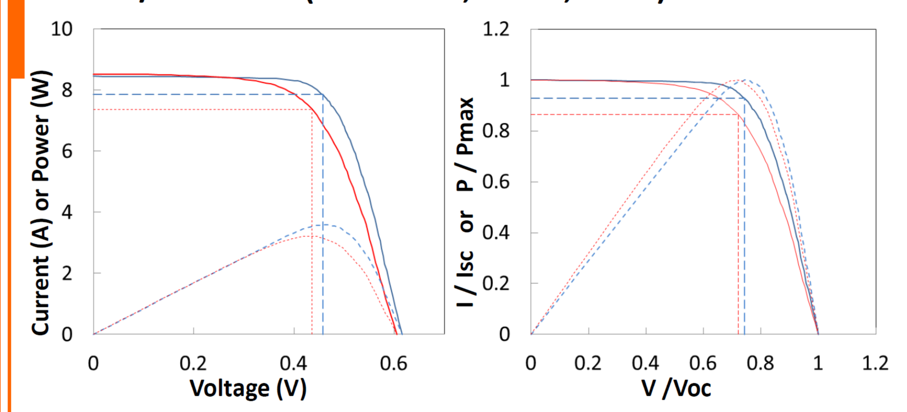


Δ Pmax	-10.35 %	Δ Vpm	- 8.54 %
Δ Voc	0.25 %	Δ Ipm	- 2.07 %
Δ Isc	1.54 %	Δ Rs-LP	- 8.69 %
Δ FF	-11.94 %	Δ Rsh-LP	- 3.56 %

Appendix 3

I-V Characteristics in PV Modules

105℃ / 100% RH (— : Initial, — : 1,000 h)



Δ Pmax	- 10.53 %	Δ Vpm	- 4.69 %
Δ Voc	- 1.73 %	Δ Ipm	- 6.13 %
Δ Isc	0.87 %	Δ Rs-LP	- 3.01%
Δ FF	- 9.74 %	Δ Rsh-LP	- 6.94 %

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