

Evaluation of a cleaning robot on PV modules regarding its influence on electrical and optical module properties

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Task description

- To evaluate mechanical influences on photovoltaic (PV) modules, electrical and optical module properties are determined and compared before and after mechanical stress. This is done by power measurement and electroluminescence imaging - both under STC and low light conditions.
- For the evaluation of the influence of the PV cleaning robot, corresponding test modules are characterized accordingly before and after each test run of the cleaning robot and compared for evaluation.
- A corresponding horizontal test setup was installed for flat lying PV modules on a thin mounting structure over the ground to be passed over with the cleaning robot L1 including brushes and activated water system.
- After initial module characterization, the cleaning robot makes 50 cleaning passes over the modules. The modules are characterized again, and the robot makes another 150 cleaning passes with subsequent final characterization of the modules.
- Performance measurements and EL images are analyzed for comparative evaluation of the influence of the cleaning robot.



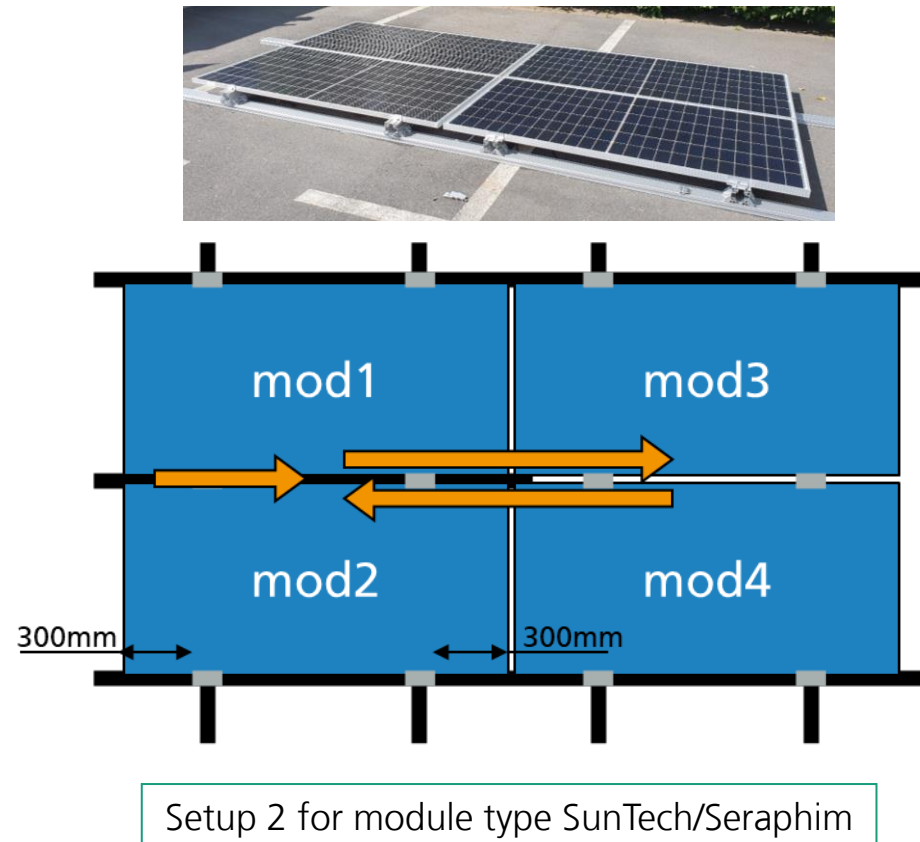
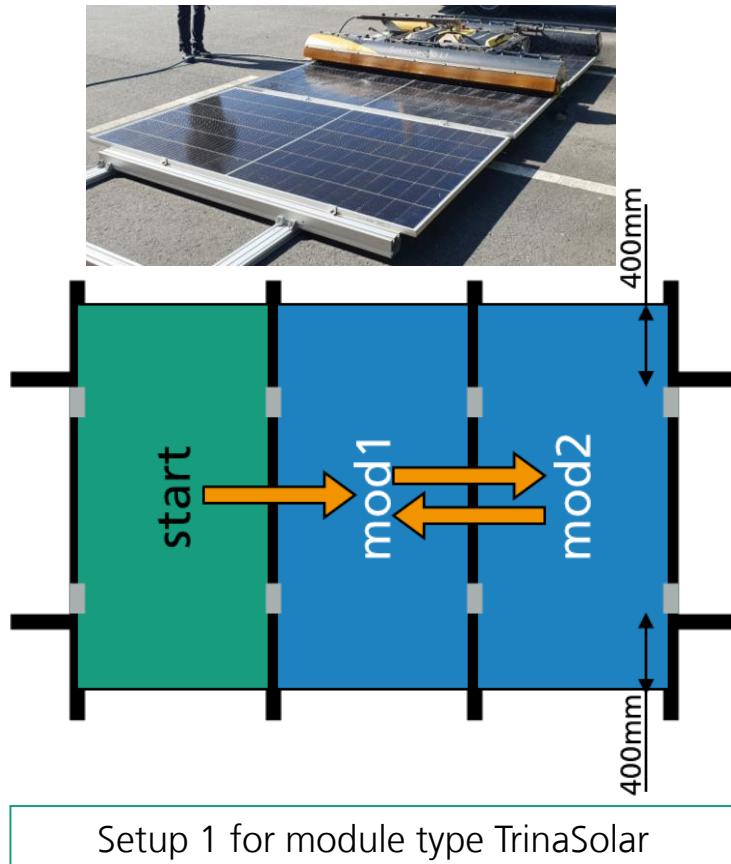
Sample overview

- Test samples (PV modules) brought by SolarCleanO on 27.08.2024

#	CSP-Number	Type	Comment	Used for test / measurement
1	CSP_SolOur_1_P01	TrinaSolar TSM-650	dirty and some minor dark spots in EL	yes
2	CSP_SolOur_1_P02	TrinaSolar TSM-650	some minor dark spots in EL	yes
3	CSP_SolOur_1_P03	Suntech STP410S-A72	some small cell cracks	yes
4	CSP_SolOur_1_P04	TrinaSolar TSM-650	some minor dark spots in EL	yes
5	CSP_SolOur_1_P05	Suntech STP410S-A72	some small cell cracks	yes
6	CSP_SolOur_1_P06	Suntech STP410S-A72	large cell cracks	no
7	CSP_BeGro_2_P03	Seraphim SRP-400-BMA-HV	Supplied by Fraunhofer, no cracks, no noticeable defects	yes
8	CSP_BeGro_2_P04	Seraphim SRP-400-BMA-HV	Supplied by Fraunhofer, no cracks, no noticeable defects	yes

Test setup

- The two different module types from SolarCleanO for testing required different test setups for module mounting (incl. clamp positions)



Module characterization methods

Performance measurement and electroluminescence

Equipment: Halm elektronik Solar Simulator cetisPV-Moduletest4

Parameter:

- STC (standard test conditions): $(25 \pm 1)^\circ\text{C}$, irradiation 1000 W/m^2 , Spectrum AM1.5
- Flash length : 85 ms
- Measurements are made without spectral mismatch correction
- Integrated EL measurement near I_{SC}

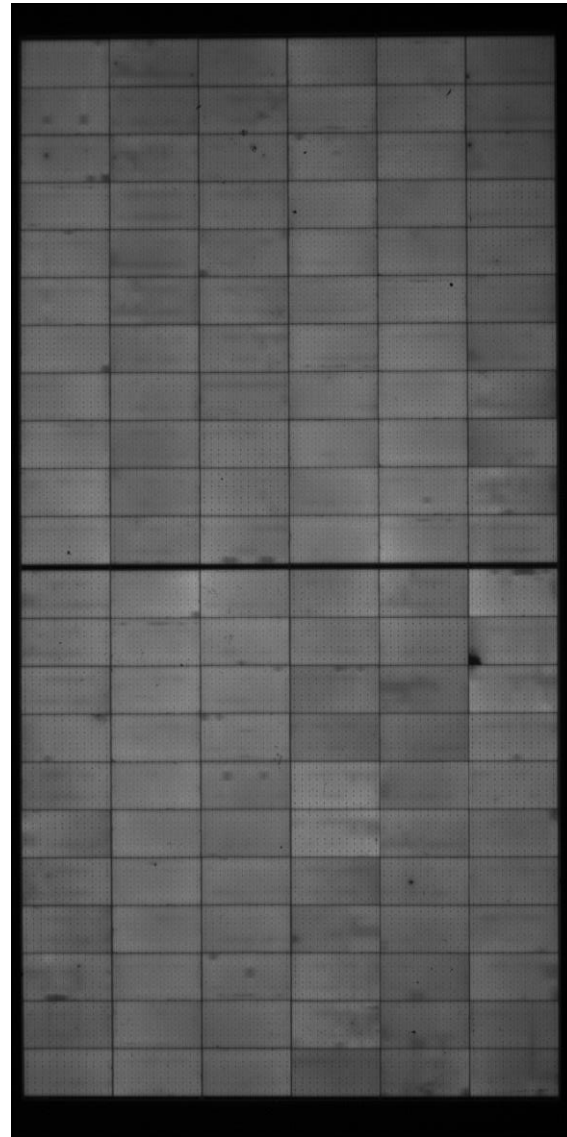
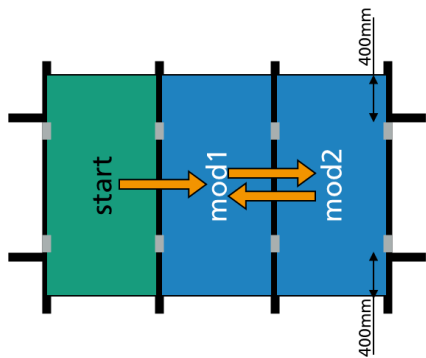
Technical Specifications	
Homogeneity	class A+ ($<1 \%$)
Spectral match	class A+ (0.875 - 1.125)
Stability over time	class A+ ($<0.8 \%$)
max. module size	$2700 \times 1700 \text{ mm}^2$
Flash length	10 – 145 ms
Irradiation	$100 \dots 1300 \text{ W/m}^2$ (low irradiance with cetisPV-NDF2)
Repeatability	$< 0.15 \%$ für P_{mpp}
Measurement uncertainty without reference module	2.0 %



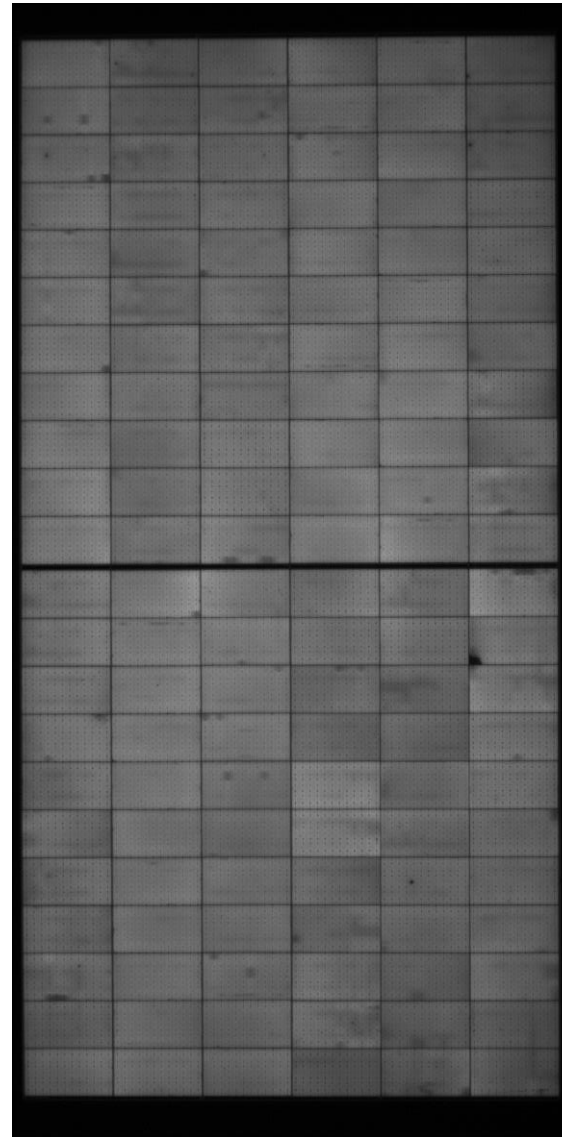
Results

Electroluminescence

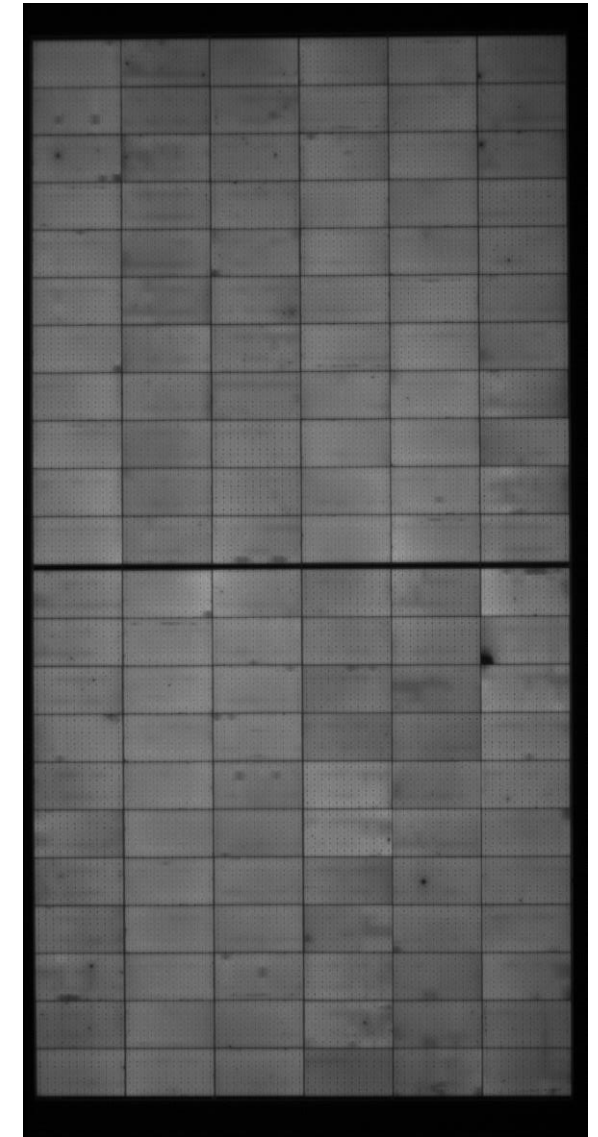
- CSP_SolOur_1_P01
 - No significant changes detected like:
 - additional cracks
 - crack growth



initial



50 passes

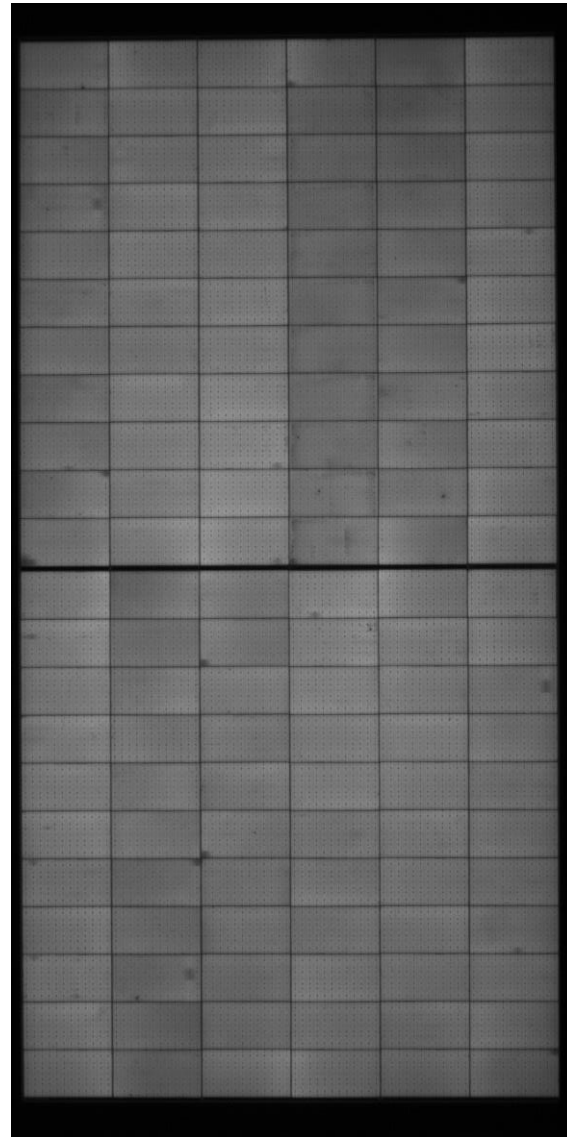
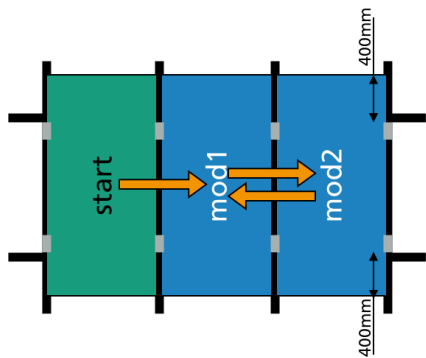


200 passes

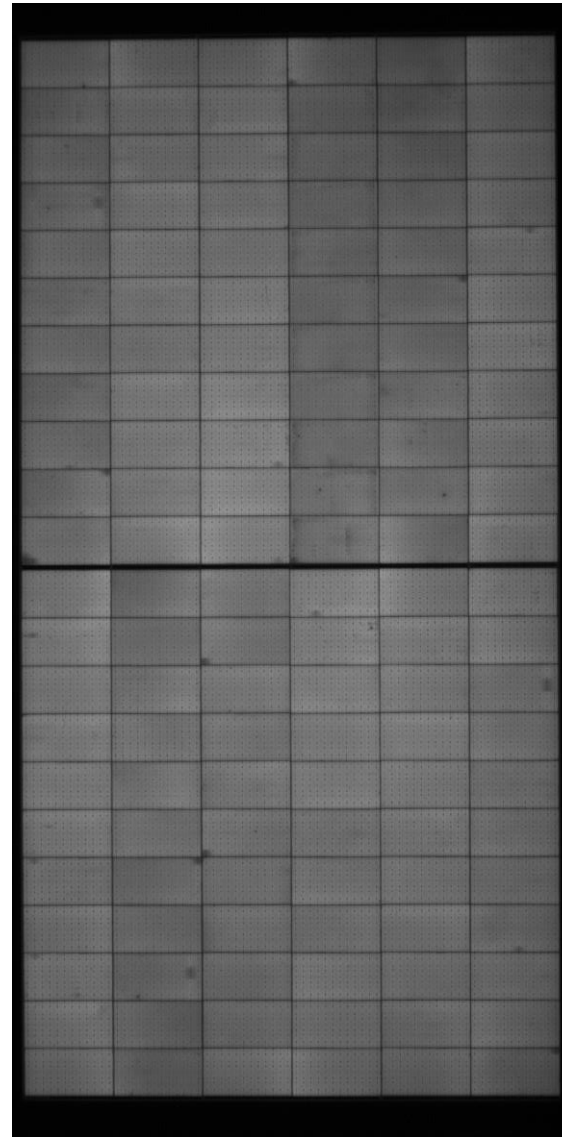
Results

Electroluminescence

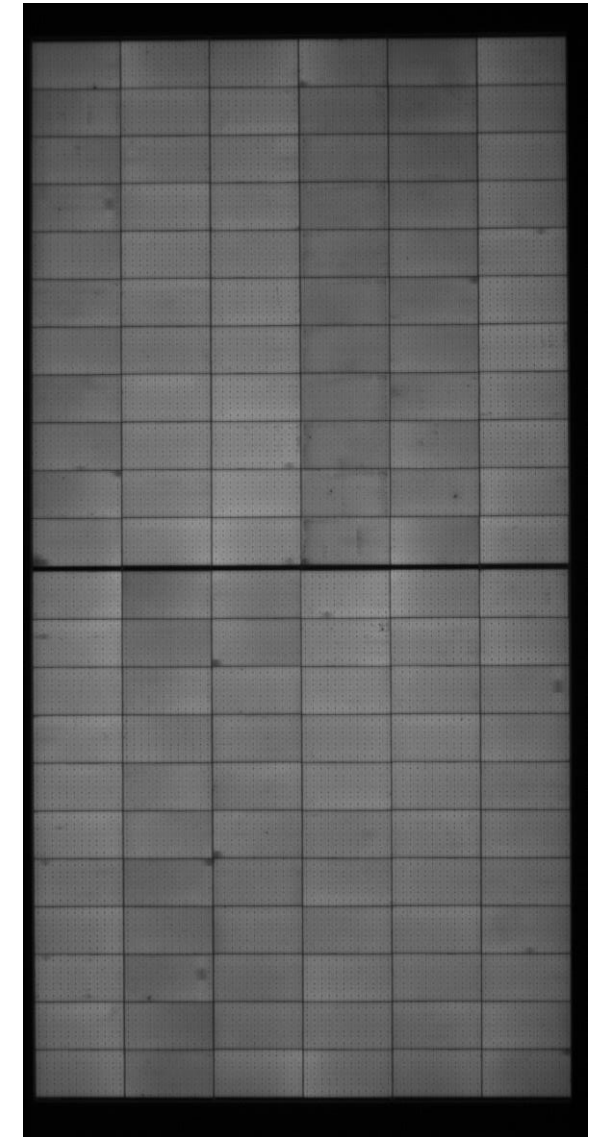
- CSP_SolOur_1_P04
 - No significant changes detected like:
 - additional cracks
 - crack growth



initial



50 passes

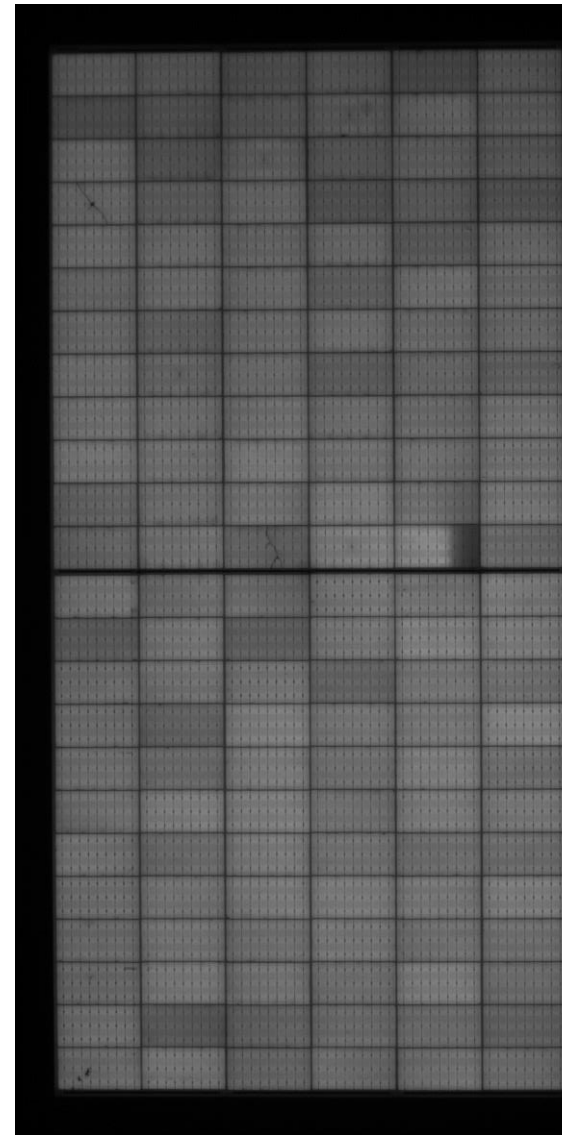
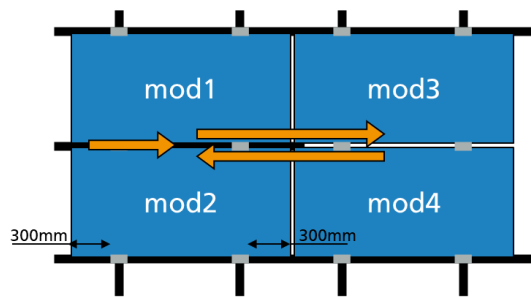


200 passes

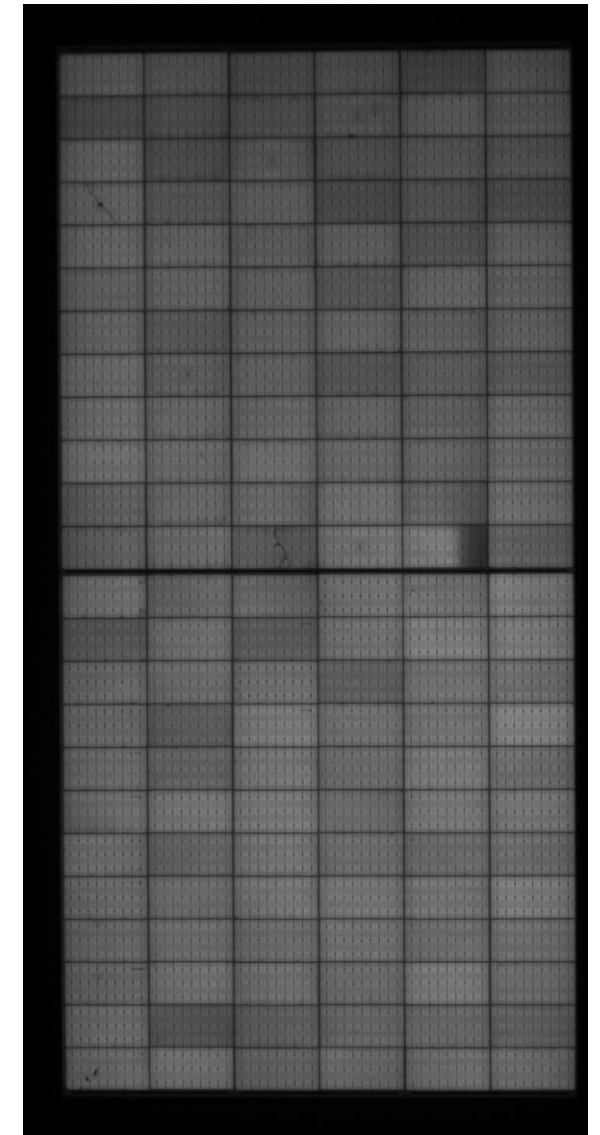
Results

Electroluminescence

- CSP_SolOur_1_P03
 - minor crack growth detected (pre-existing crack)
 - no additional cracks detected



initial

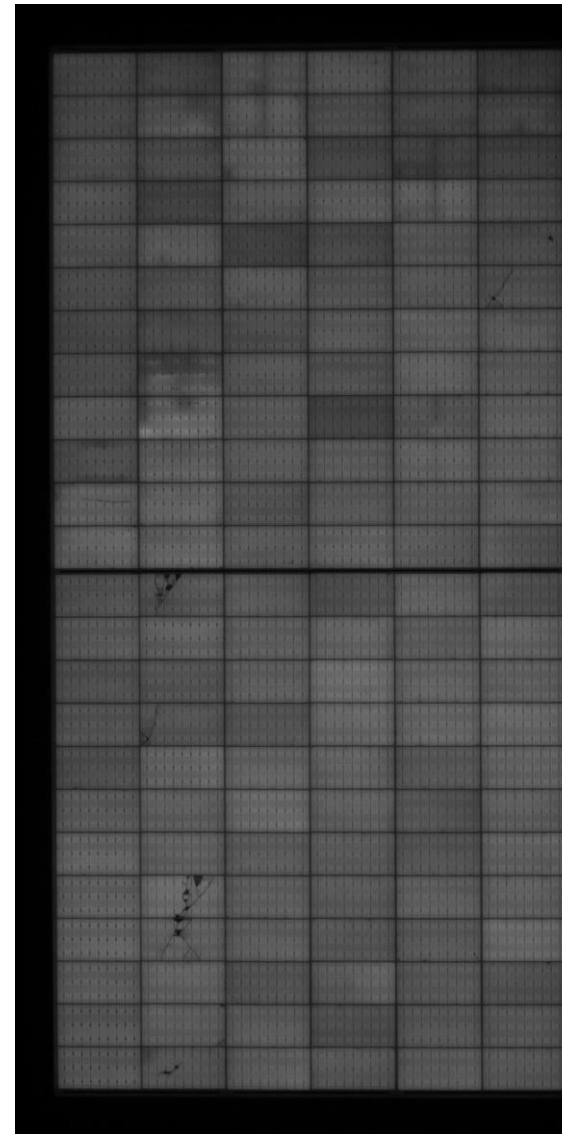
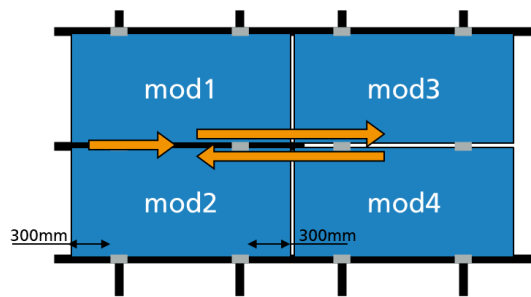


200 passes

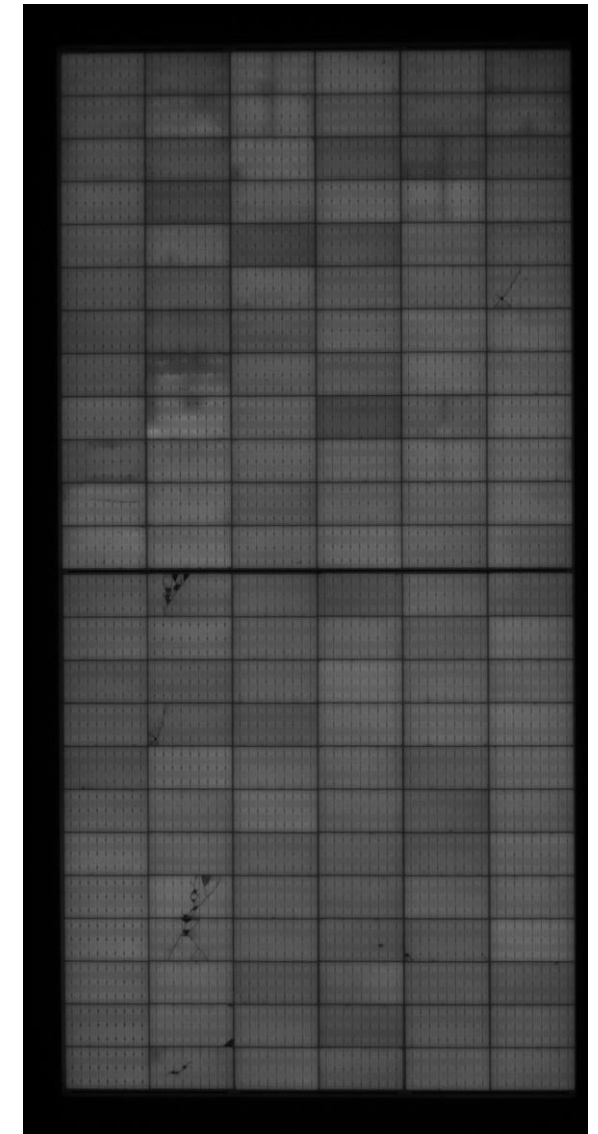
Results

Electroluminescence

- CSP_SolOur_1_P05
 - minor crack growth detected (pre-existing crack)
 - no additional cracks detected



initial

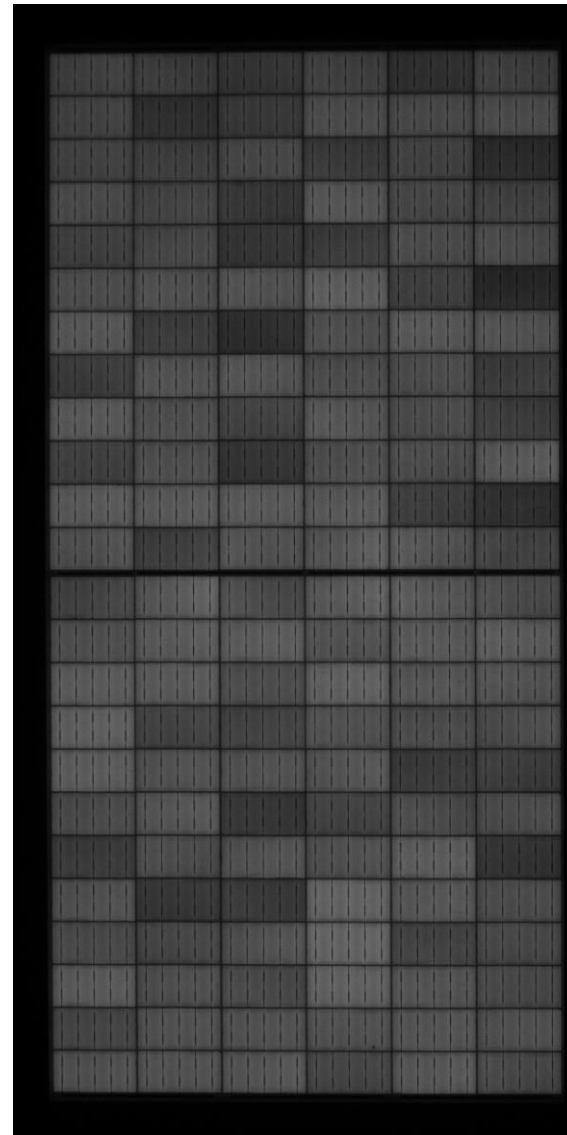
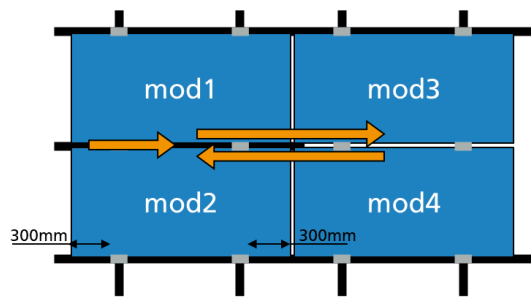


200 passes

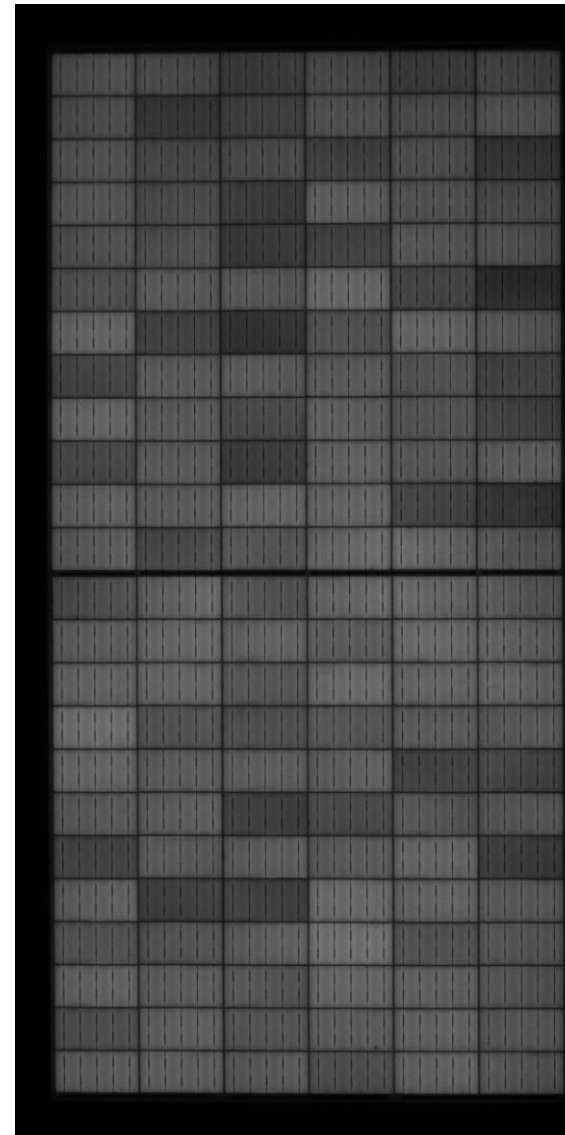
Results

Electroluminescence

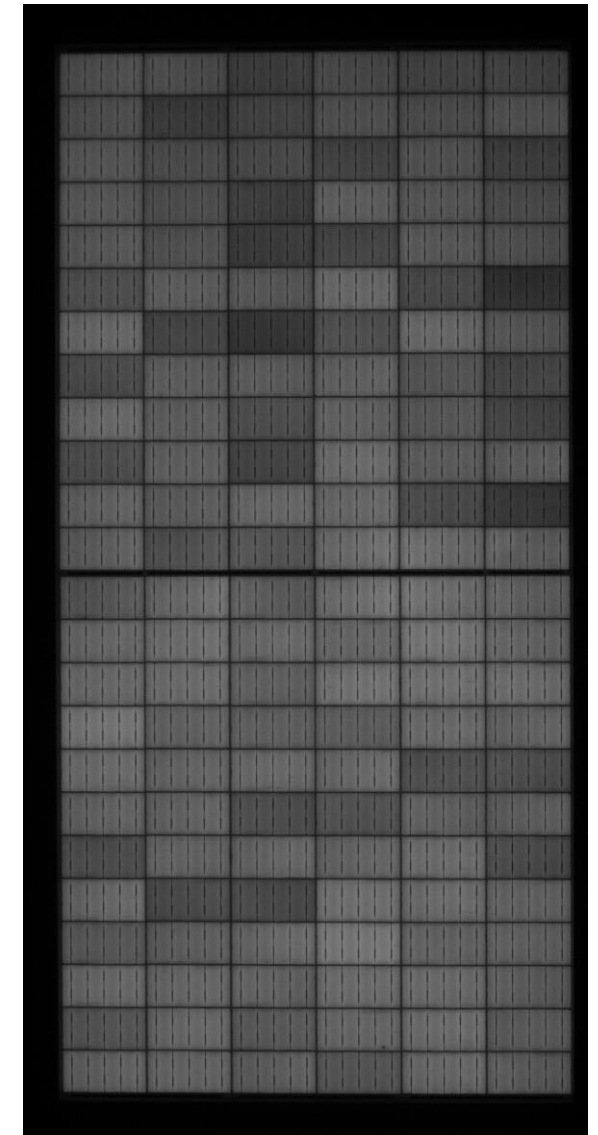
- CSP_BeGro_2_P03
 - No significant changes detected like:
 - additional cracks
 - crack growth



initial



50 passes

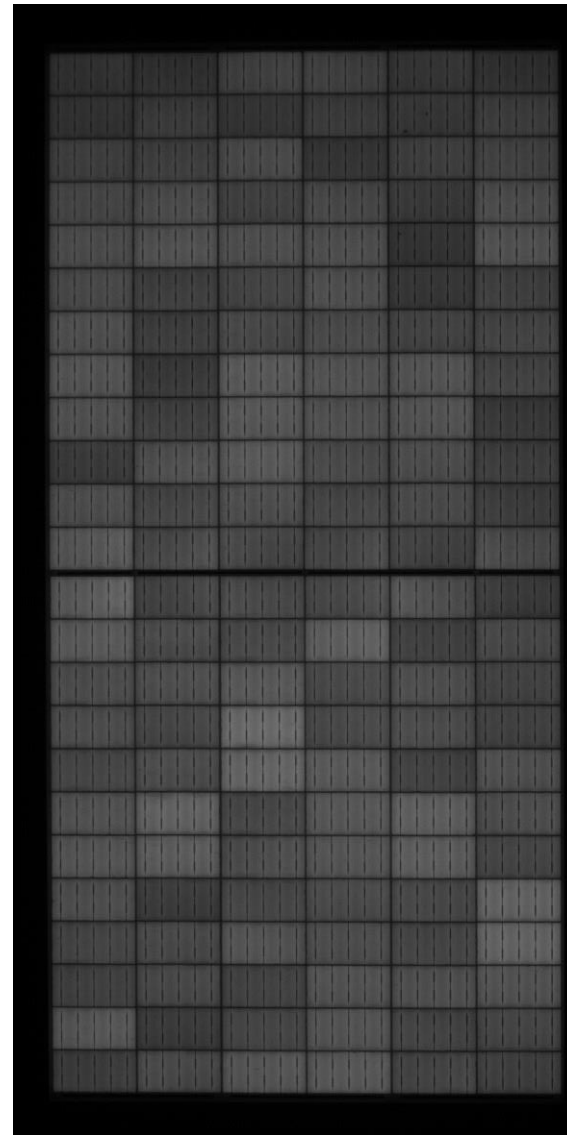
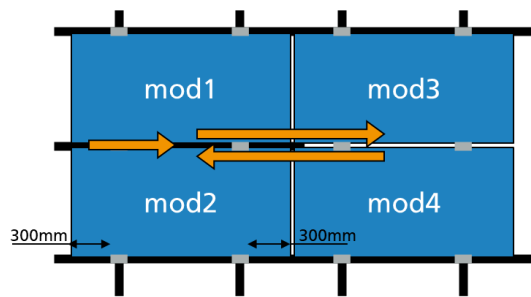


200 passes

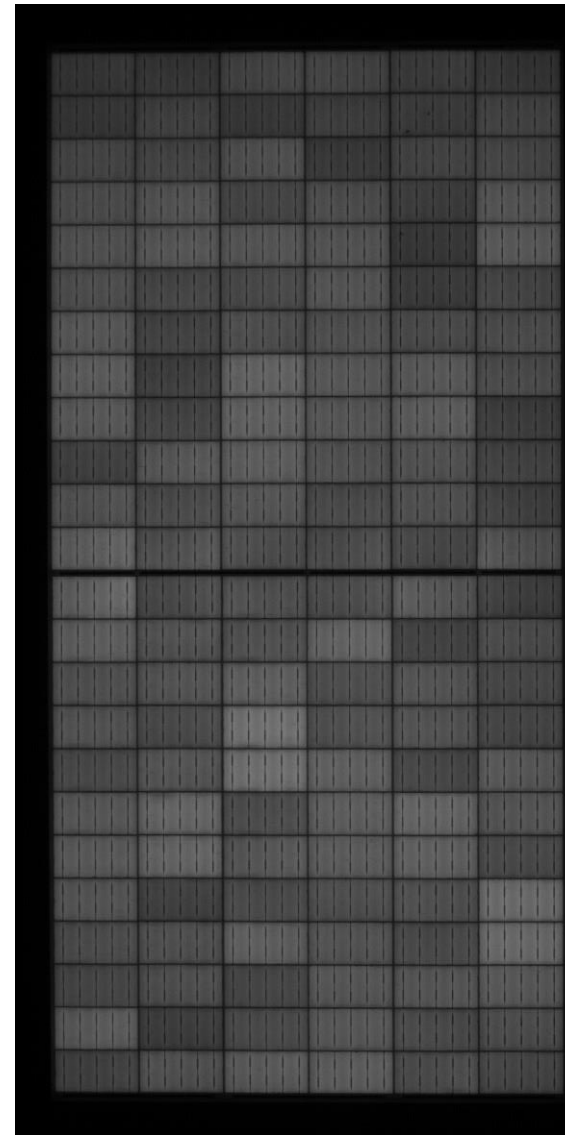
Results

Electroluminescence

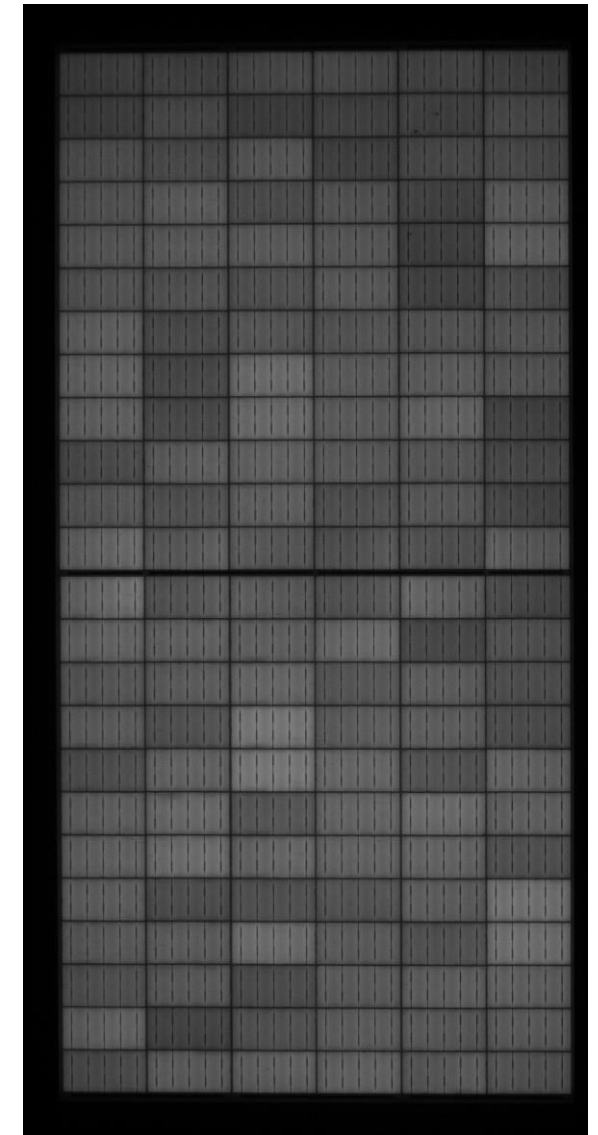
- CSP_BeGro_2_P04
 - No significant changes detected like:
 - additional cracks
 - crack growth



initial



50 passes



200 passes

Results

Performance measurement

- CSP_SolOur_1_P01
 - Isc ↗ and Pmpp ↗ due to cleaning
- CSP_SolOur_1_P03
 - No change
- CSP_SolOur_1_P04
 - Isc ↘ and Pmpp ↘ due to abrasion
- CSP_SolOur_1_P05
 - No change
- CSP_BeGro_2_P03+04
 - No change
- CSP_SolOur_1_P02+06
 - For the sake of completeness

TestTimeDate	sample ID	Comment	1000 W/m² (STC)						200 W/m² (low light)						Tcell [°C]
			Isc [A]	Imp [A]	Umpp [V]	Pmpp [W]	Uoc [V]	FF [%]	Isc [A]	Imp [A]	Umpp [V]	Pmpp [W]	Uoc [V]	FF [%]	
27.08.2024-09:49:39	CSP_SolOur_1_P01	initial	17,34	16,57	38,01	629,74	45,72	79,45	3,47	3,32	37,01	122,91	42,98	82,52	20,35
27.08.2024-11:07:50	CSP_SolOur_1_P01	50 passes	17,76	16,90	37,77	638,21	45,96	78,17	3,55	3,38	36,89	124,56	43,03	81,52	32,95
27.08.2024-12:06:54	CSP_SolOur_1_P01	200 passes	17,83	16,98	37,86	642,93	45,83	78,67	3,56	3,40	36,93	125,68	43,02	81,97	25,75
27.08.2024-10:25:20	CSP_SolOur_1_P03	initial	10,25	9,79	40,66	397,92	48,22	80,49	2,06	1,97	39,11	77,00	45,28	82,62	15,79
27.08.2024-15:09:24	CSP_SolOur_1_P03	200 passes	10,27	9,78	40,63	397,49	48,84	79,27	2,06	1,96	39,19	76,83	45,63	81,73	28,04
27.08.2024-10:34:59	CSP_SolOur_1_P04	initial	18,06	17,22	37,98	653,86	45,77	79,10	3,61	3,45	37,03	127,73	43,06	82,23	20,23
27.08.2024-11:01:26	CSP_SolOur_1_P04	50 passes	17,59	16,84	38,09	641,62	45,93	79,43	3,52	3,37	37,20	125,24	43,10	82,54	28,00
27.08.2024-11:40:11	CSP_SolOur_1_P04	200 passes	17,50	16,73	37,92	634,36	45,92	78,94	3,50	3,34	37,02	123,69	43,03	82,13	31,98
27.08.2024-11:17:27	CSP_SolOur_1_P05	initial	10,28	9,80	40,43	395,98	48,25	79,85	2,06	1,96	39,01	76,32	45,14	81,94	21,02
27.08.2024-15:02:59	CSP_SolOur_1_P05	200 passes	10,30	9,79	40,35	394,85	48,45	79,16	2,07	1,97	38,64	75,95	45,19	81,32	28,60
27.08.2024-12:12:34	CSP_BeGro_2_P03	initial	10,01	9,54	40,01	381,59	48,37	78,85	2,00	1,91	38,41	73,30	44,84	81,59	22,57
27.08.2024-14:00:42	CSP_BeGro_2_P03	50 passes	10,01	9,49	40,51	384,45	48,86	78,58	2,01	1,90	38,79	73,80	45,36	80,96	29,93
27.08.2024-15:15:06	CSP_BeGro_2_P03	200 passes	10,02	9,49	40,70	386,34	48,90	78,88	2,01	1,90	39,07	74,15	45,53	80,99	27,79
27.08.2024-13:16:47	CSP_BeGro_2_P04	initial	9,98	9,51	40,02	380,81	48,32	78,94	2,00	1,91	38,42	73,21	44,80	81,72	23,50
27.08.2024-14:04:01	CSP_BeGro_2_P04	50 passes	9,98	9,49	40,41	383,56	48,62	79,00	2,00	1,91	38,58	73,54	45,12	81,37	27,35
27.08.2024-15:12:12	CSP_BeGro_2_P04	200 passes	10,00	9,50	40,72	386,71	48,92	79,07	2,00	1,91	38,87	74,22	45,50	81,36	29,77
27.08.2024-10:09:20	CSP_SolOur_1_P02	initial	17,98	17,12	37,99	650,22	45,72	79,10	3,59	3,43	37,15	127,23	43,00	82,43	19,16
27.08.2024-11:22:49	CSP_SolOur_1_P06	initial	10,27	9,80	40,54	397,46	48,35	80,00	2,06	1,96	39,01	76,42	45,25	81,83	21,59

Note: The accuracy of the flash tests is affected by module temperature variations at delivery (cold) and due to heating caused by solar radiation, repeatability: 1 %

Summary

- The influence of the cleaning robot L1 during operation in terms of mechanical and electrical stability of the investigated PV modules is not harmful to the module performance or the electrical-mechanical integrity with the applied test methods.
- The test drives of 200 passes over the modules show no significant changes in electroluminescence images and power measurement (taking into account the progressively increased module temperature and the associated increased measurement uncertainty).
- A slight and non-significant reduction in performance could be attributed to the abrasion of the cleaning brushes and chain drive and the resulting accelerated abrasion of the anti-reflective coating. (this is a long-term effect after several cleaning drives)

