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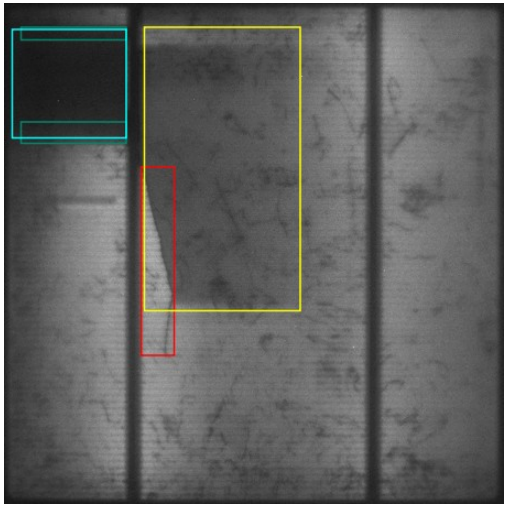
Advanced EL inspection with predictive estimation of module power loss



Ralph Schmidt (Dipl.-Ing)
pi4_robotics GmbH Berlin

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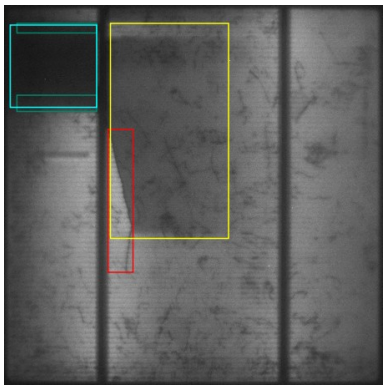
Agenda:

- Introduction pi4
- The idea: Estimate power loss at an early stage in production
- Investigation of single cells with defects
- Estimation of Power loss for PV module
- Conclusion

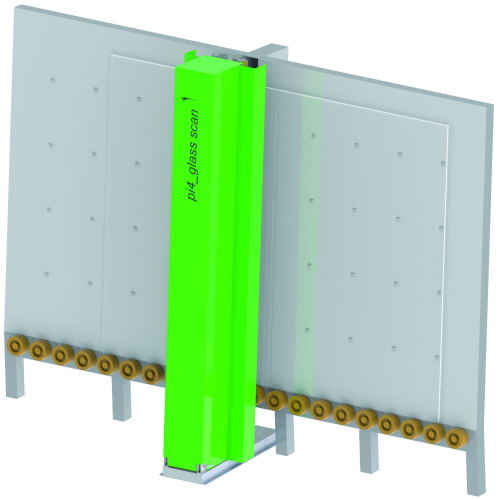


Introduction pi4

20 Years Experience as Supplier of:

- Optical inspection systems
- Automatic handling systems
- Robotics
- Specialist for 1D, 2D and 3D optical inspection

- 45 employees in 2013
- Manufacturing location Berlin
- World wide sales activity



Selection of pi4 systems for PV

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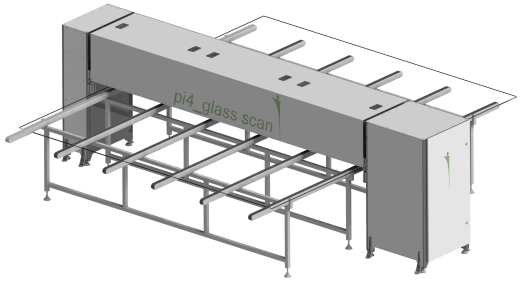
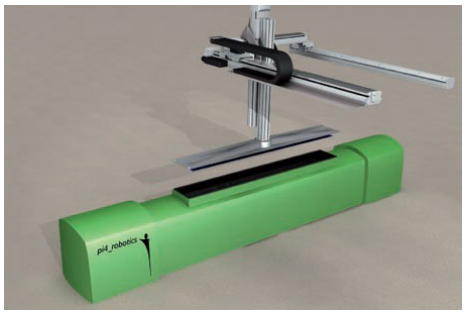


Glass inspection

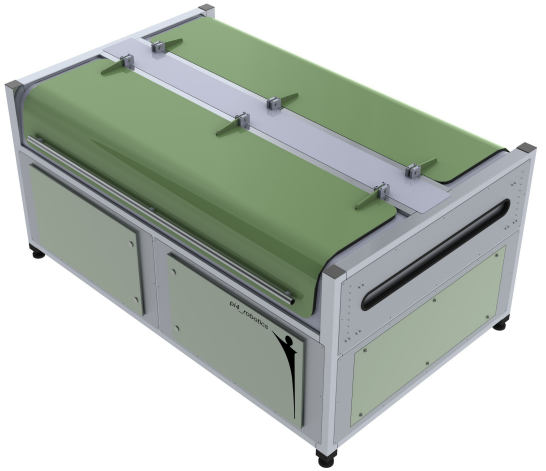
Automatic inline EL-inspection

Solder inspection



EL-string inspection

EL visual inspection system



Inline EL-inspection for thin film PV

EL integrated to flasher

Why EL inspection in PV module production ?

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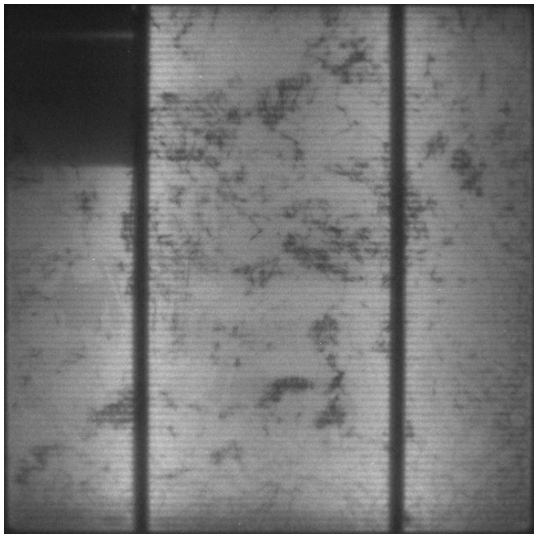
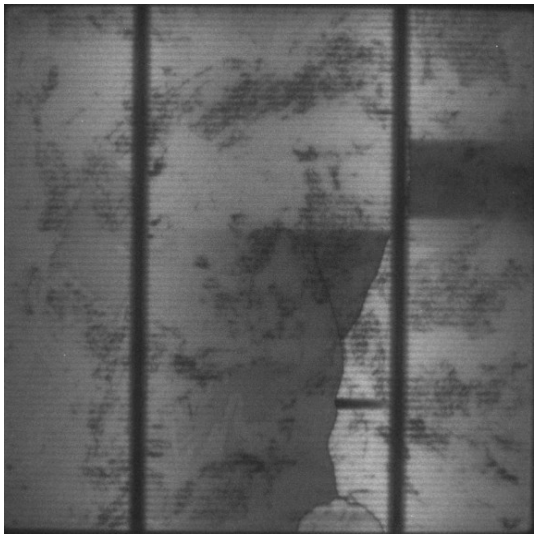
- High consistency of module quality by EL inspection

- Cost reduction by optimizing production process (save material, increase module power)

Yield loss of a module production line today: 1% bis 2%
share of stringer 0.25% declared, + percentage undiscovered in production ???
share of laminator 0.20% declared, + percentage undiscovered in production ???

remaining 0.55% bis 1.55% ???

Sources ITRPV 2011 and manufacturer data

Why EL-Inspection in PV module production ?

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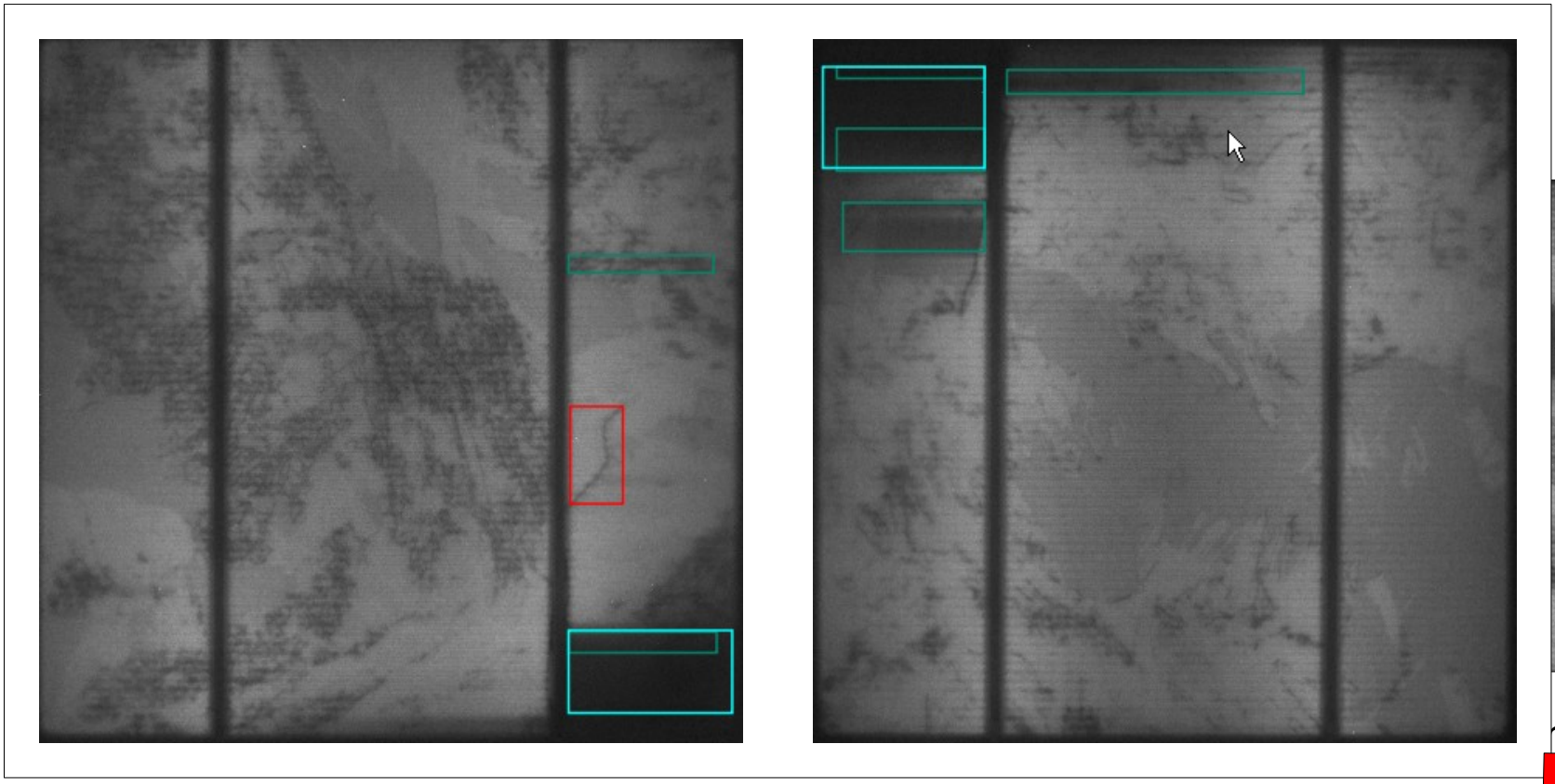

nodule power)

Yield Loss of a module production line today: 1% bis 2%

share of stringer	0.25% declared,	undiscovered in production ???
share of laminator	0.20% declared,	undiscovered in production ???

remaining 0.55% bis 1.55% ???

Sources ITRPV 2011 and manufacturer data

Typical Quality Specification Today:

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Item	Class A	Class B	Class C	Failed
No. of Micro Cracks	<= 1 cracks / cell <= 1 cell / module	<= 2 cracks / cell <= 5 cells / module	> 2 cracks / cell <= 12 cells / module	> 12 cells / module
ActiveCracks	0	1	>=1	>=2
Dark or Black Cells	0	0	0	>=1
Inefficient Area per Cell	<= 4%	<= 7%	> 7%	> 10%

It basically is counting cracks
with no relation to its significance on potential power degradation

The idea:
Estimate power loss at an early stage in production

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Providing a tool to

- automatically judge defects by its significance for future power generation capability of each cell
- Estimate the power loss for each cell as tested
- Estimate the power loss after an assumed load or aging
- Estimate the power loss for the complete module *)
- Perform a quality classification of the module
- Send service messages to operators such as

Classifier Message:	F104: Stringer solder conveyor wear or contamination. Cells sticking to conveyor when picked up

*) based on publication of M Koentges “The risk of power loss in crystalline silicon based photovoltaic modules due to micro-cracks”

Three step approach to estimate power loss

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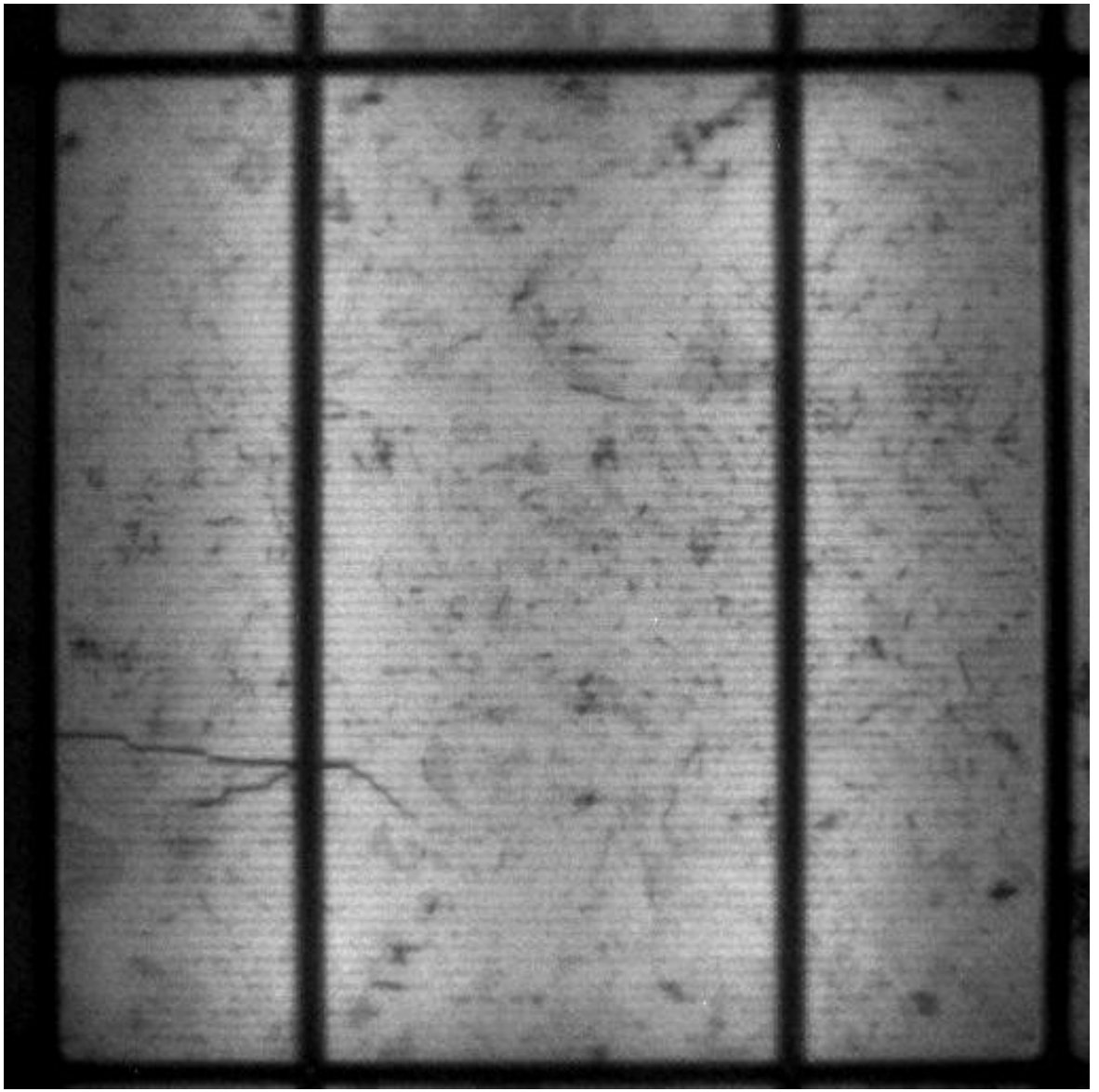
- PL1 : power loss is calculated with the defects as detected in the EL image
- PL2 : power loss is calculated assuming all micro cracks turn into active cracks after aging process of module
- PL3 : Power loss is calculated assuming an amount of crack growth.

  The amount of crack growth in reality is not known, however the user may set the software to a maximum value for the worst case when the crack propagates through the entire cell.

Original cell image



Power Loss Estimation

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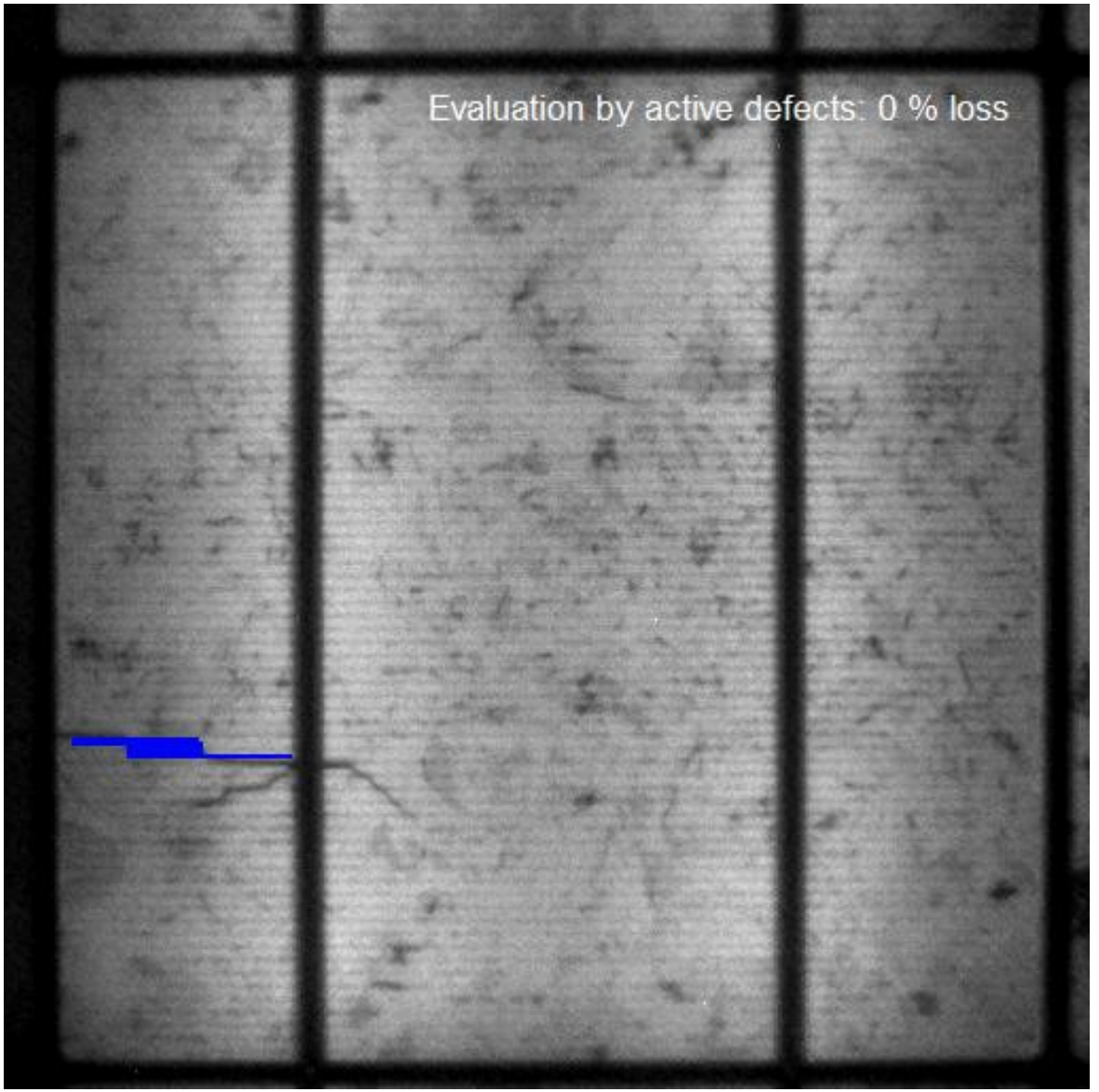
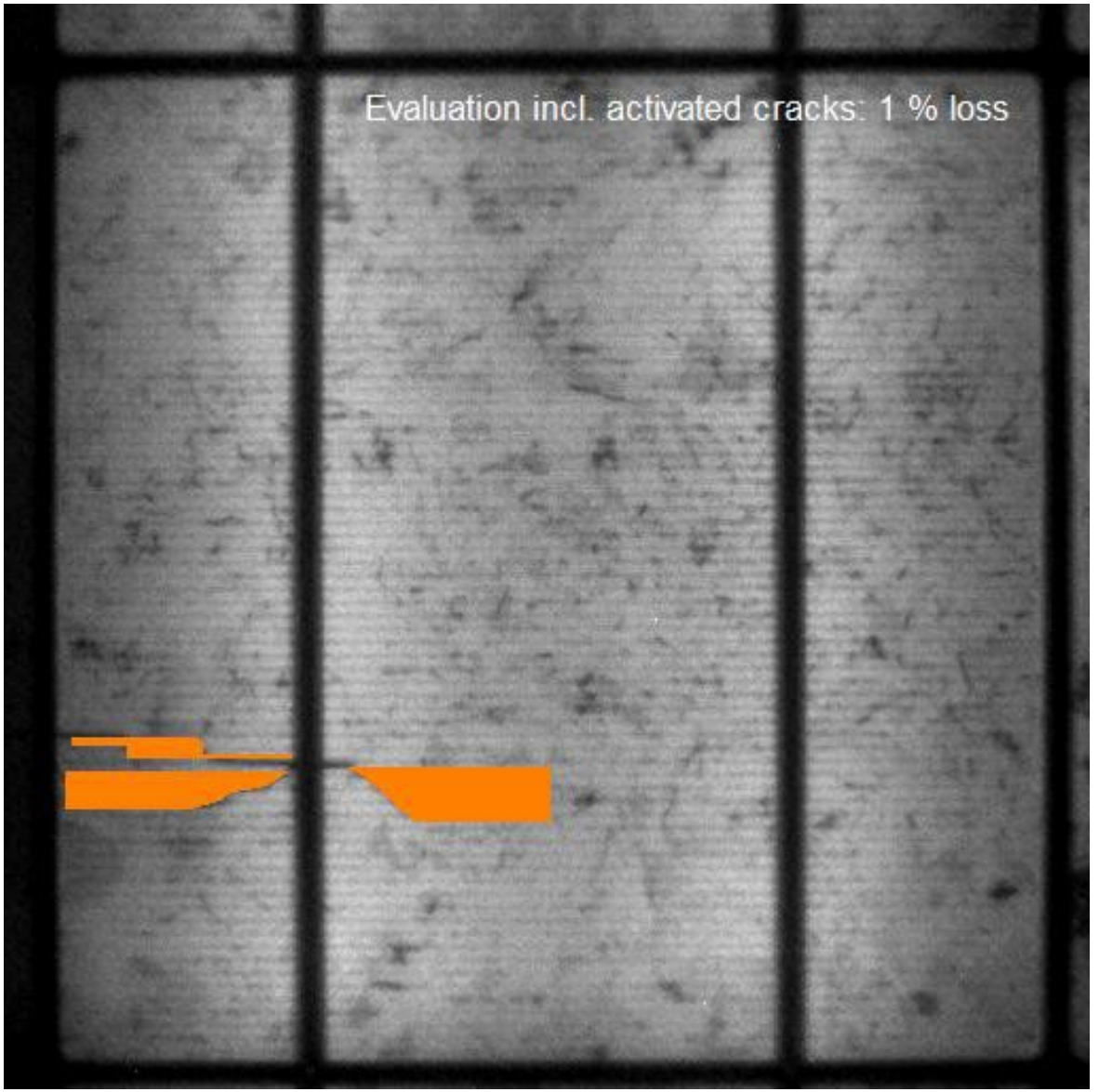
PL1:
All defects showing power loss



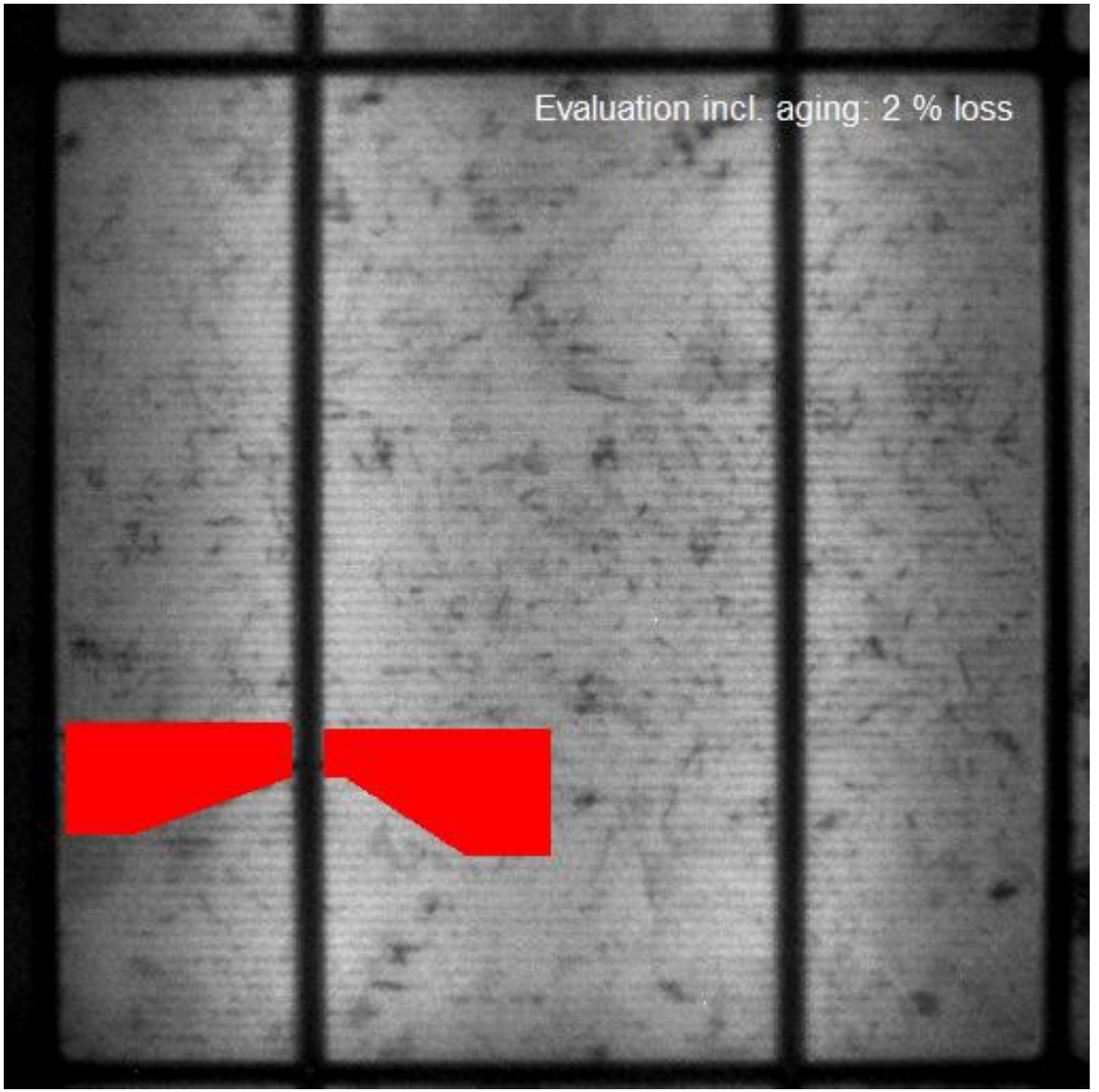
Power Loss Estimation

pi4_robotics

PL2:
All defects showing power loss +
micro cracks turned into active cracks



PL3:
All defects
after aging



Power Loss Estimation

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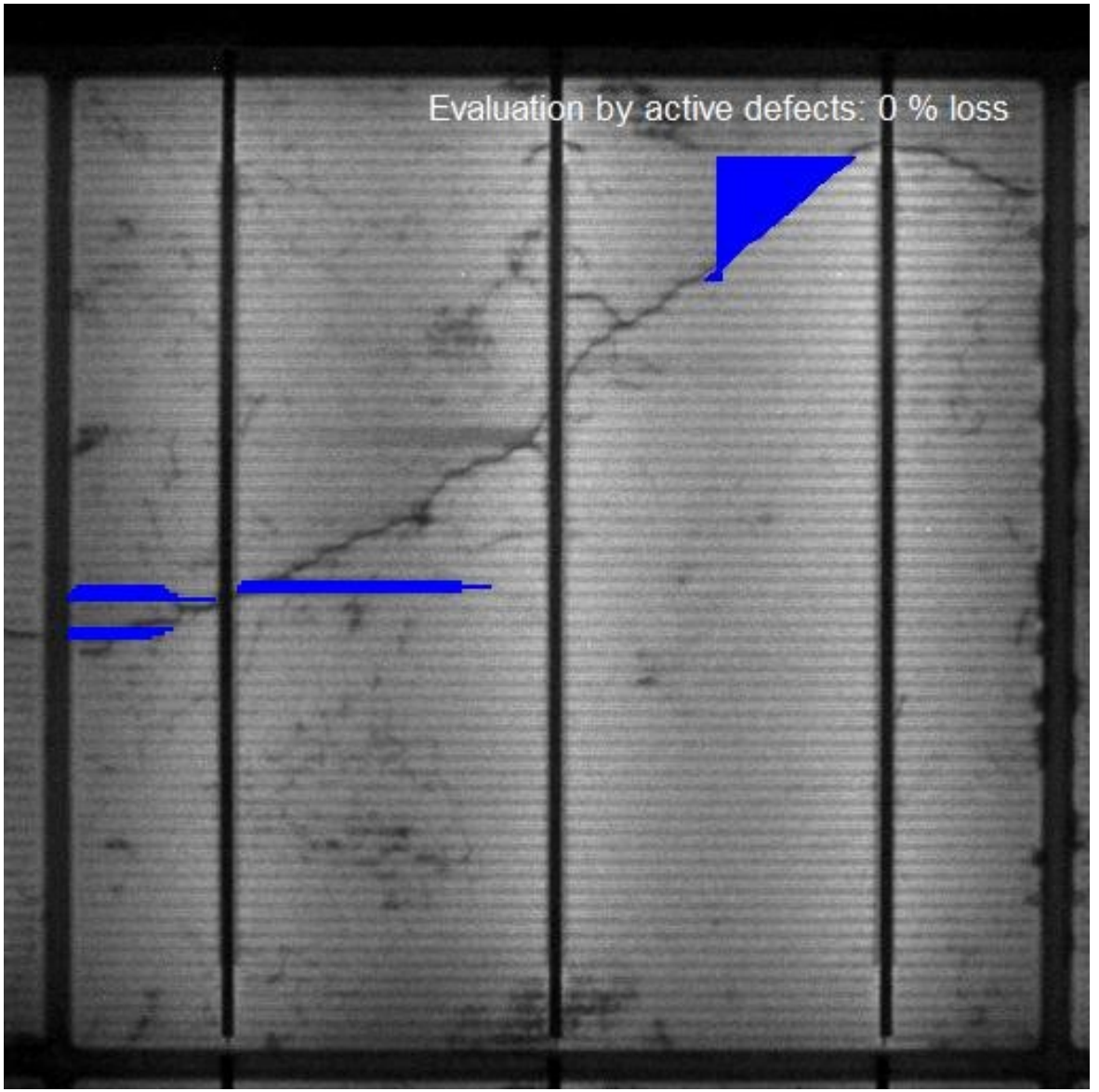
Original cell image

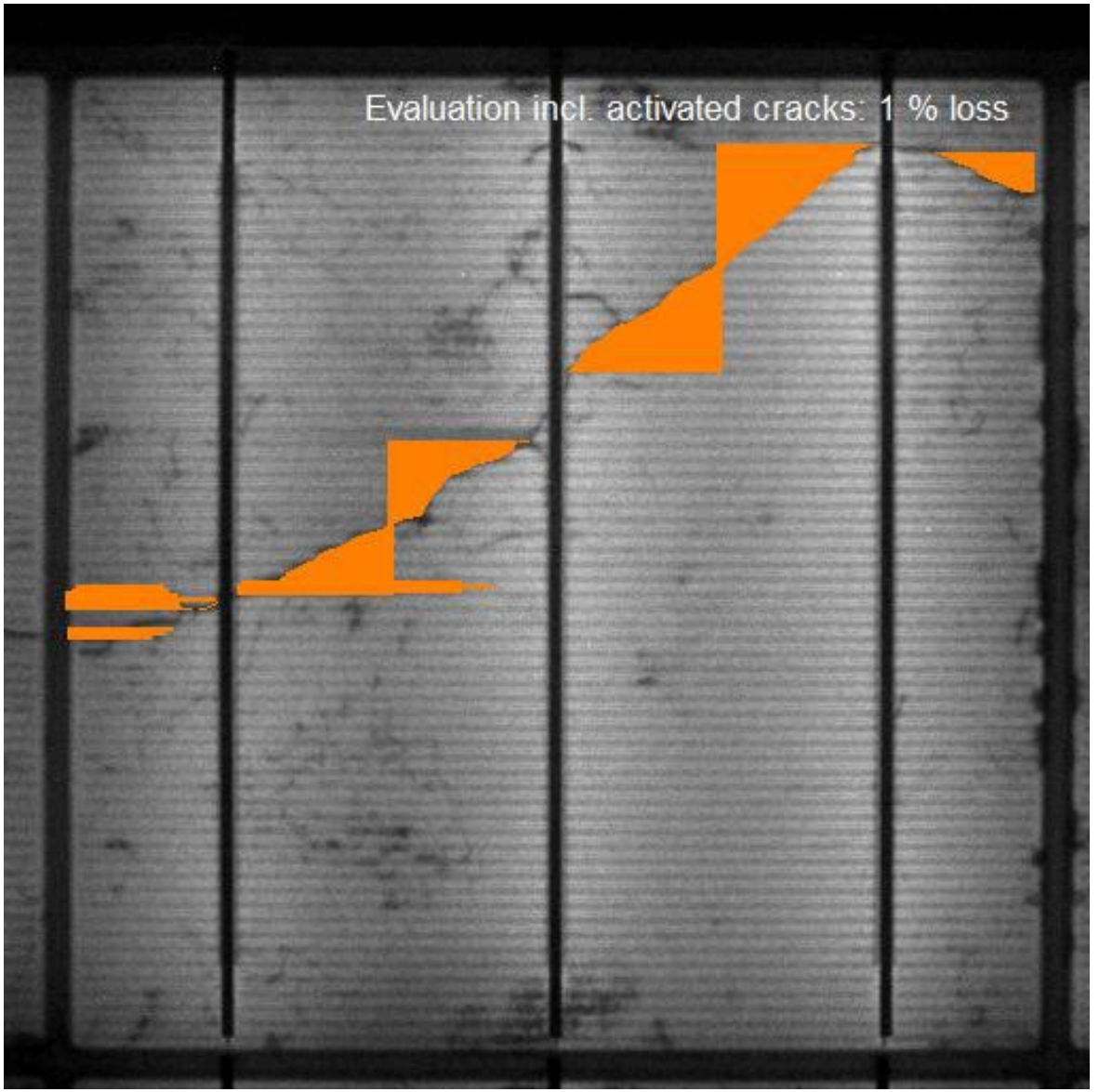
Power Loss Estimation

pi4_robotics

PL1:
All defects showing power loss

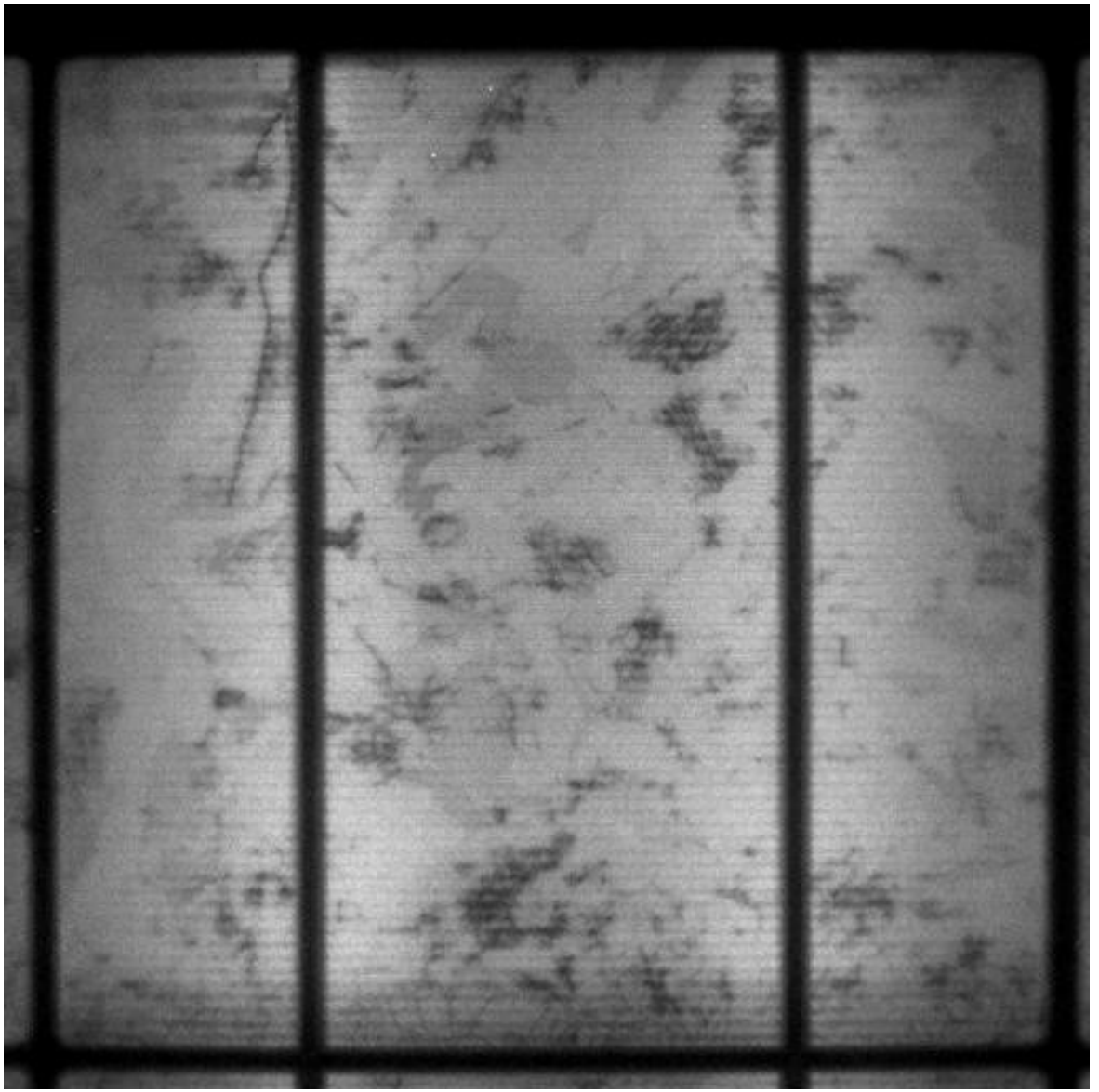


PL2:
All defects showing power loss +
micro cracks turned into active cracks



PL3:
All defects
after aging

Original cell image



Power Loss Estimation

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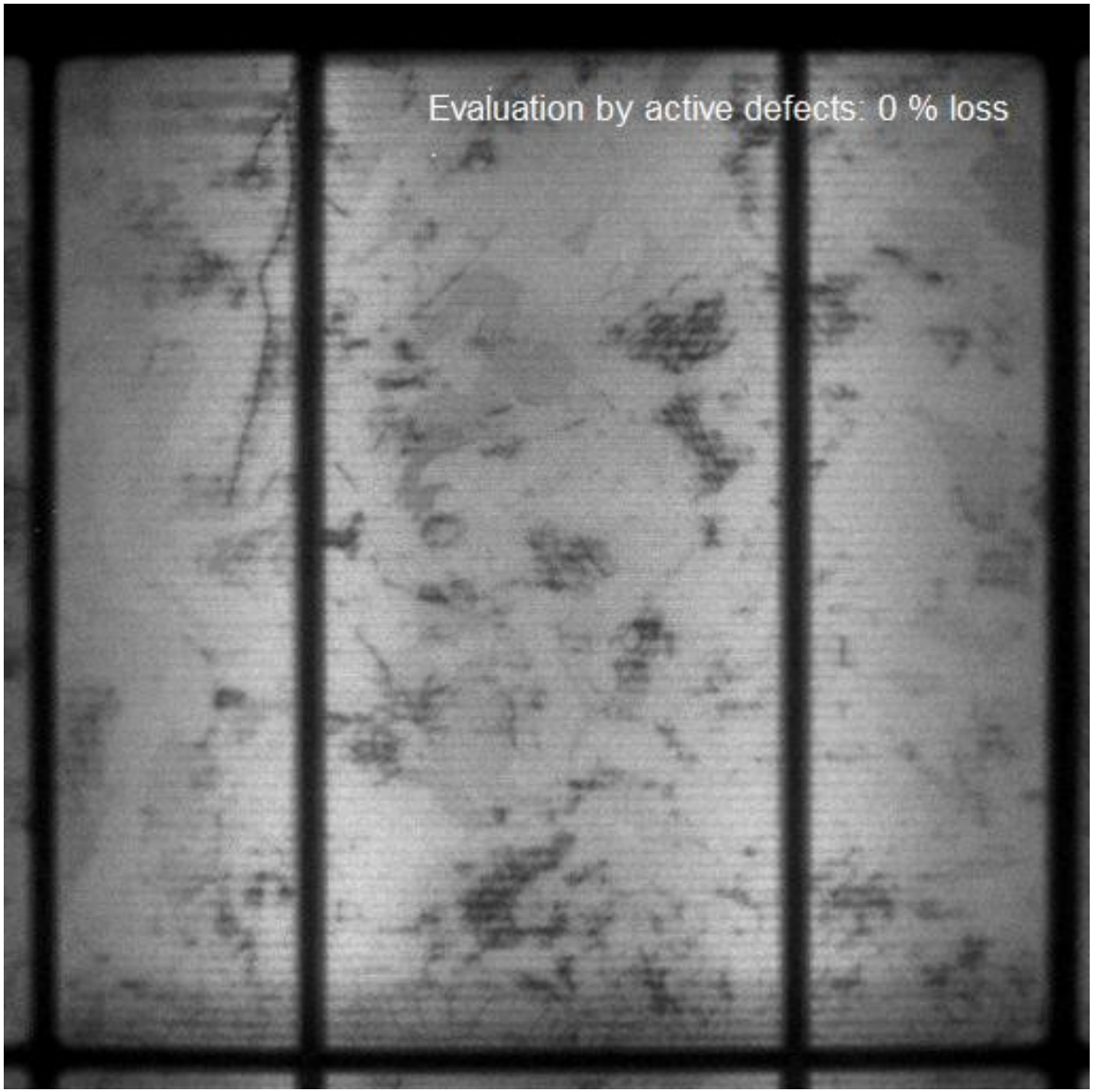
PL1:
All defects showing power loss



Power Loss Estimation

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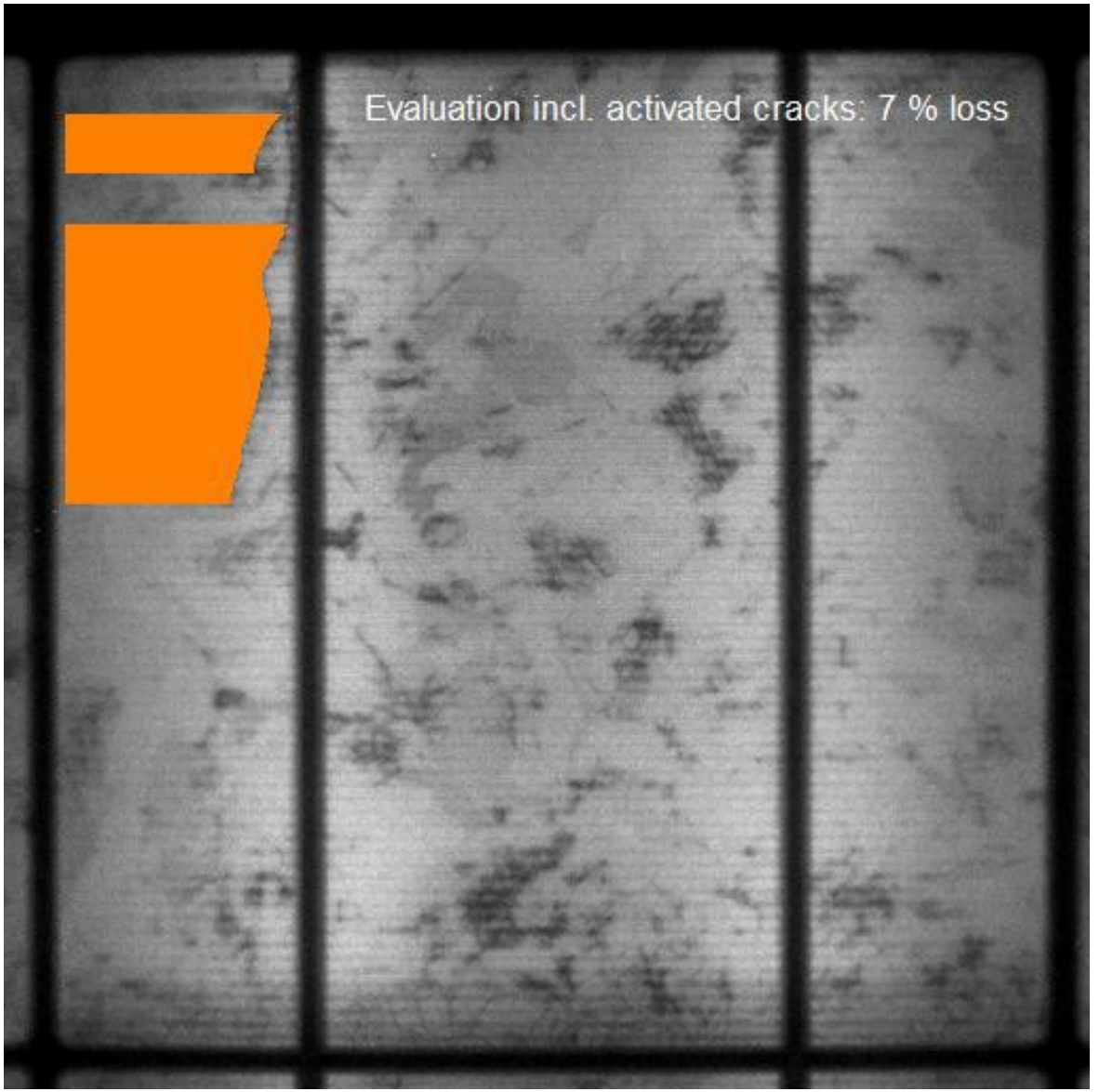
PL2:
All defects showing power loss +
micro cracks turned into active cracks



PL3:
All defects
after aging

Investigation of single cells with defects

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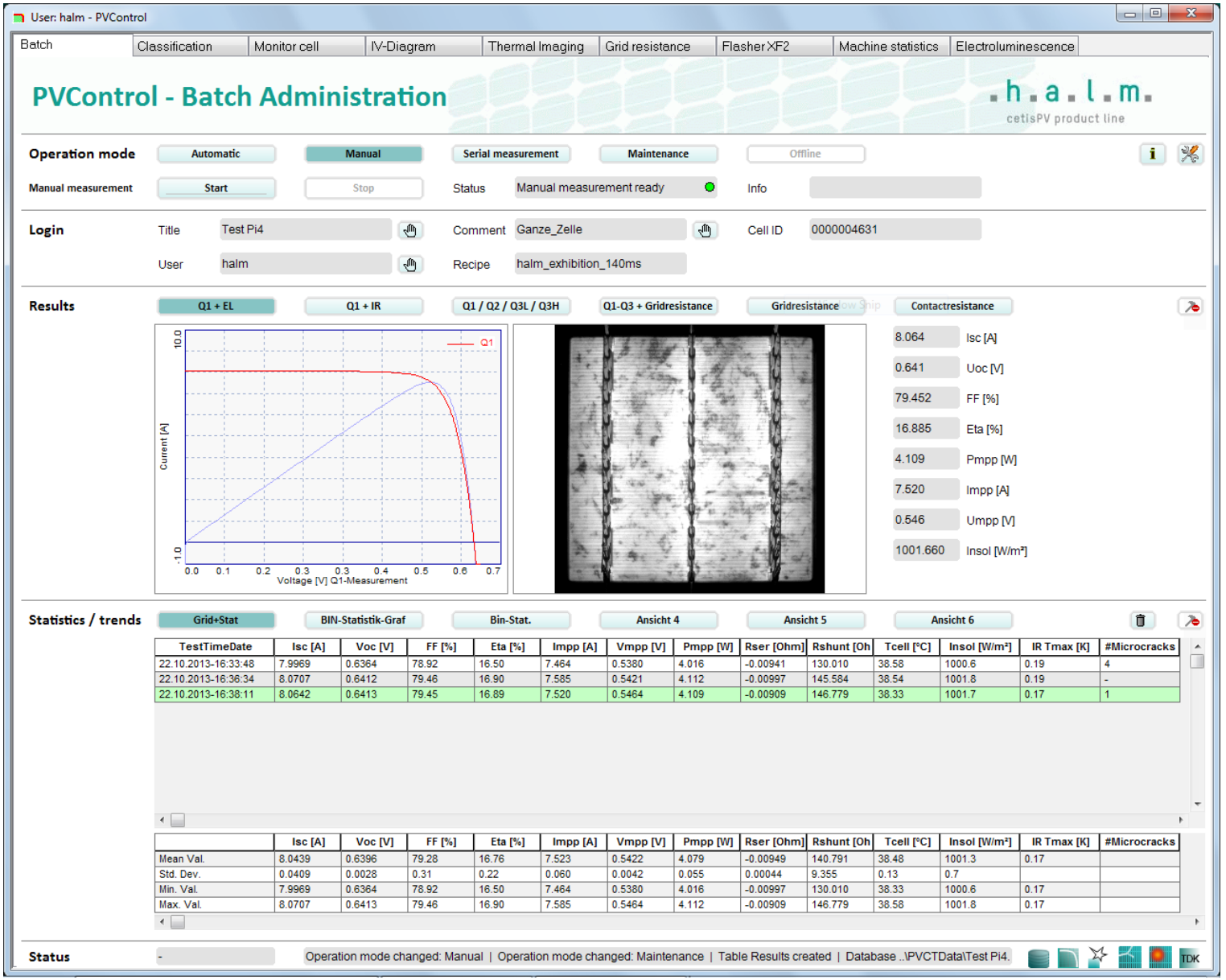


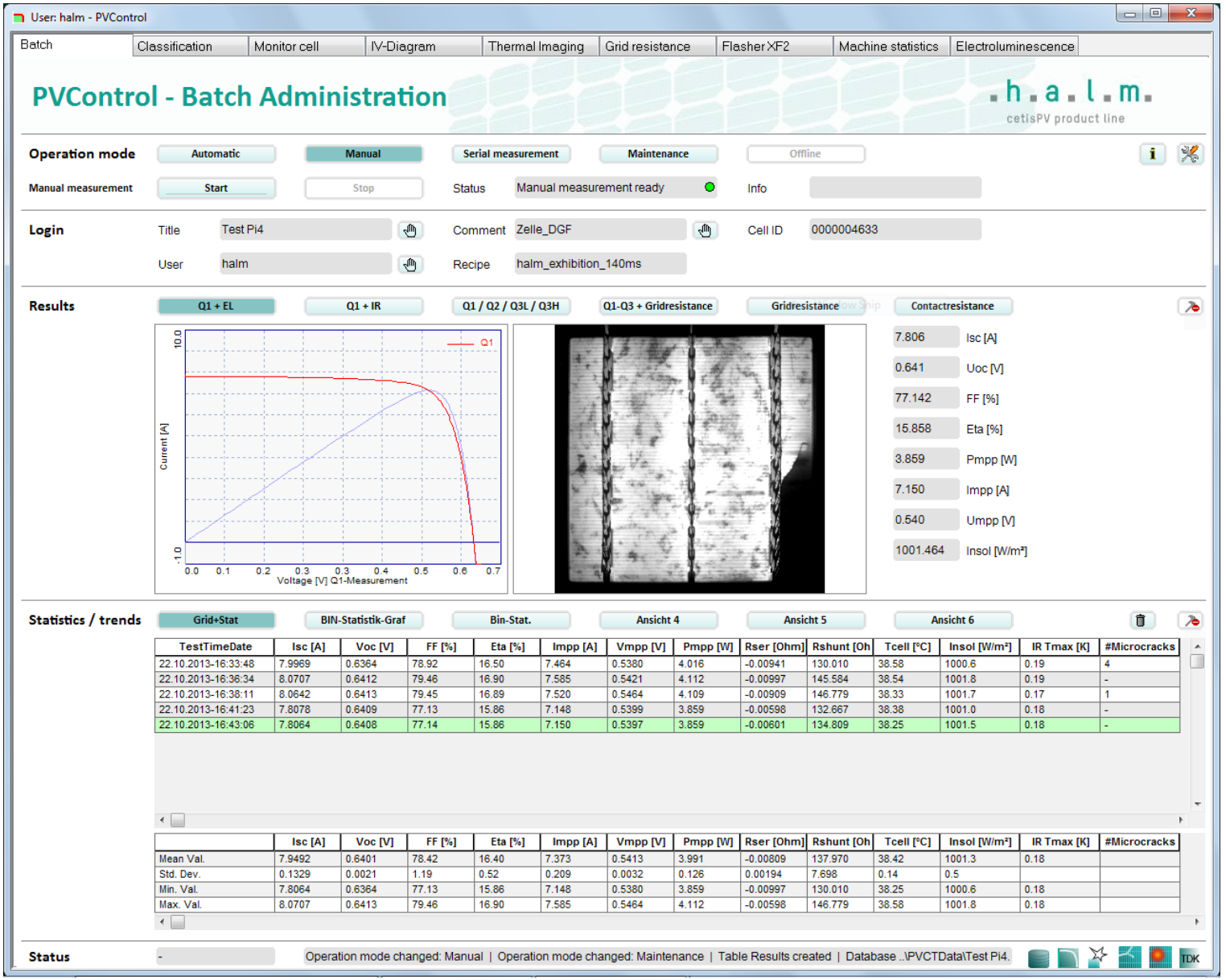
TestTimeDate	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
22.10.2013-16:33:48	7.9969	0.6364	78.92	16.50	7.464	0.5380	4.016	-0.00941	130.010	38.58	1000.6	0.19	4
22.10.2013-16:36:34	8.0707	0.6412	79.46	16.90	7.585	0.5421	4.112	-0.00997	145.584	38.54	1001.8	0.19	-
22.10.2013-16:38:11	8.0642	0.6413	79.45	16.89	7.520	0.5464	4.109	-0.00909	146.779	38.33	1001.7	0.17	1

	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
Mean Val.	8.0439	0.6396	79.28	16.76	7.523	0.5422	4.079	-0.00949	140.791	38.48	1001.3	0.17	
Std. Dev.	0.0409	0.0028	0.31	0.22	0.060	0.0042	0.055	0.00044	9.355	0.13	0.7		
Min. Val.	7.9969	0.6364	78.92	16.50	7.464	0.5380	4.016	-0.00997	130.010	38.33	1000.6	0.17	
Max. Val.	8.0707	0.6413	79.46	16.90	7.585	0.5464	4.112	-0.00909	146.779	38.58	1001.8	0.17	

Pmpp=4.109 W

Investigation of single cells with defects

pi4_robotics



TestTimeDate	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
22.10.2013-16:33:48	7.9969	0.6364	78.92	16.50	7.464	0.5380	4.016	-0.00941	130.010	38.58	1000.6	0.19	4
22.10.2013-16:36:34	8.0707	0.6412	79.46	16.90	7.585	0.5421	4.112	-0.00997	145.584	38.54	1001.8	0.19	-
22.10.2013-16:38:11	8.0642	0.6413	79.45	16.89	7.520	0.5464	4.109	-0.00909	146.779	38.33	1001.7	0.17	1
22.10.2013-16:41:23	7.8078	0.6409	77.13	15.86	7.148	0.5399	3.859	-0.00598	132.667	38.38	1001.0	0.18	-
22.10.2013-16:43:06	7.8064	0.6408	77.14	15.86	7.150	0.5397	3.859	-0.00601	134.809	38.25	1001.5	0.18	-

	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
Mean Val.	7.9492	0.6401	78.42	16.40	7.373	0.5413	3.991	-0.00809	137.970	38.42	1001.3	0.18	
Std. Dev.	0.1329	0.0021	1.19	0.52	0.209	0.0032	0.126	0.00194	7.698	0.14	0.5		
Min. Val.	7.8064	0.6364	77.13	15.86	7.148	0.5380	3.859	-0.00997	130.010	38.25	1000.6	0.18	
Max. Val.	8.0707	0.6413	79.46	16.90	7.585	0.5464	4.112	-0.00598	146.779	38.58	1001.8	0.18	

Pmpp=3.859 W

Degradation = 6.084 % of cell power

EL evaluation of cell with crack

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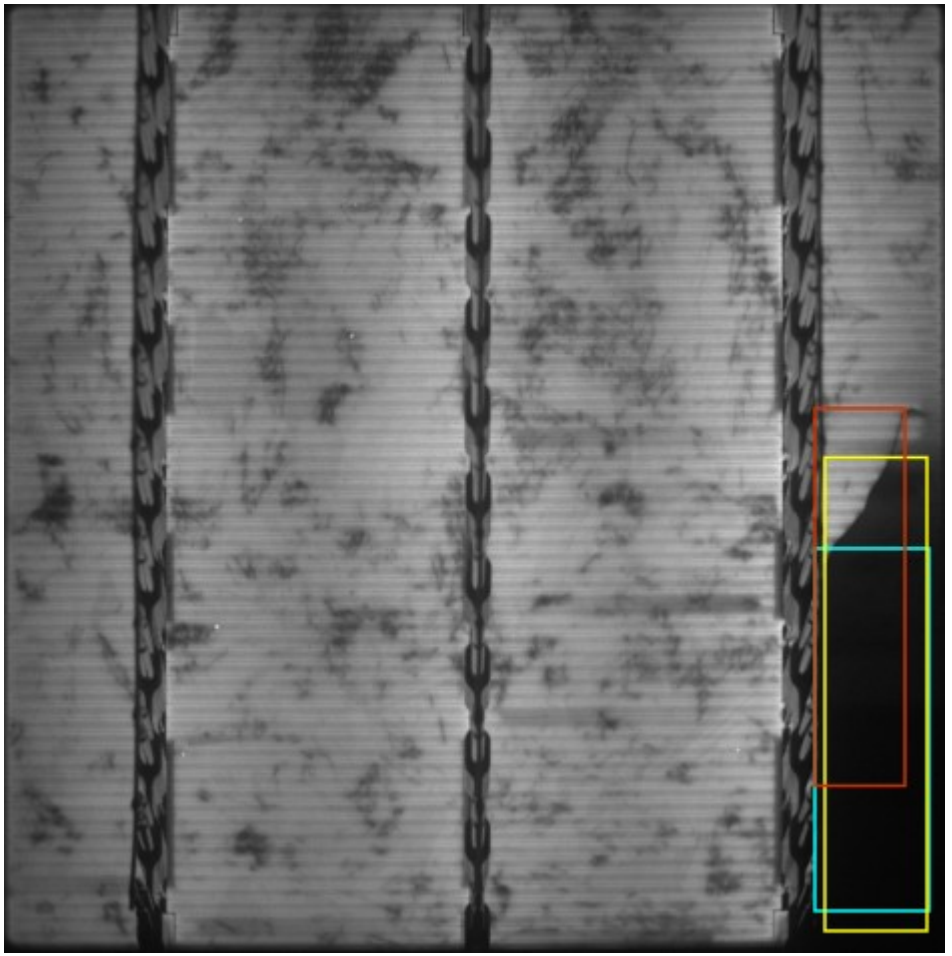
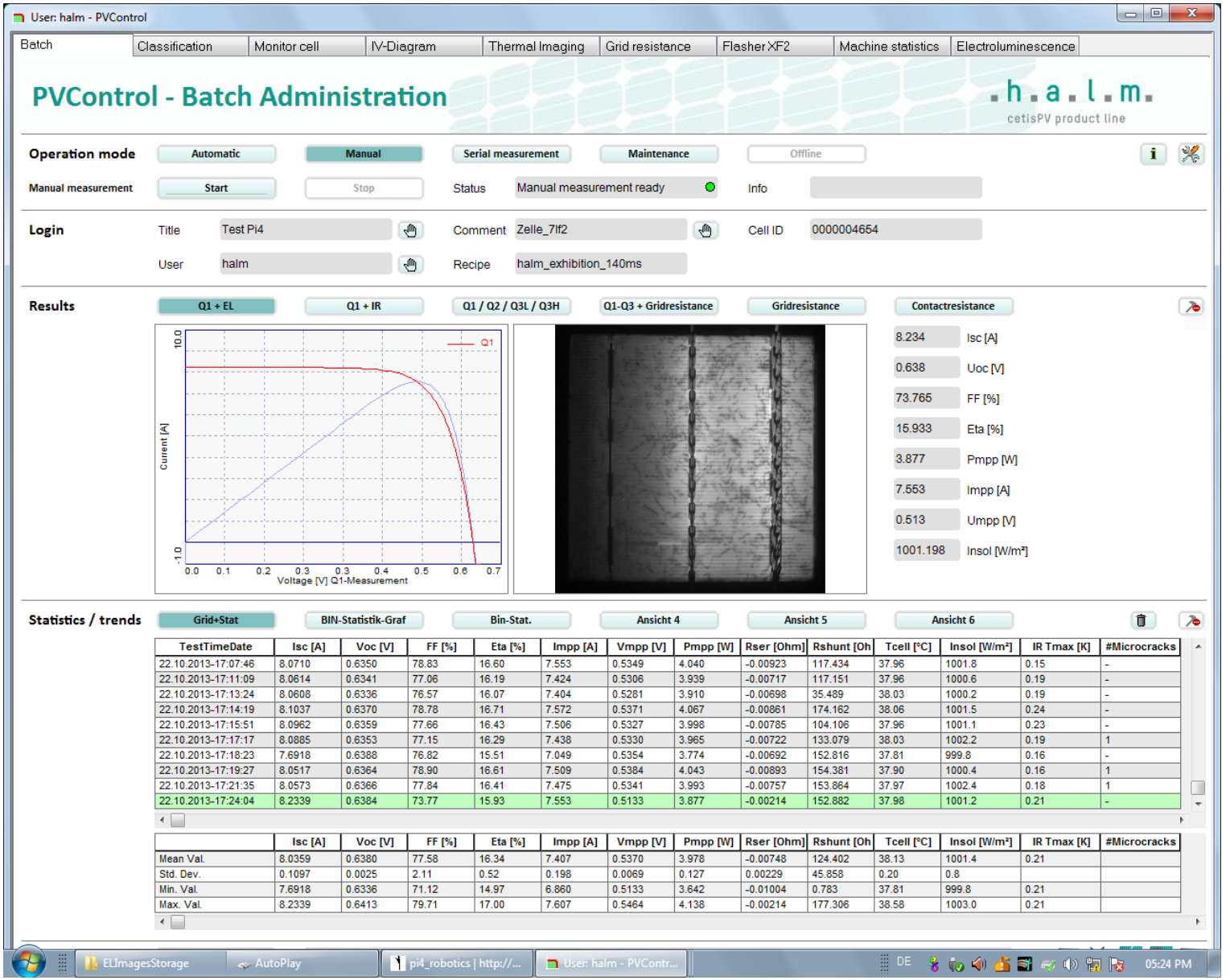
Estimated power loss of cell : 7.21 %

Deviation from flasher result : 1.13 %



Investigation of cell with busing solder error

pi4_robotics



TestTimeDate	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
22.10.2013-17:07:46	8.0710	0.6350	78.83	16.60	7.553	0.5349	4.040	-0.00923	117.434	37.96	1001.8	0.15	-
22.10.2013-17:11:09	8.0614	0.6341	77.06	16.19	7.424	0.5306	3.939	-0.00717	117.151	37.96	1000.6	0.19	-
22.10.2013-17:13:24	8.0608	0.6336	76.57	16.07	7.404	0.5281	3.910	-0.00698	35.489	38.03	1000.2	0.19	-
22.10.2013-17:14:19	8.1037	0.6370	78.78	16.71	7.572	0.5371	4.067	-0.00861	174.162	38.06	1001.5	0.24	-
22.10.2013-17:15:51	8.0962	0.6359	77.66	16.43	7.506	0.5327	3.998	-0.00785	104.106	37.96	1001.1	0.23	-
22.10.2013-17:17:17	8.0885	0.6353	77.15	16.29	7.438	0.5330	3.965	-0.00722	133.079	38.03	1002.2	0.19	1
22.10.2013-17:18:23	7.6918	0.6388	76.82	15.51	7.049	0.5354	3.774	-0.00692	152.816	37.81	999.8	0.16	-
22.10.2013-17:19:27	8.0517	0.6364	78.90	16.61	7.509	0.5384	4.043	-0.00893	154.381	37.90	1000.4	0.16	1
22.10.2013-17:21:35	8.0573	0.6366	77.84	16.41	7.475	0.5341	3.993	-0.00757	153.864	37.97	1002.4	0.18	1
22.10.2013-17:24:04	8.2339	0.6384	73.77	15.93	7.553	0.5133	3.877	-0.00214	152.882	37.98	1001.2	0.21	-

	Isc [A]	Voc [V]	FF [%]	Eta [%]	Impp [A]	Vmpp [V]	Pmpp [W]	Rser [Ohm]	Rshunt [Oh	Tcell [°C]	Insol [W/m²]	IR Tmax [K]	#Microcracks
Mean Val.	8.0359	0.6380	77.58	16.34	7.407	0.5370	3.978	-0.00748	124.402	38.13	1001.4	0.21	
Std. Dev.	0.1097	0.0025	2.11	0.52	0.198	0.0069	0.127	0.00229	45.858	0.20	0.8		
Min. Val.	7.6918	0.6336	71.12	14.97	6.860	0.5133	3.642	-0.01004	0.783	37.81	999.8	0.21	
Max. Val.	8.2339	0.6413	79.71	17.00	7.607	0.5464	4.138	-0.00214	177.306	38.58	1003.0	0.21	

Pmpp=4.043 W undamaged

Pmpp=3.859 W with solder error

Degradation = 4.106% of cell power

EL evaluation of cell with busing solder error

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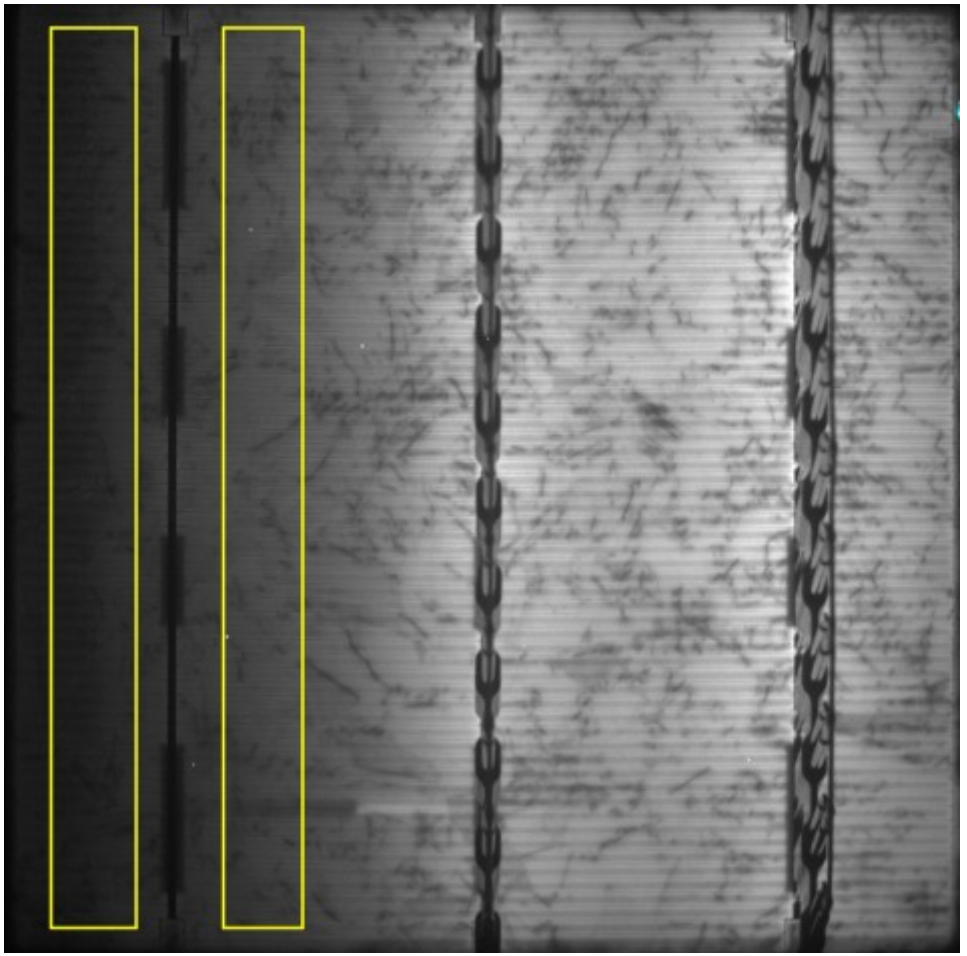
Estimated power loss of cell : 4,418 %

Deviation from flasher result : 0.312 %



Investigation of a complete module with defects

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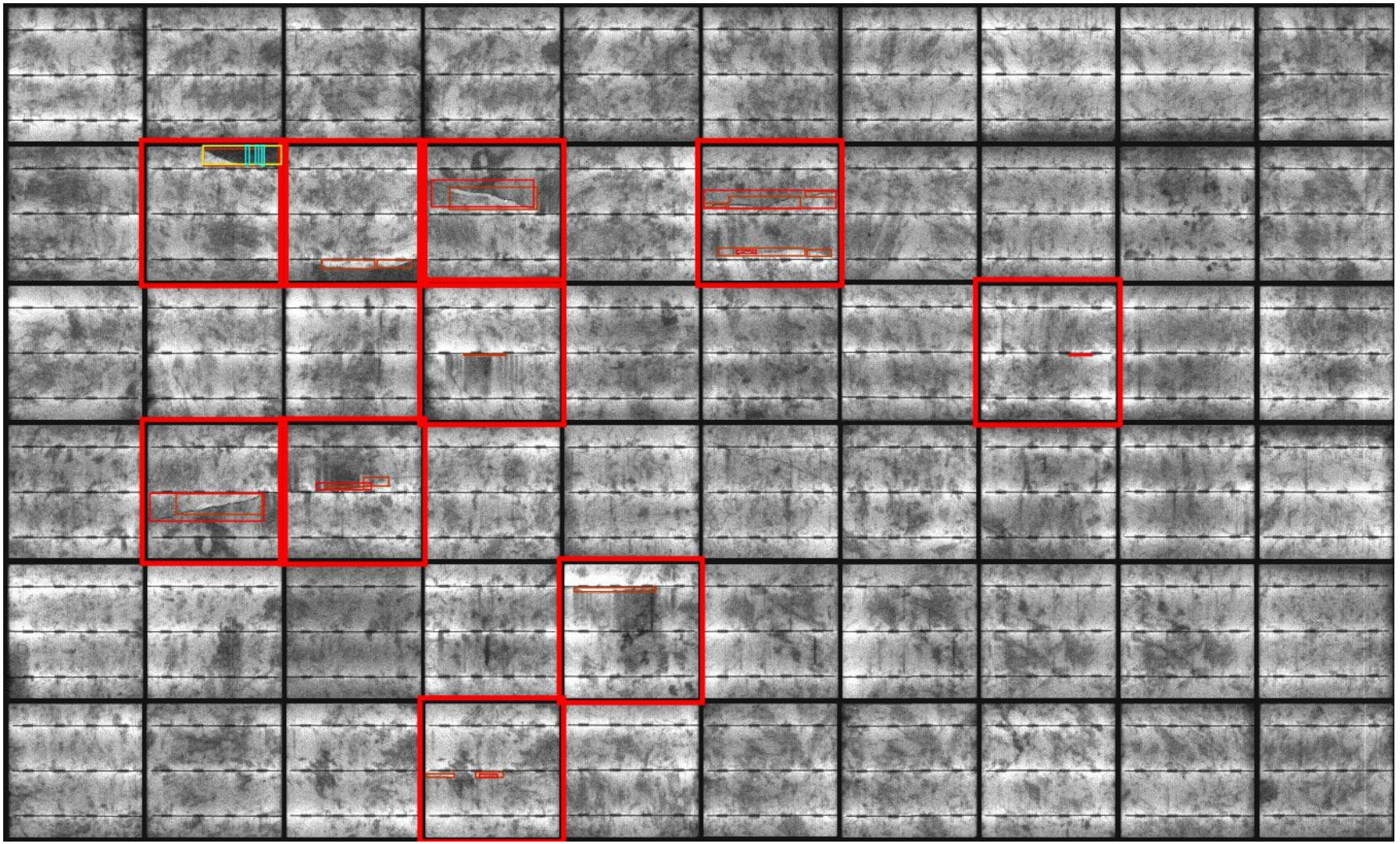
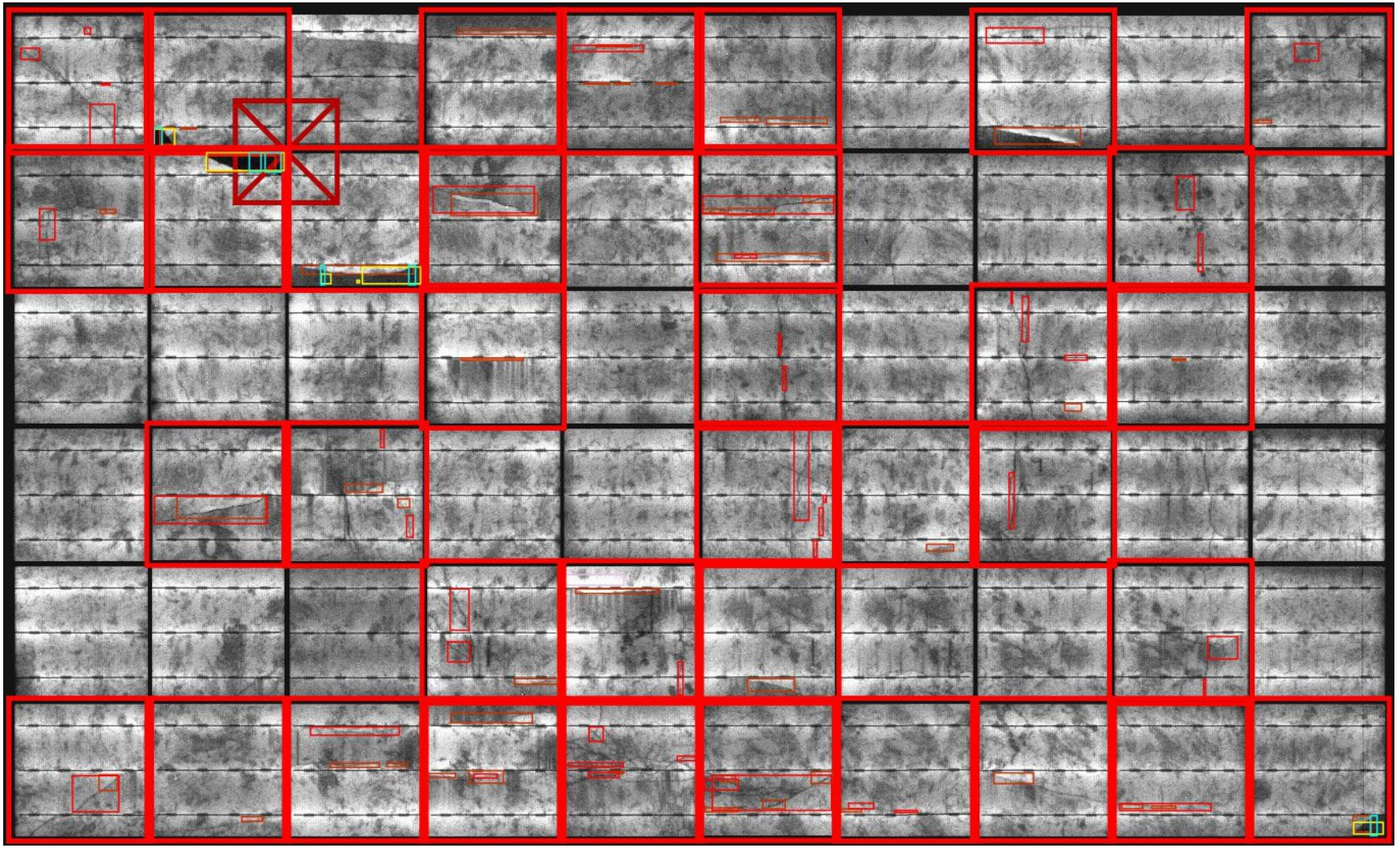


Pmpp=235 W

(Raw EL image and flash data supplied by courtesy of TÜV Rheinland)

Investigation of a complete module with defects

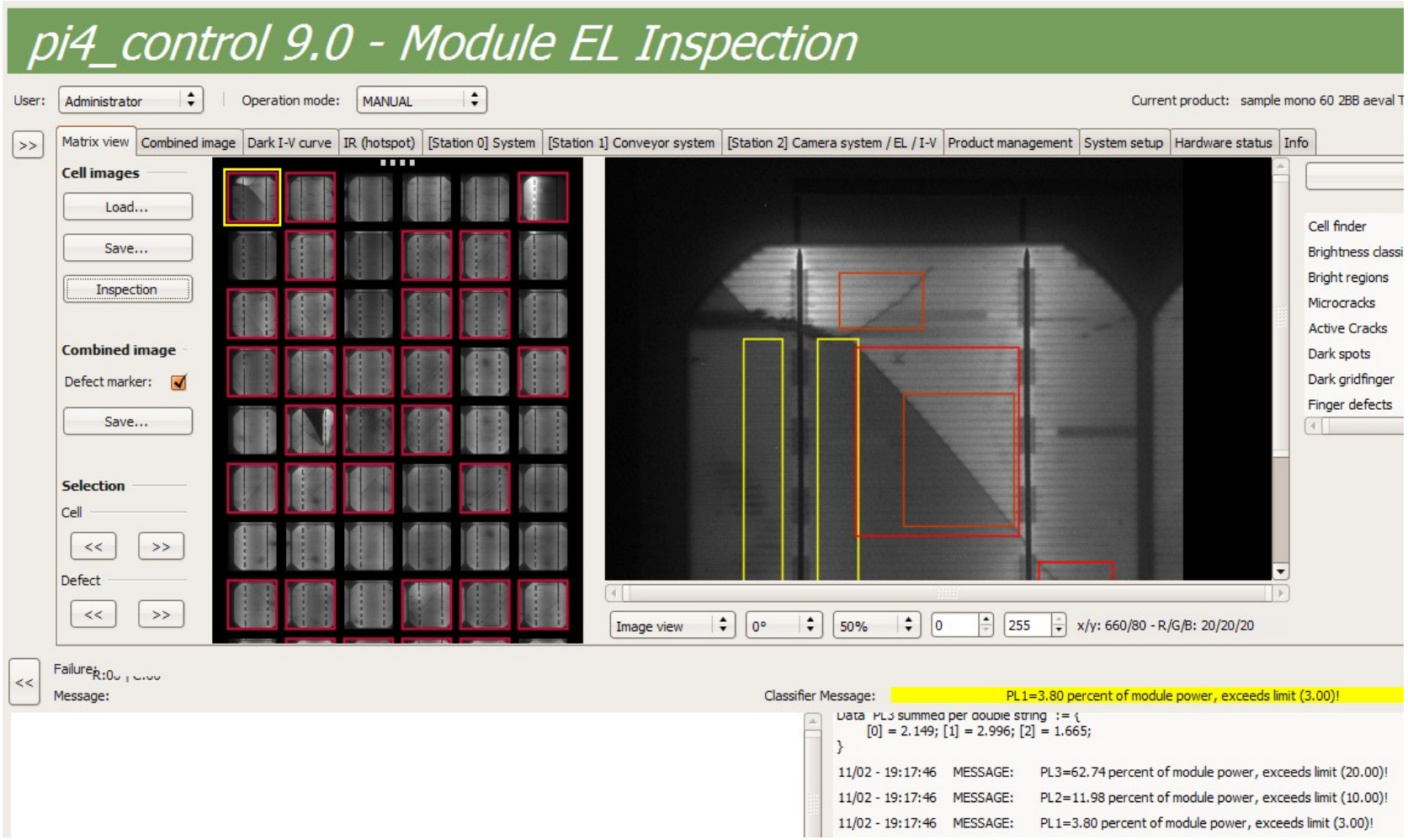
pi4_robotics



After mechanical load test 5.400 Pa Pmpp=232,5 W
Power degradation = 1.1 %
Estimated Power loss = 1.25 % **Deviation from flash test = 0.15%**

Investigation of a complete module with defects

pi4_robotics

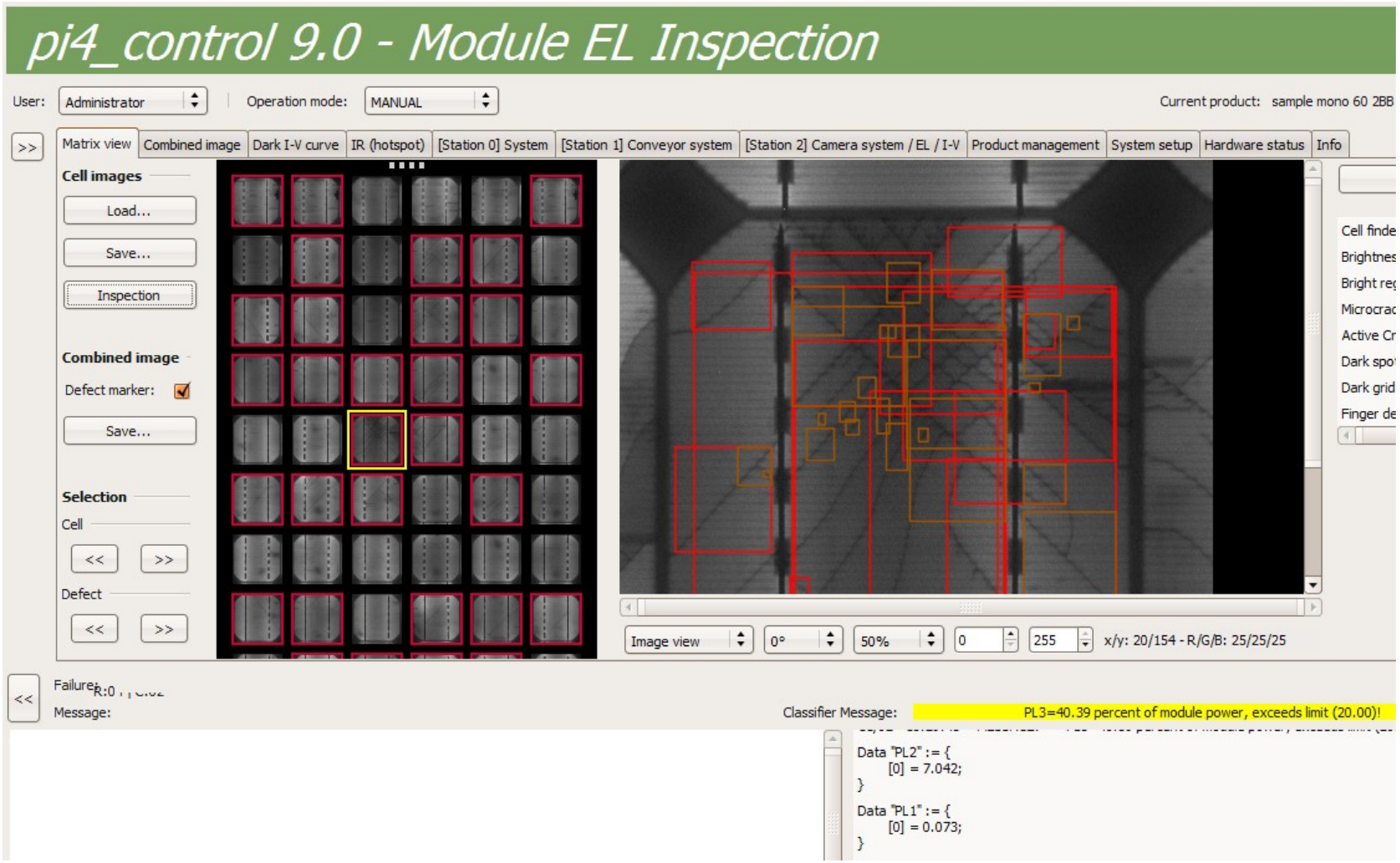


PL1 = 3.80 %
PL2 = 11.98 %
PL3 = 62.74 %

Conergy module with rated power of 175 W flashed in Schletter Mobile PV Lab Mpp=170.7 W
Estimated Power loss = 3.8 % = 6.65 W
Deviation from flash test = -2.35 W or -1.3 %

Investigation of a complete module with defects

pi4_robotics



The same module with the three most seriously damaged cells replaced

PL1 = 0.07 %
PL2 = 7.04 %
PL3 = 40.39 %

Conclusions

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- Estimation of power loss from high resolution EL images is possible within an accuracy of ± 2.5%
- By knowing the significance of damages to the potential power loss, automatic decisions may be taken about pre lamination repair
- Not all cells with cracks necessarily have to be removed in pre lamination repair.
- Yield loss can be reduced by doing less pre lamination repair.
- Yield loss can be reduced by better knowledge of upstream machine's service state; service messages give dedicated warnings to the operators.
- With the help of automated high resolution EL inspection the cost per Wp may be reduced by more than 0.15 €cent.

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