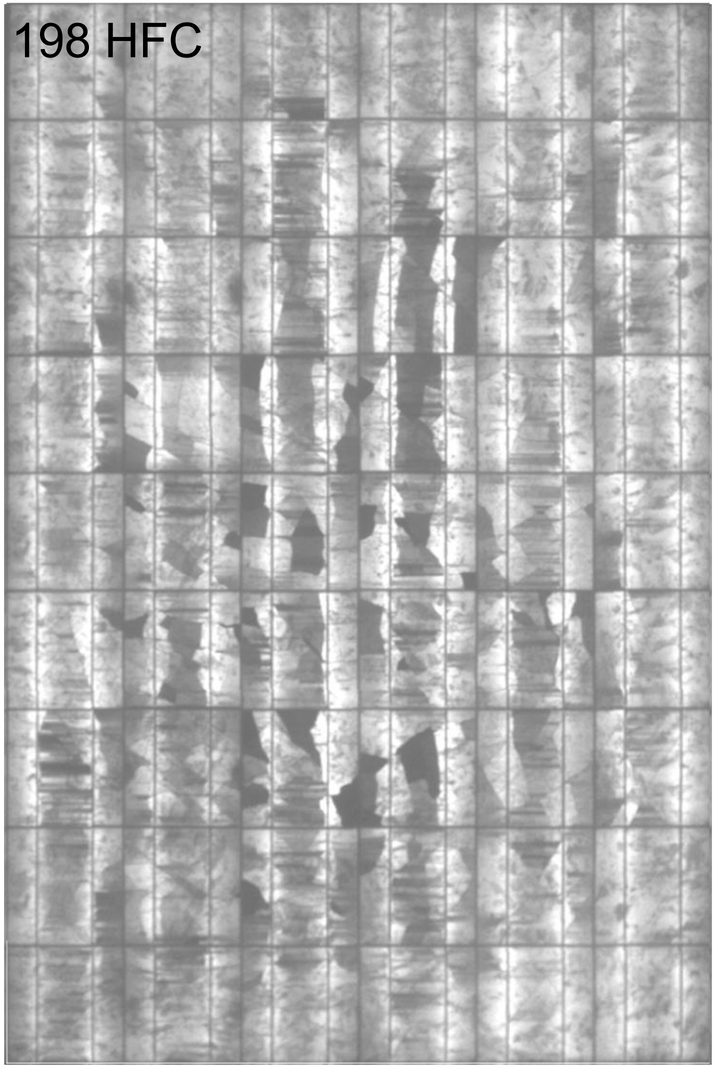


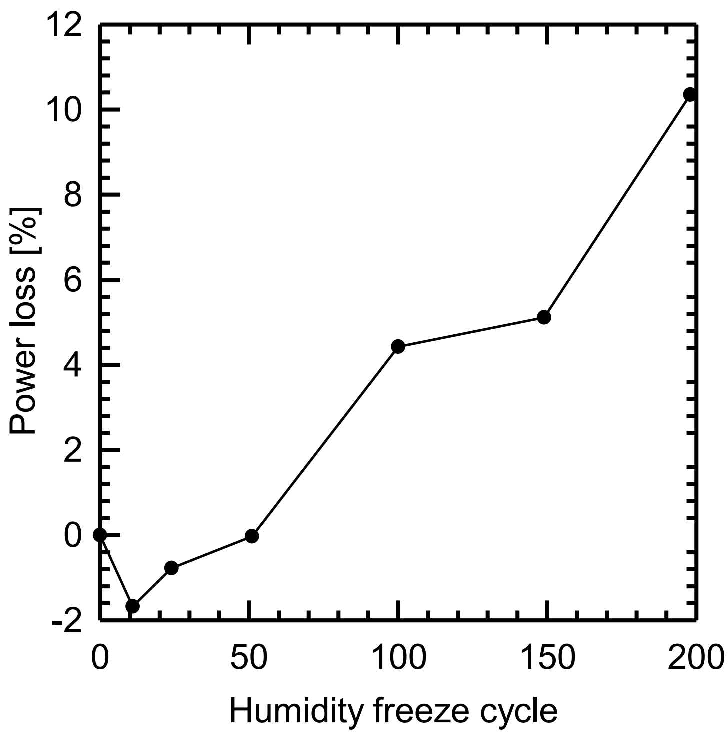
Origin and Consequences of (Micro)-Cracks in Crystalline Silicon Solar modules

M. Köntges[1], I. Kunze[1],
S. Kajari-Schröder[1],
X. Breitenmoser[2] and B. Bjørneklett[2]

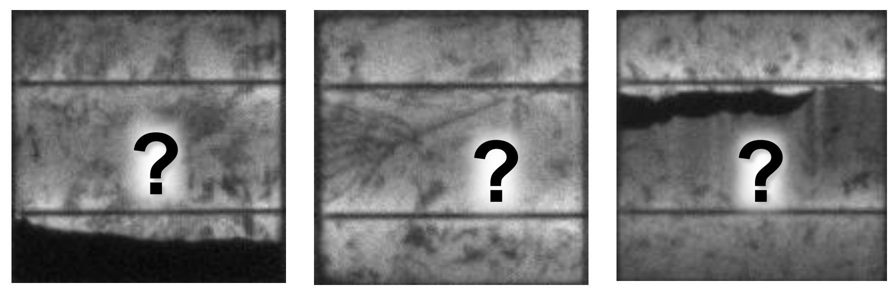
[1]Institute for Solar Energy Research Hamelin
[2]REC Solar AS

Motivation / Outline

Initially all cells show micro cracks



- Crack detection methods
- Influence on power generation
- How much cracking is acceptable ?
- Origin of statistical distribution of cracks



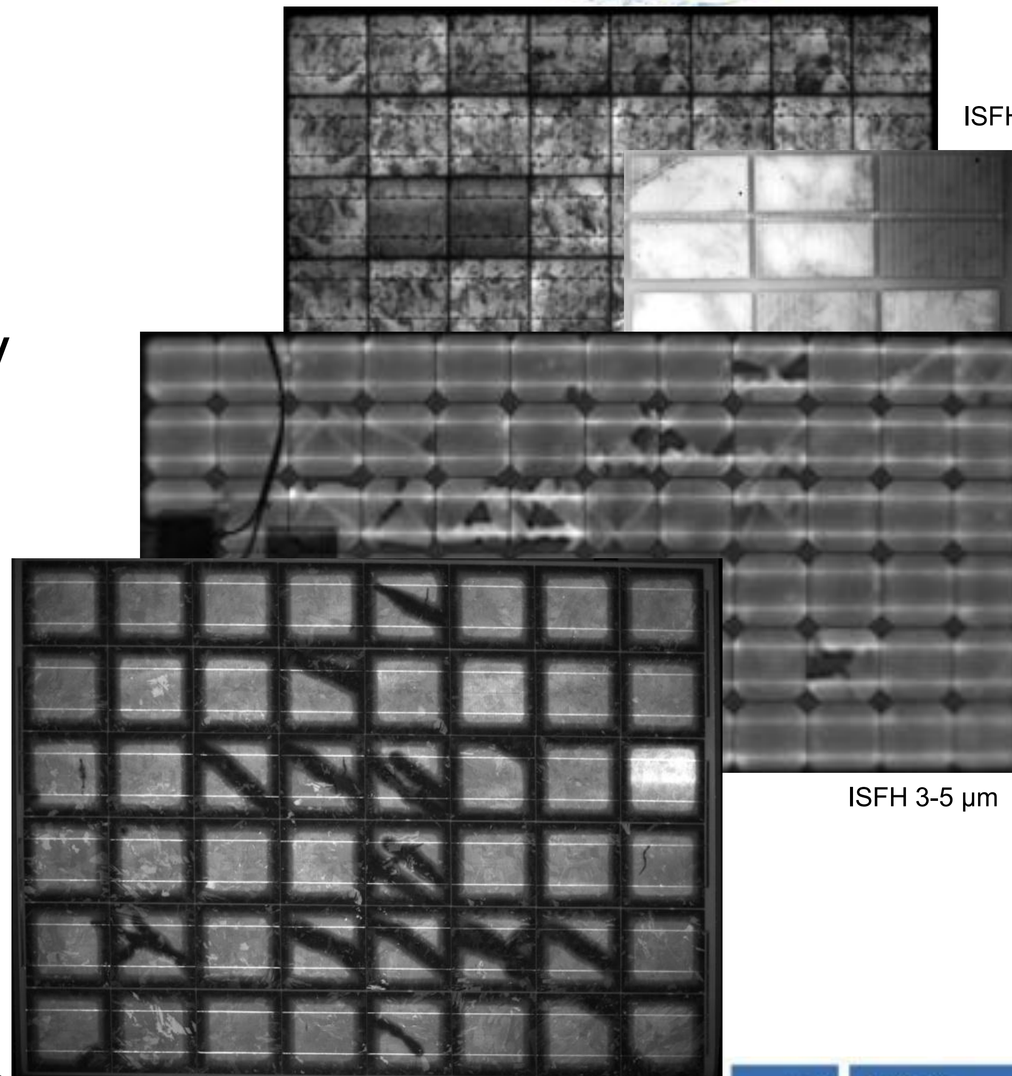
M. Köntges, et al., Sol. Energy Mater. Sol. Cells (2011),doi:10.1016/j.solmat.2010.10.034
M. Köntges, et al., 25th EUPVSEC (Valencia, Spain, 2010,WIP) , 4BO.9.4

Crack detection in the PV module

- Electroluminescence[1]
- Si photoluminescence
- Dark lock-in thermography

After aging, indirect

- EVA fluorescence[2] oxidation/vanishing of fluorescing molecules through cracks



ISFH 1150 nm

ISFH 3-5 µm

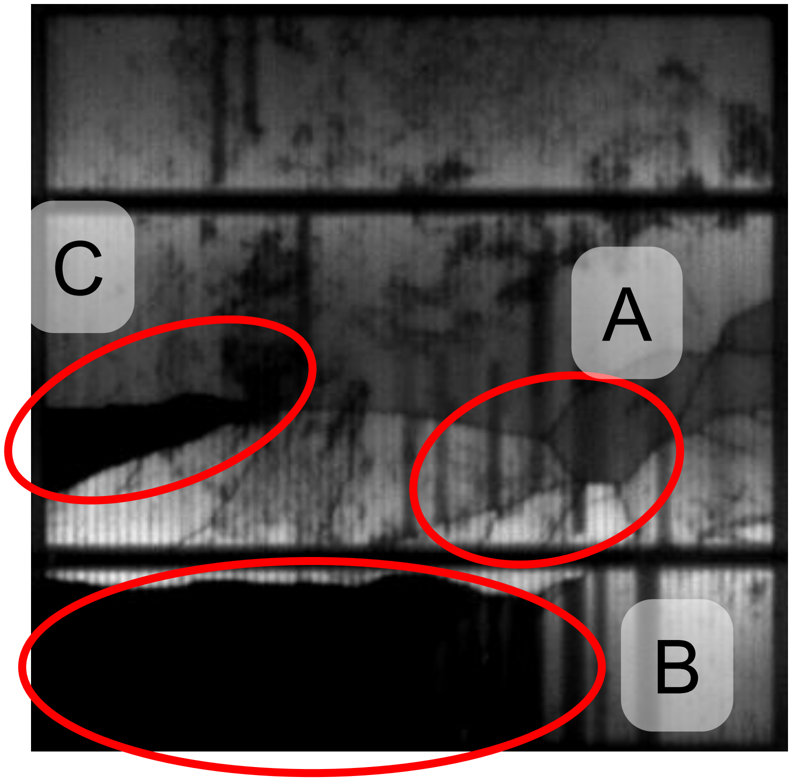
ISFH 534 nm

[1]T. Fuyuki, et al., *Applied Physics Letters* **86** (2005) 262108
[2]J. Schlothauer, et al., Photovoltaik International 10 (2010), 149-154

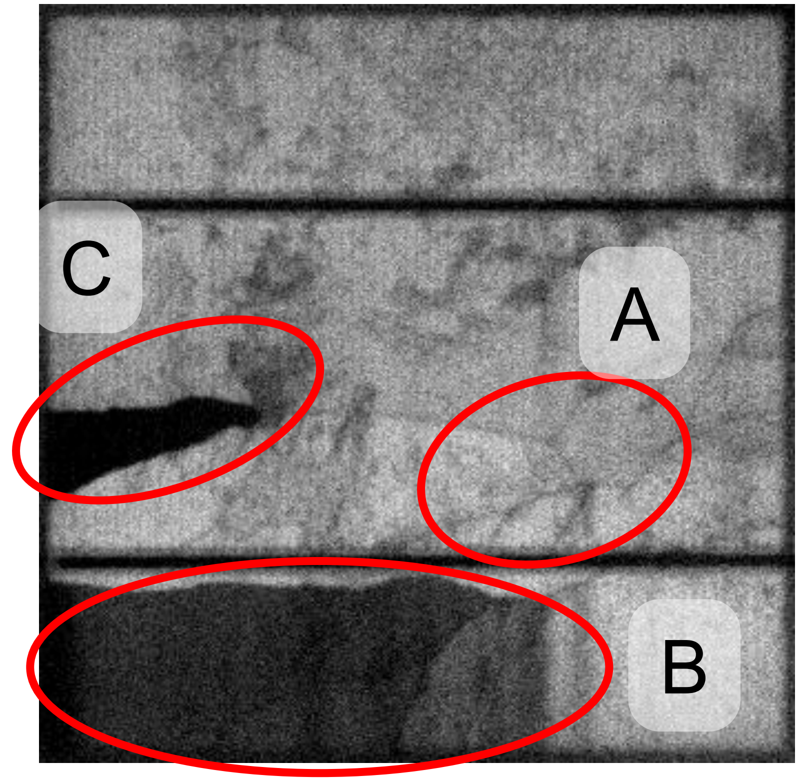
Infuence on power generation ?

Crack mode definition

EL image @ I_{sc}



EL image @ 1/10 I_{sc}



Crack mode:

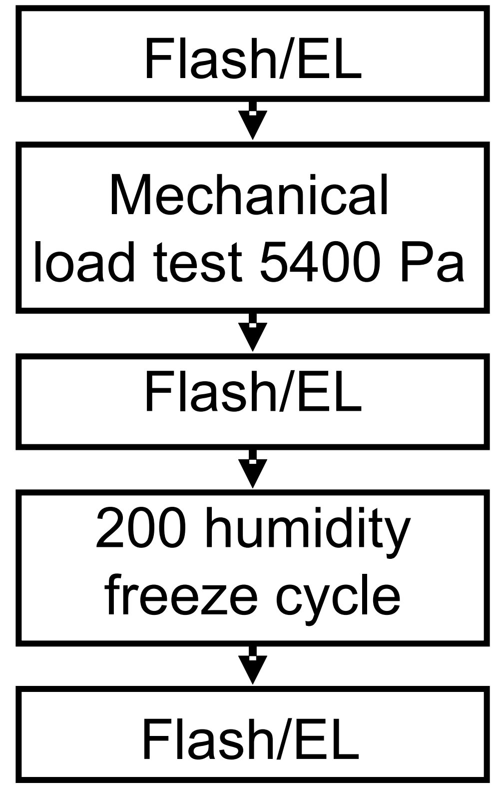
A ➔ no increased resistivity

B ➔ still connected but increased resistivity

C ➔ disconnected, inactive cell area

Experimental

- 230 W modules with 60 15.6 cm^2 cells
- Inflict cracks to cells in PV module by mechanical load test (IEC 61215)
- Stress cracked cells by 200 HFC (similar to IEC 61215)
- Determine power loss due to mechanical load
- Determine power loss after 200 HFC aging



Find influence of cracks to PV module power

Transportsimulation + TC: S. Pingel et al., 24th EUPVSEC (2009, Hamburg, Germany, WIP) 4AV3.49
Simular test: Wohlgemuth et al., 23rd EUPVSEC (2008, Valencia, Spain, WIP) 4EP1.2

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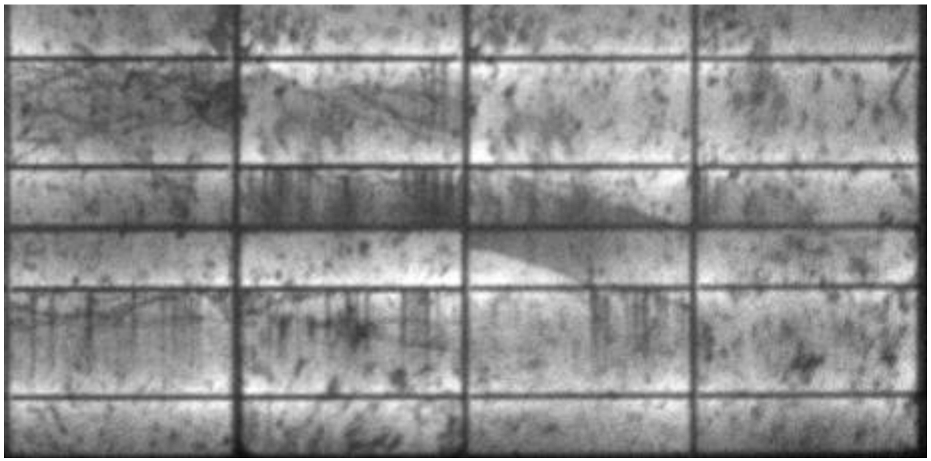
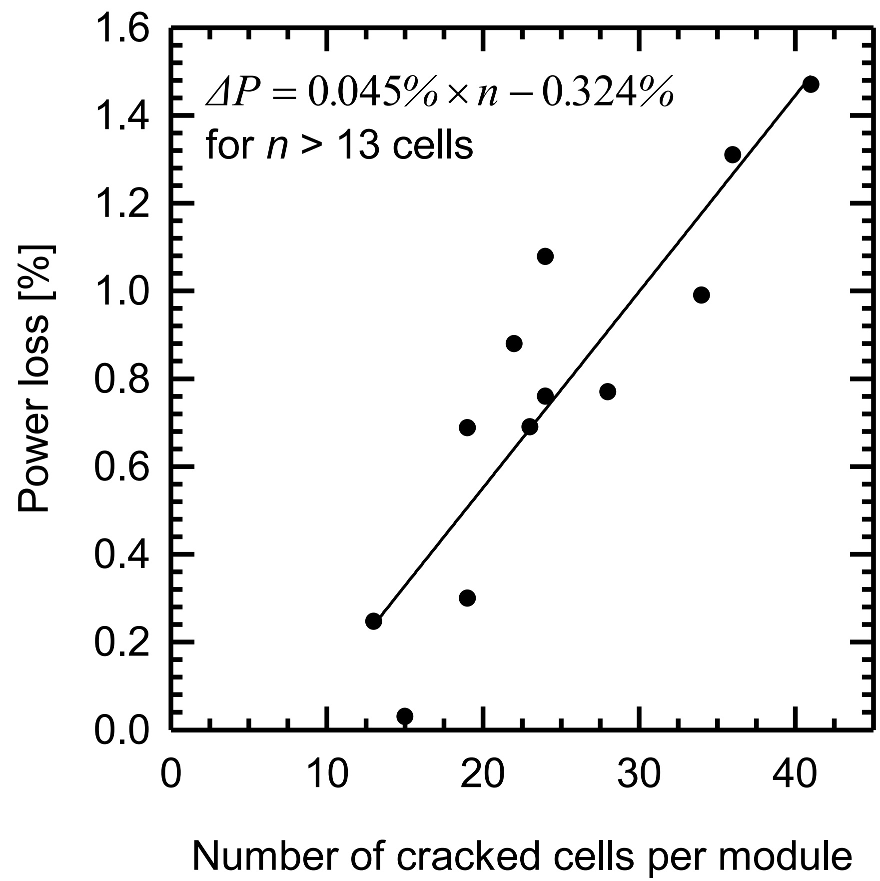
Mode A cracks

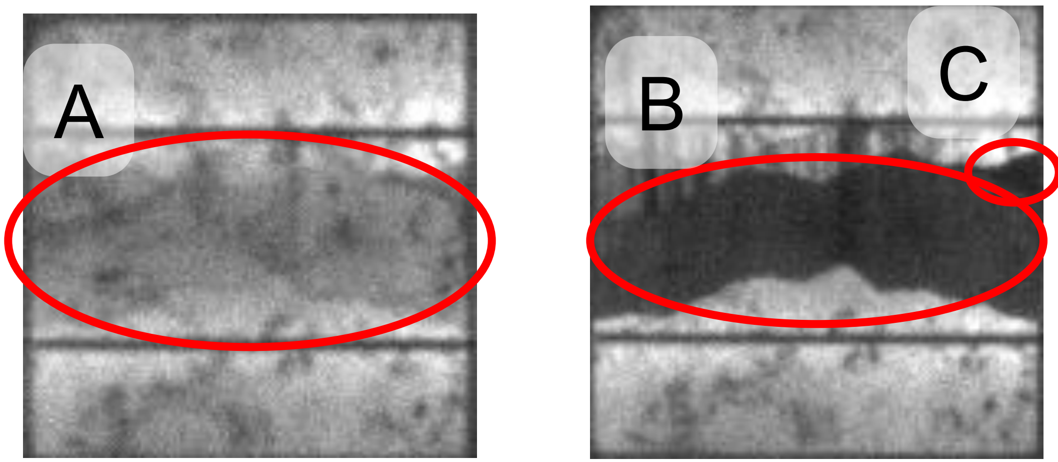
PV modules of 60 x 15.6 cm cells



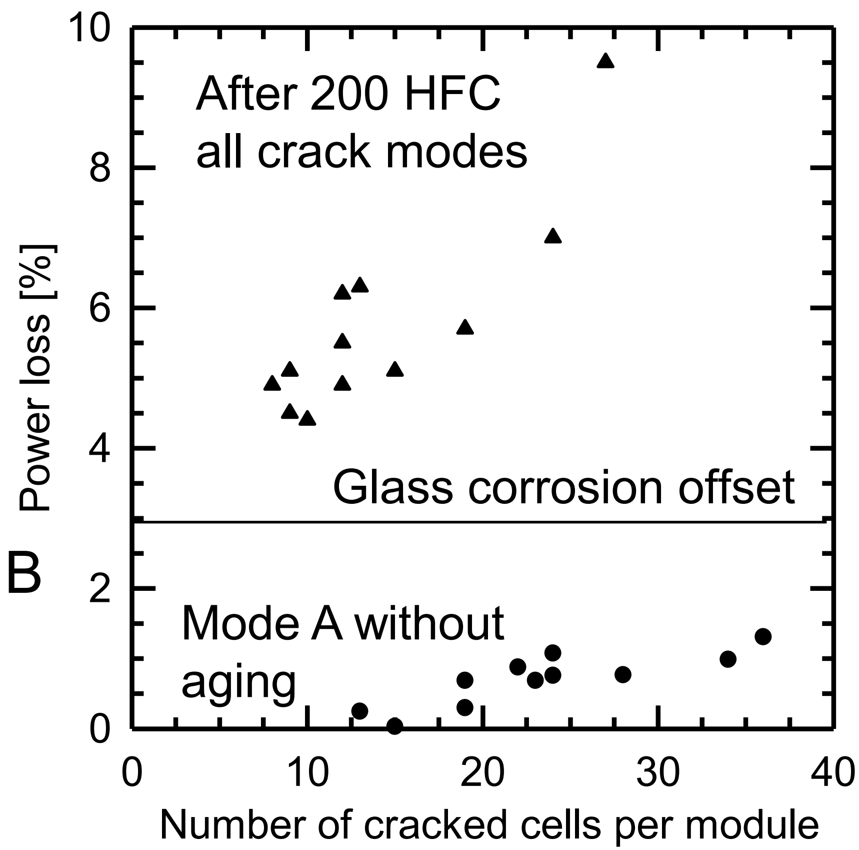


- Some solar cells with cracks
  ➔ power loss not measurable
- Half of cells show cracks
  ➔ only approx. 1% power loss
- All cells show micro cracks
  ➔ < 2.5% power loss

After 200 humidity freeze cycle



PV modules of 60 x 15.6 cm cells



- 3% degradation offset due to glass corrosion (I_{sc} loss)
- Predominant change from mode A to B
- Few cases A to C
- Power loss increases with no. of cracked cells

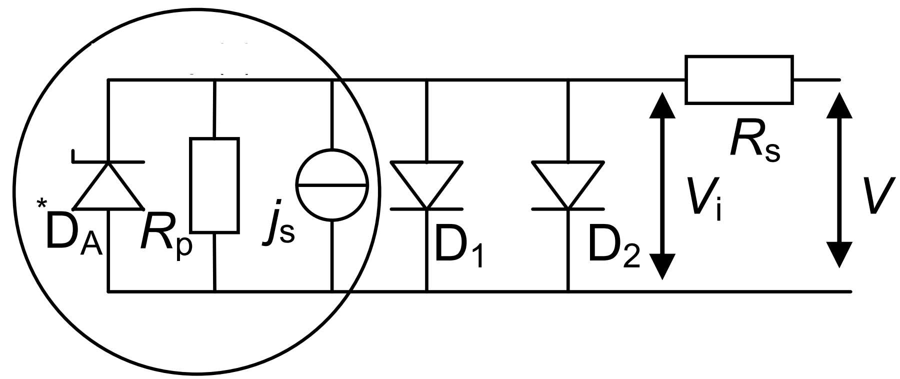
How much cracking is acceptable ?

PV module simulation

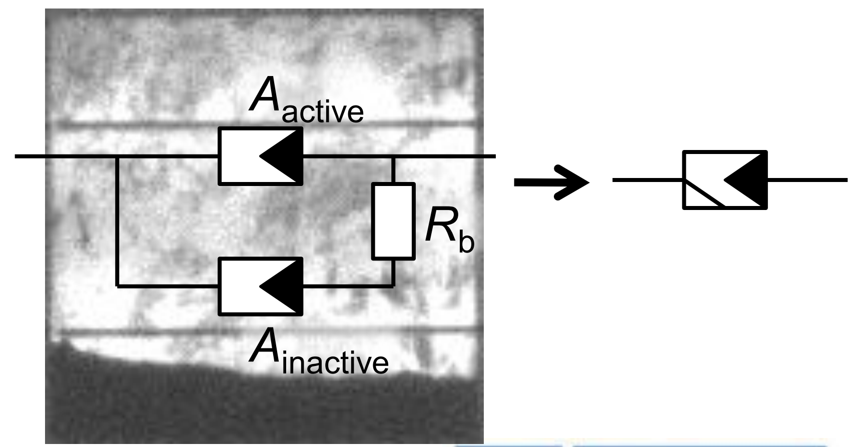
Aim: Power loss simulation
due to mode C cracks

- LT Spice for electrical simulation
- Two diode model for each cell
- Power loss due to defective cell is influenced by breakdown voltage
- Breakdown model of Alonso-Garcia*
- Break resistance R_b connect broken cell area $A_{inactive}$

Cell equivalent network

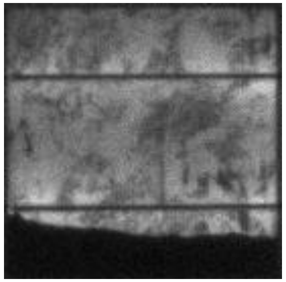


New symbol for broken cell



*M.C. Alonso-Garcia et al., *Solar Energy Materials & Solar Cells* **90** (2006) 1105–1120

Worst case scenarios

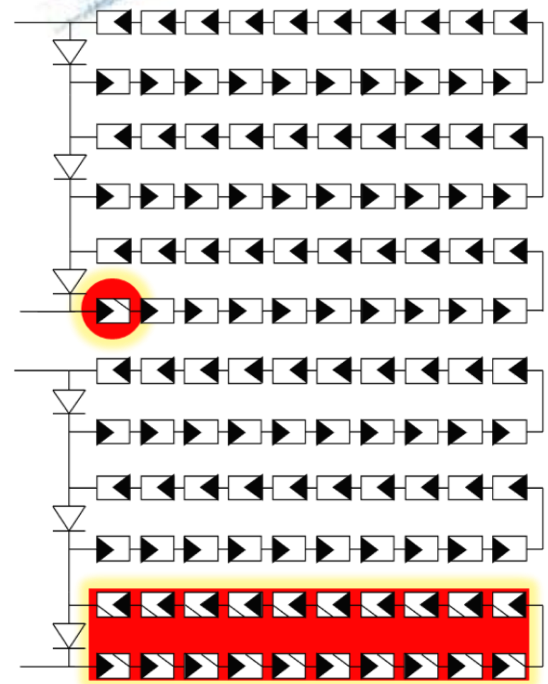


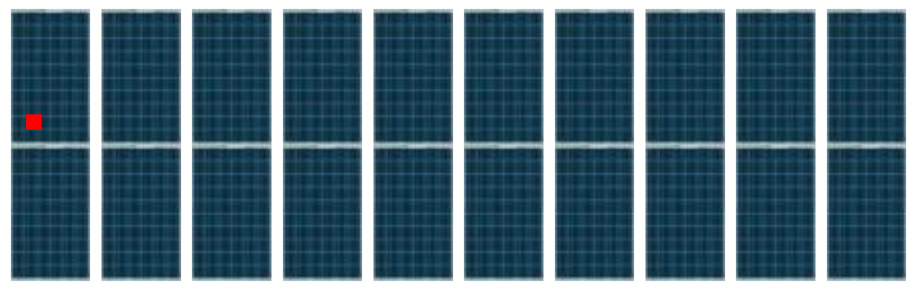
Power loss due to crack mode C

I Single defective cell in a PV module

II Multiple defective cells in a double string

III One PV module with single defective cell in a PV array





20s PV module array - series interconnected

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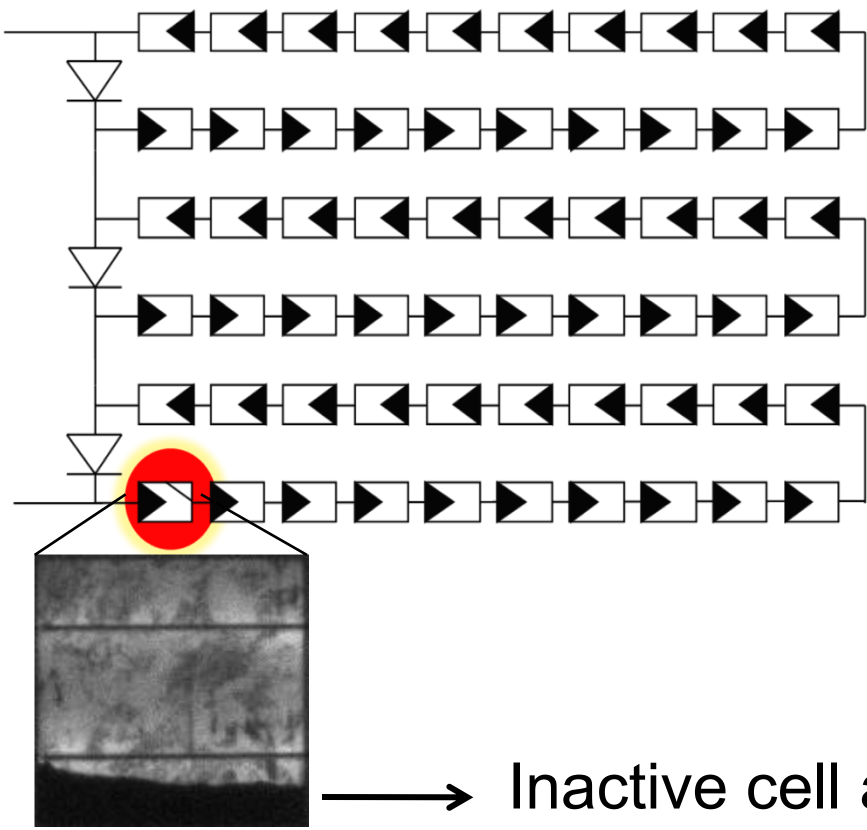
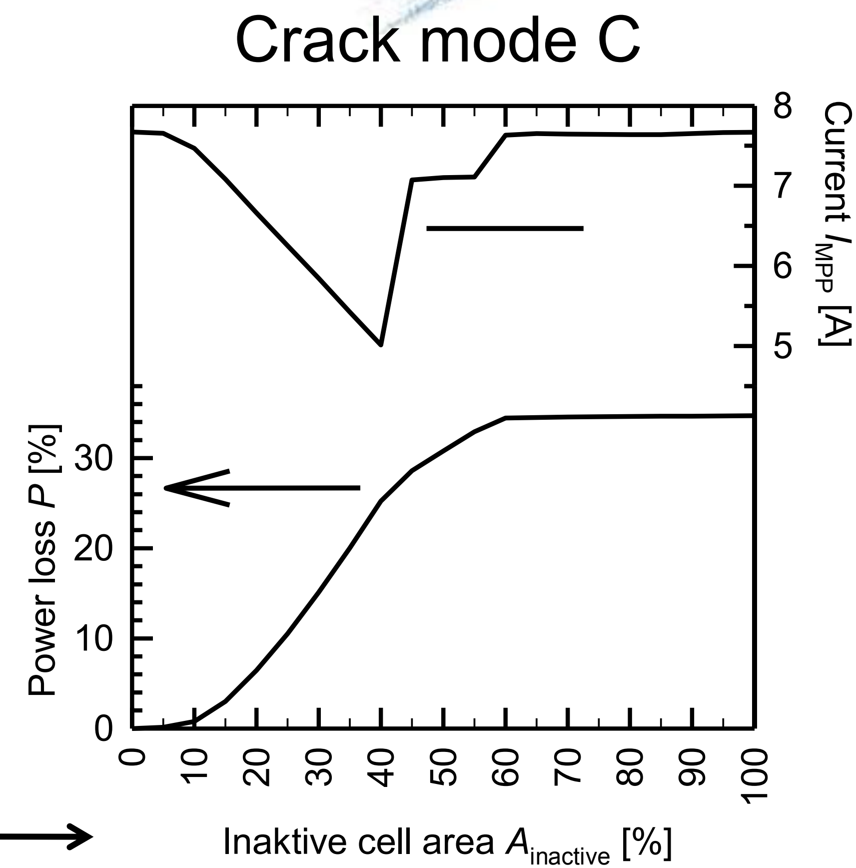
Scenario I single defective cell

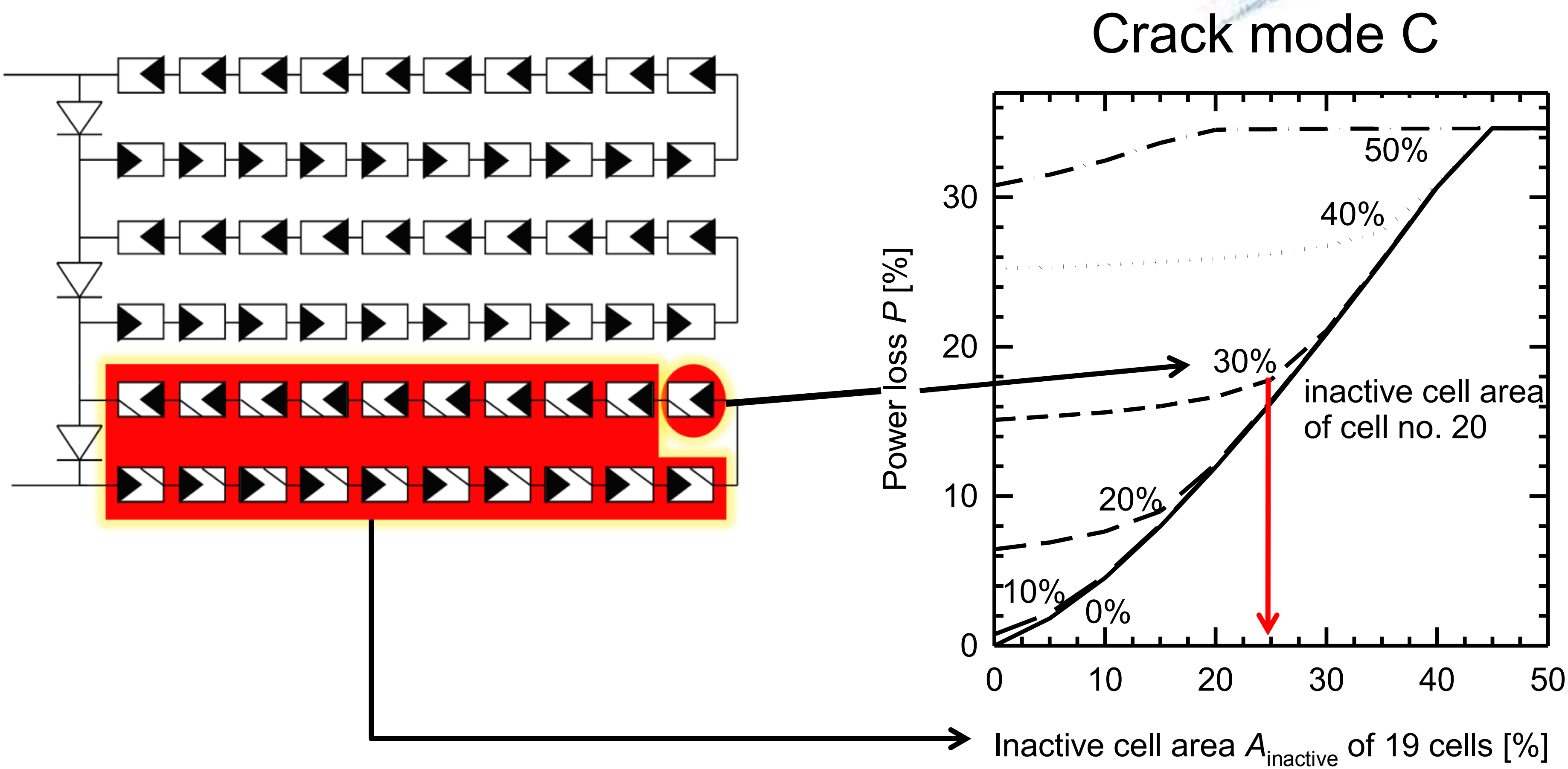


Inactive cell area



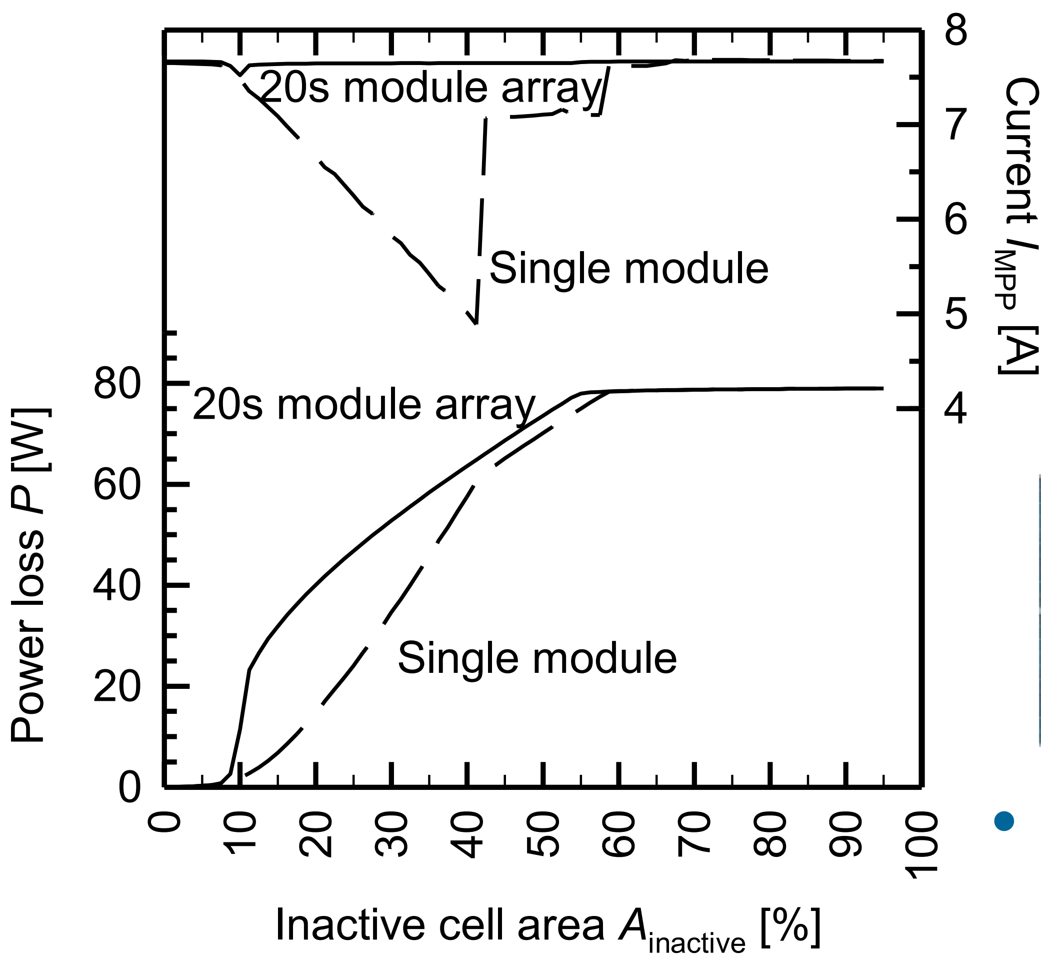
- 8% inactive cell area acceptable
- Huge inactive area rise risk of hot spots, power loss

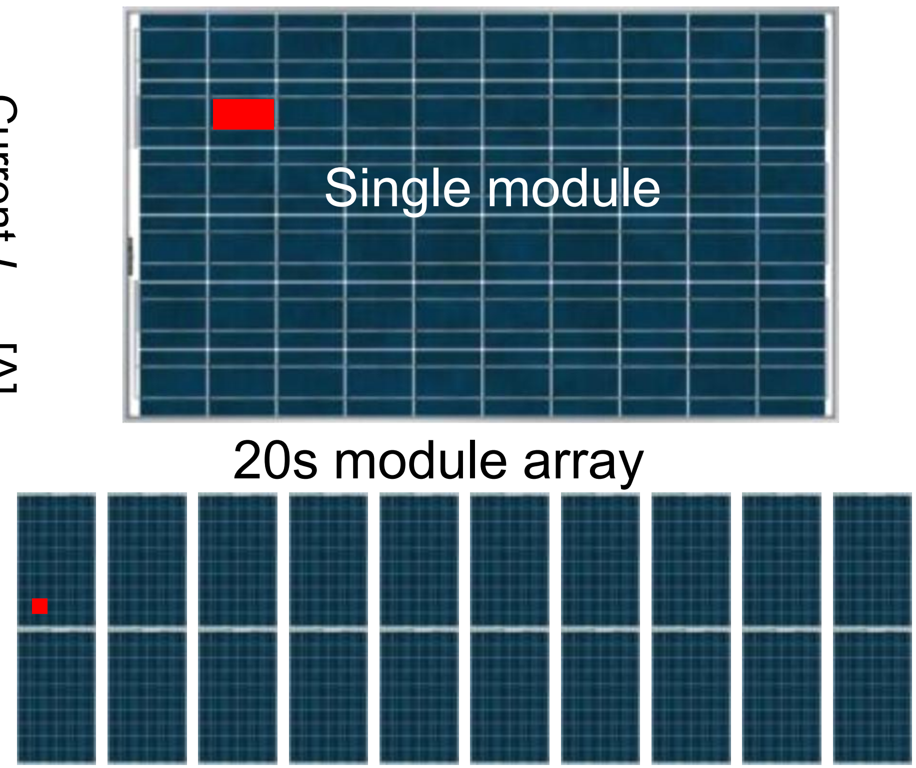
Scenario II multiple defective cells



- Maximum inactive area in double string determines power loss

Scenario III PV module array





- 8 % inactive area is acceptable for PV systems

Origin of statistical distribution of cracks

- IEC 61215 mechanical load

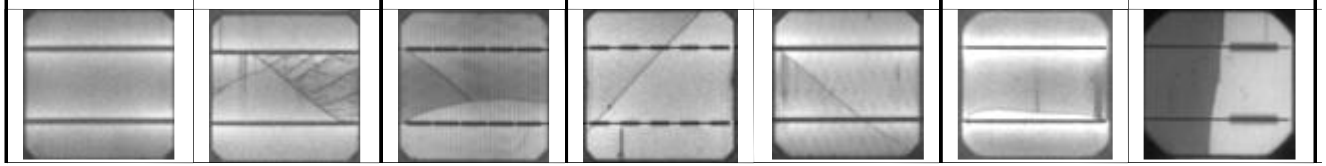
compare to

- transported PV modules

Transport simulation: F. Reil et al., 6. Workshop – „Photovoltaik-Modultechnik“, TÜV Rheinland Nov, 2009, Köln
Set up a transportation test standard: Poster from TÜV Rheinland at this Workshop

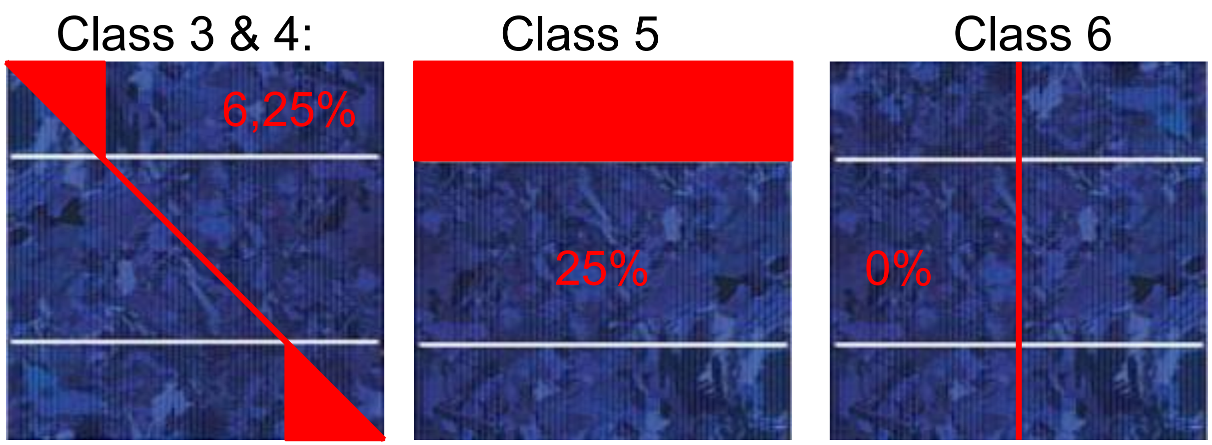
Crack classification

0	1	2	3	4	5	6
No crack	Dendritic	Various	+45°	-45°	Parallel	Perpen.



- Class 1,2 and 5: most area loss possible
- Class 3 and 4: medium area loss possible
- Class 6 : No area loss possible

Worst Case single crack



Crack classification

0	1	2	3	4	5	6
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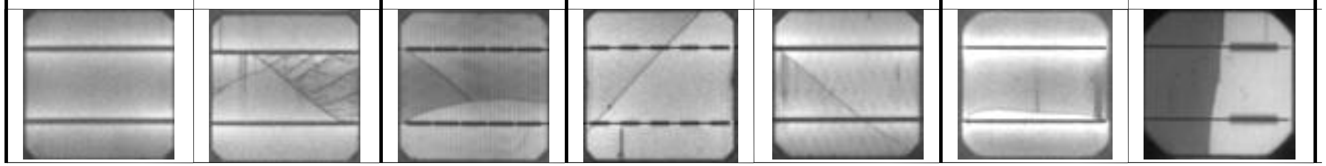
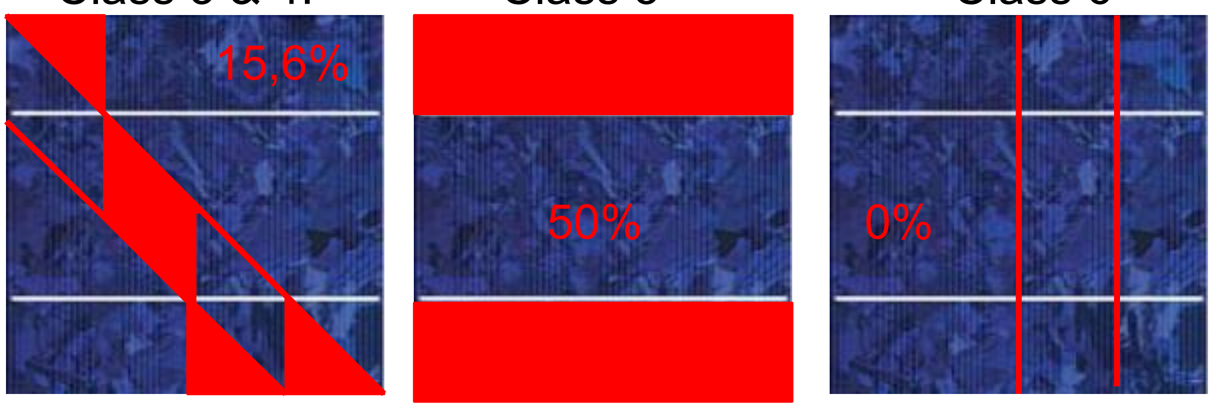


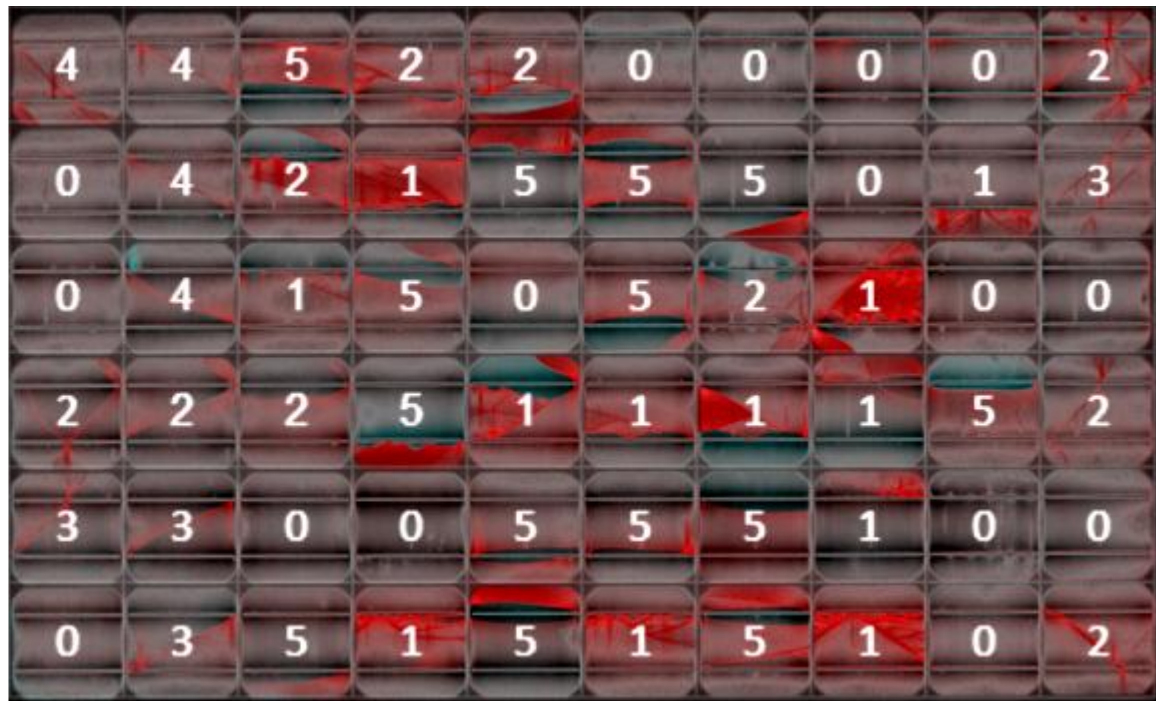
- Class 1,2 and 5: most area loss possible
- Class 3 and 4: medium area loss possible
- Class 6 : No area loss possible

Worst case double cracks



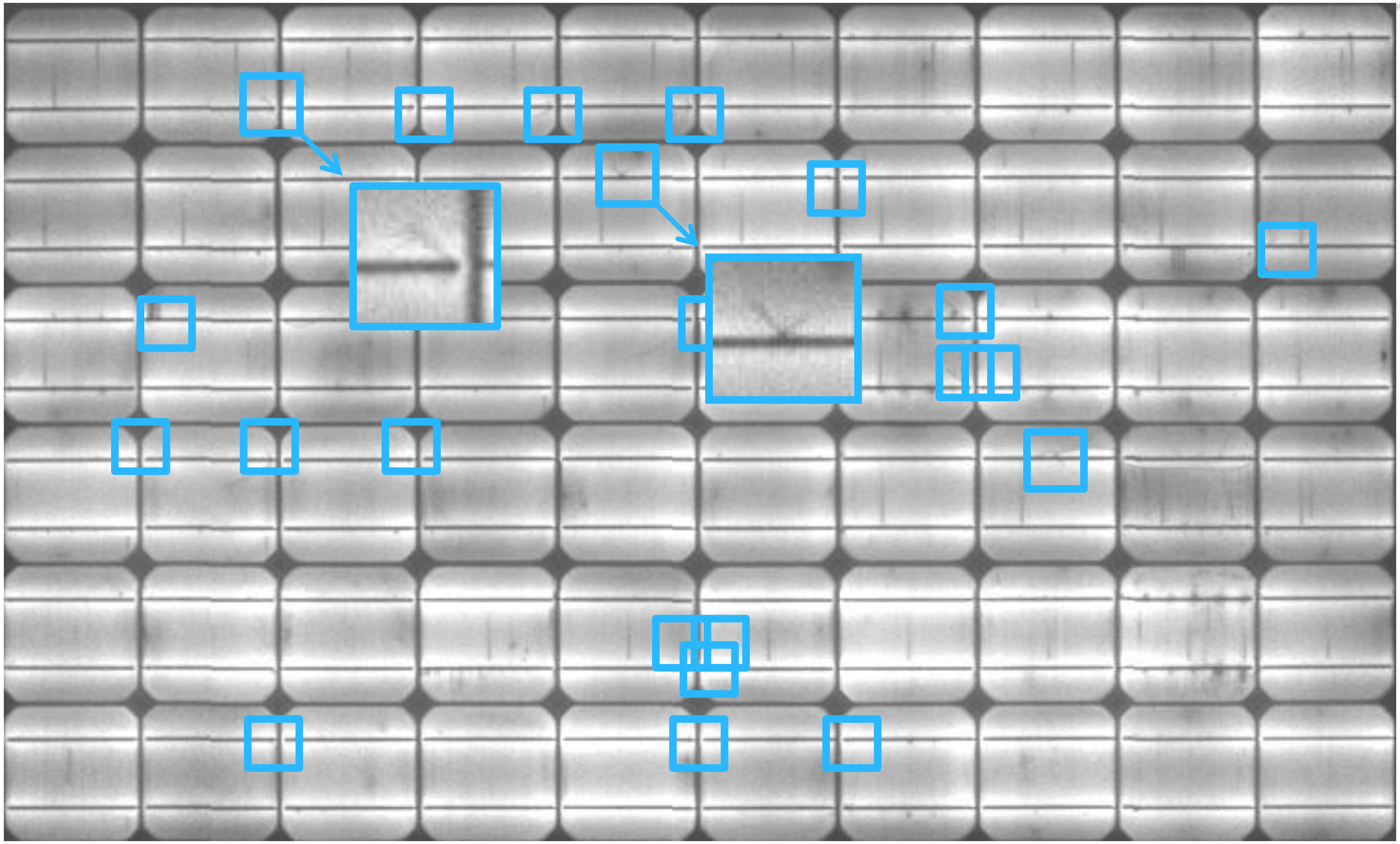
Classification for mechanical load

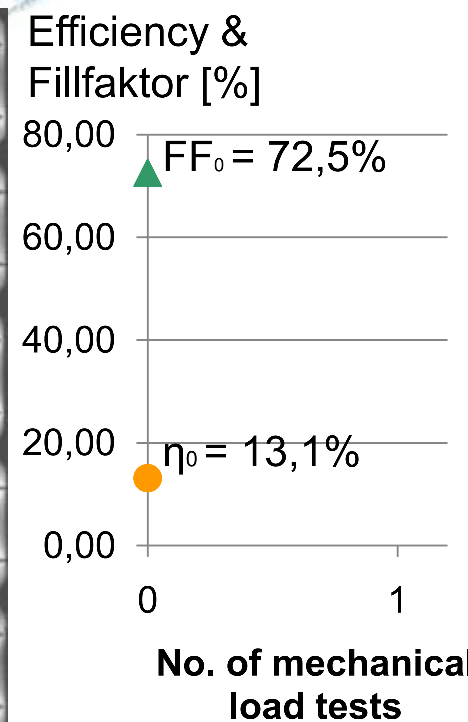
- Mechanical load 5400 Pa
- EL image before/after
- Mapping with image registration method
- Difference EL image
- Subjective classification



Red → image becomes dark
Black → image does not change
Green → image becomes brigther

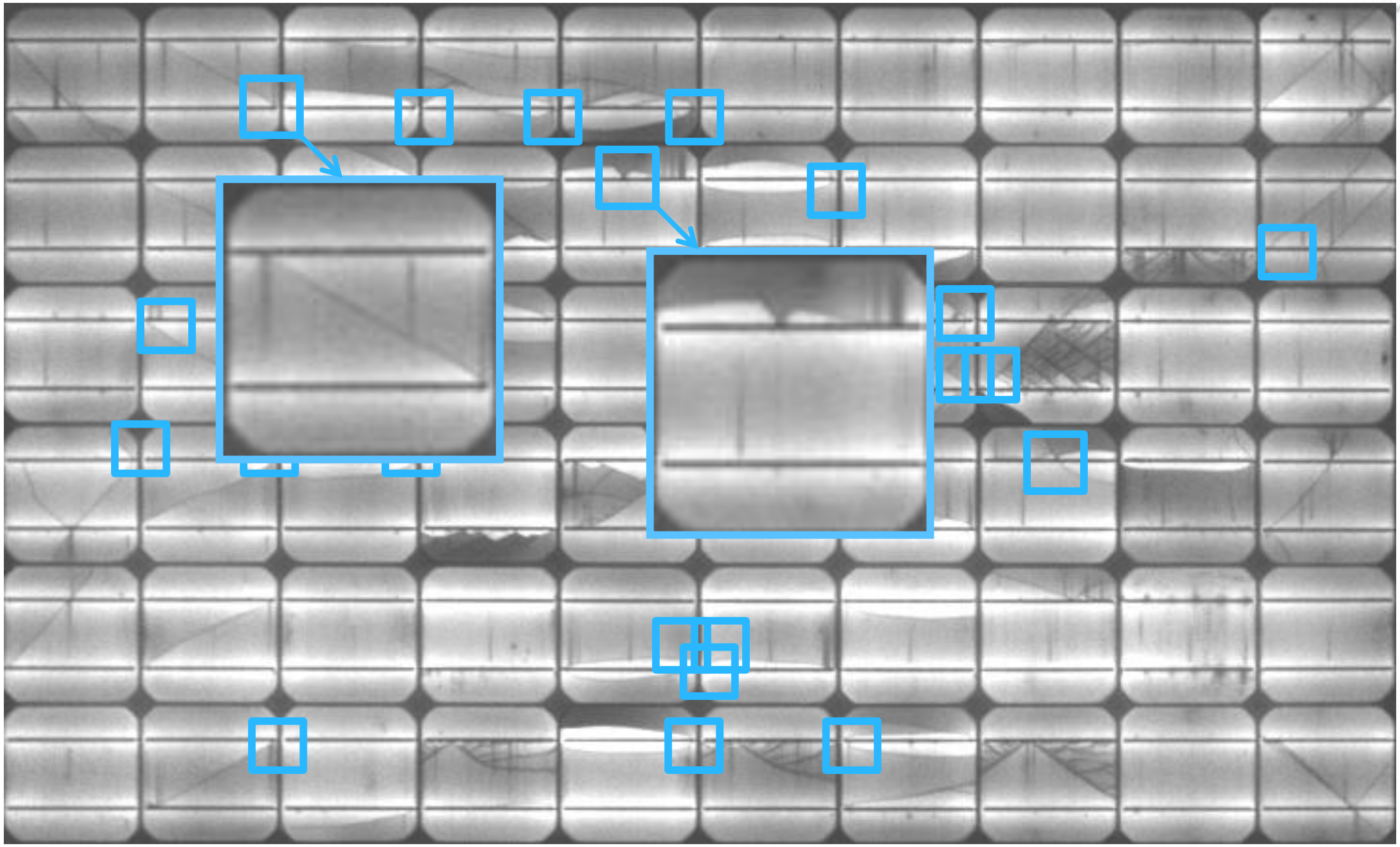
Initially precracked PV module

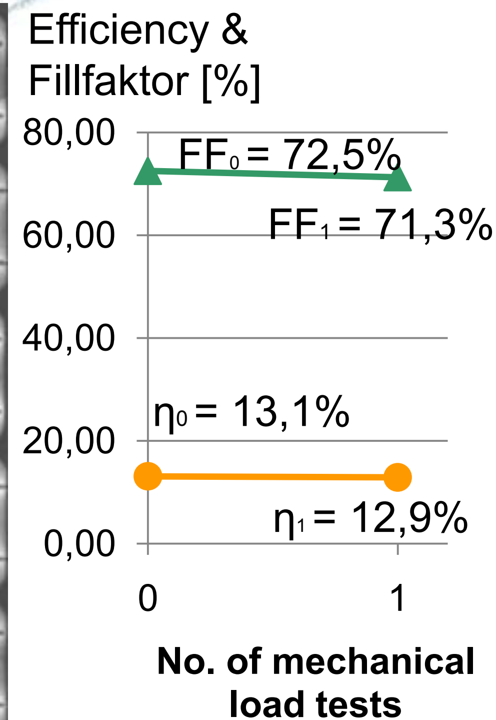




- Initial cracks at the busbars

5400 Pa mechanical load





- Cracks do not always follow the initial crack or the preferred crystallographic crack orientation !

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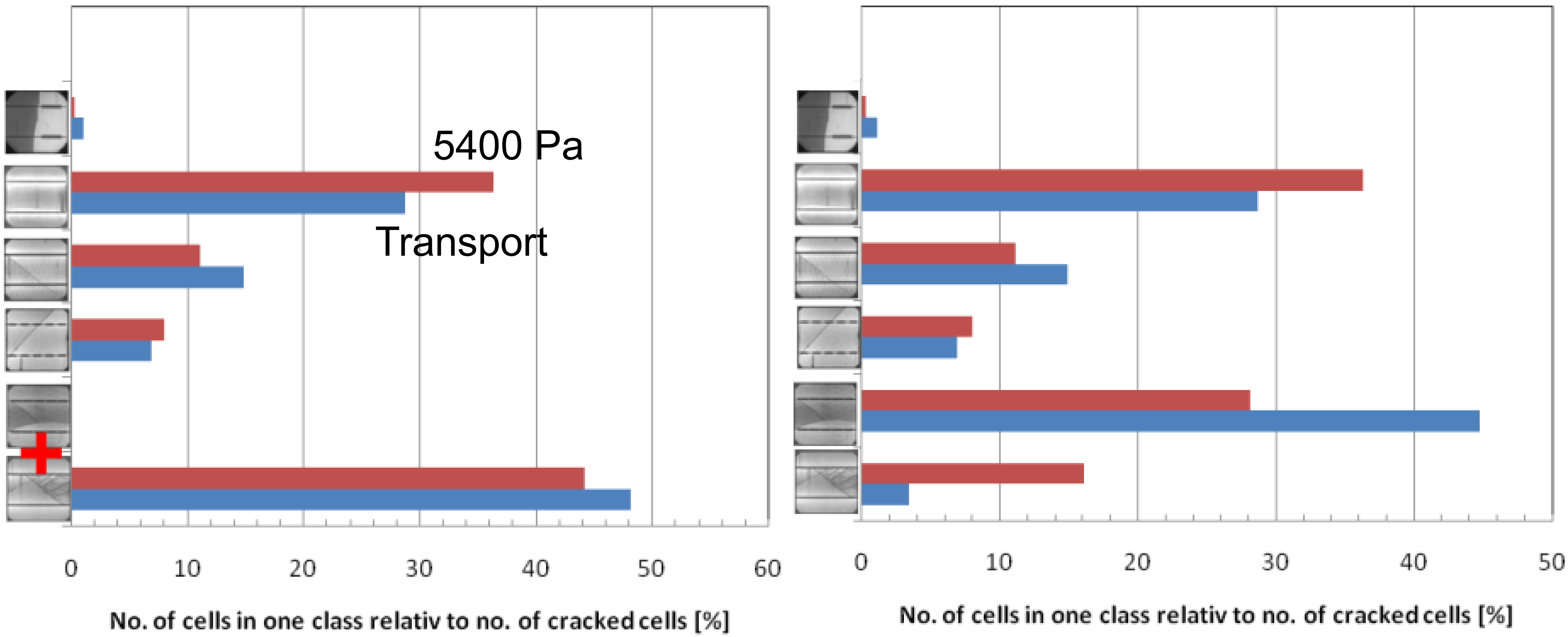
Cracks of transported PV modules



- Crack distribution of mechanical load test & transport is similar
- At 5400 Pa test shift from “Various” to “Dendritic” crack class
- Dendritic cracks occur at high strain
- High occurrence for worst case crack classes 1,2,5

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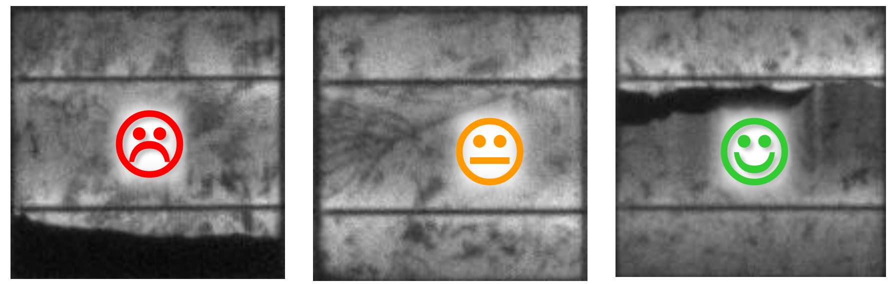
Summary

- Crack distribution of mech. load is similar to transported modules
- Most real cracks are in most disadvantageous directions

Power loss due to

- mode A cracks is linear with no. of cells & less than 2.5%
- an mode C crack is acceptable as long as inactive part is less than 8% of cell area



Power loss is

- dominated by cell with maximum inactive area per double string

Funding was provided by the State of Lower Saxony and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety with the support code 0325194C