POTENTIAL-INDUCED DEGRADATION (PID) AT THE REAR SIDE OF BIFACIAL PERC SOLAR CELLS

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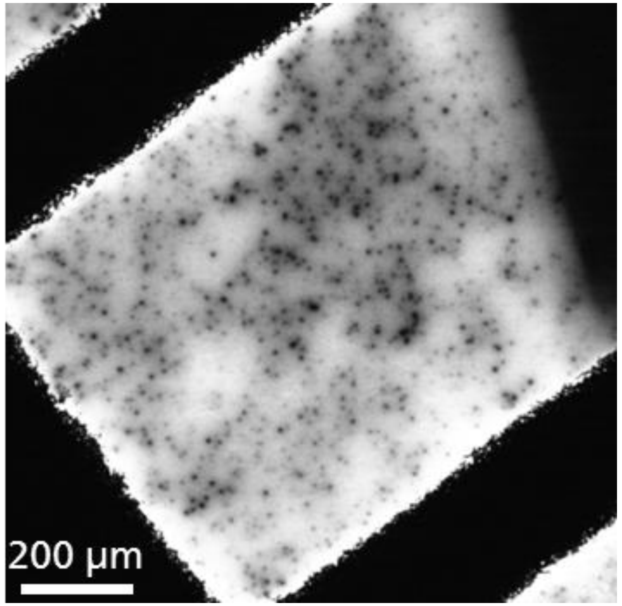

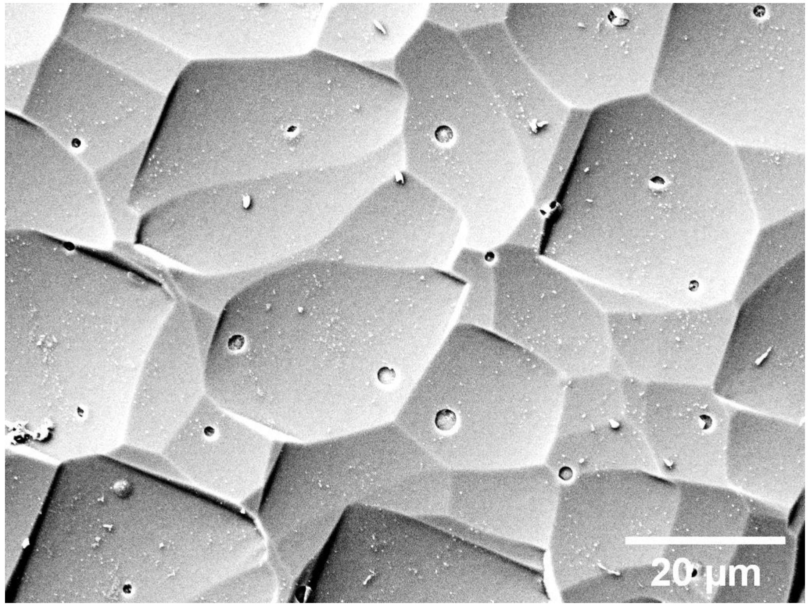

OUTLINE

- Potential induced degradation (PID) in PV power plants
- PID at the rear side of bifacial passivated emitter and rear cells (PERC)
  - Empirical findings
  - De-polarization PID (PID-p)
  - Corrosive PID (PID-c)
  - Contradictory PID behavior under illumination
- Summary

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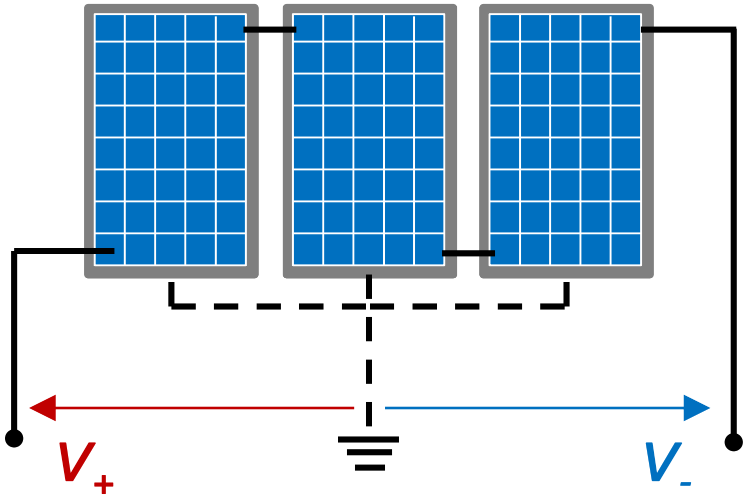
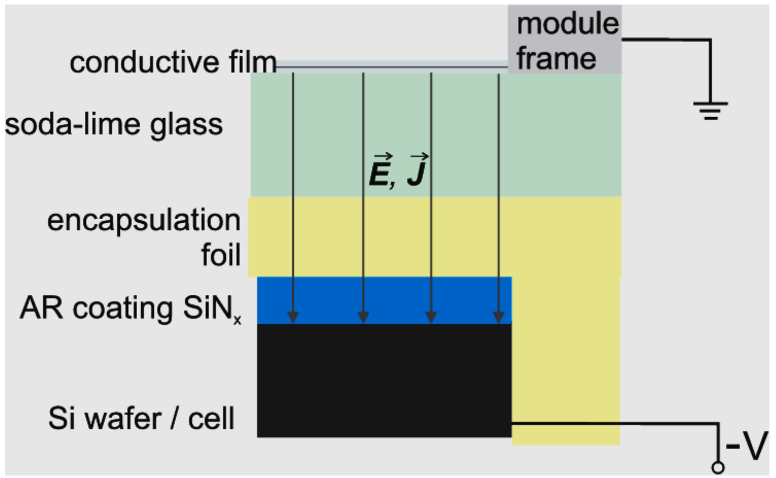
Conditions for PID in PV power plants
High voltages: the driving force for leakage currents

PID causes severe power losses in PV modules with silicon solar cells

- Addition of serially connected module voltages
- Cause: high voltage between (grounded) module surface and solar cells
- Leakage current $\vec{J}$ <u>also at the rear side of modules</u>



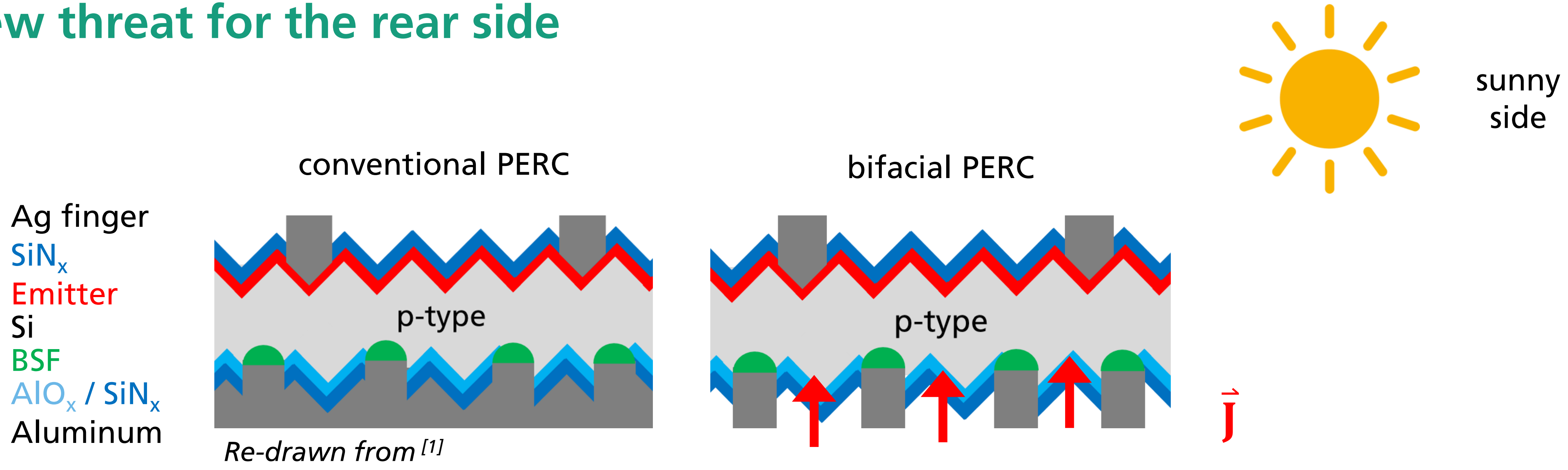
Series connection of PV modules with a floating potential



PV module under influence of high voltage

Potential induced degradation of bifacial PV modules

An new threat for the rear side



- Rear side power gain achieved by partial metallization at the rear side [1]
- Missing metallization: rear side is no longer shielded against electric fields [2]
- ➢ **Additional path for leakage currents at the rear side**

[1] Dullweber, T. et al., Bifacial PERC+ solar cells and modules: an overview, 33rd EUPVSEC 2016.
[2] Luo, W. et al., Progress in Photovoltaics: Research and Applications (2018).

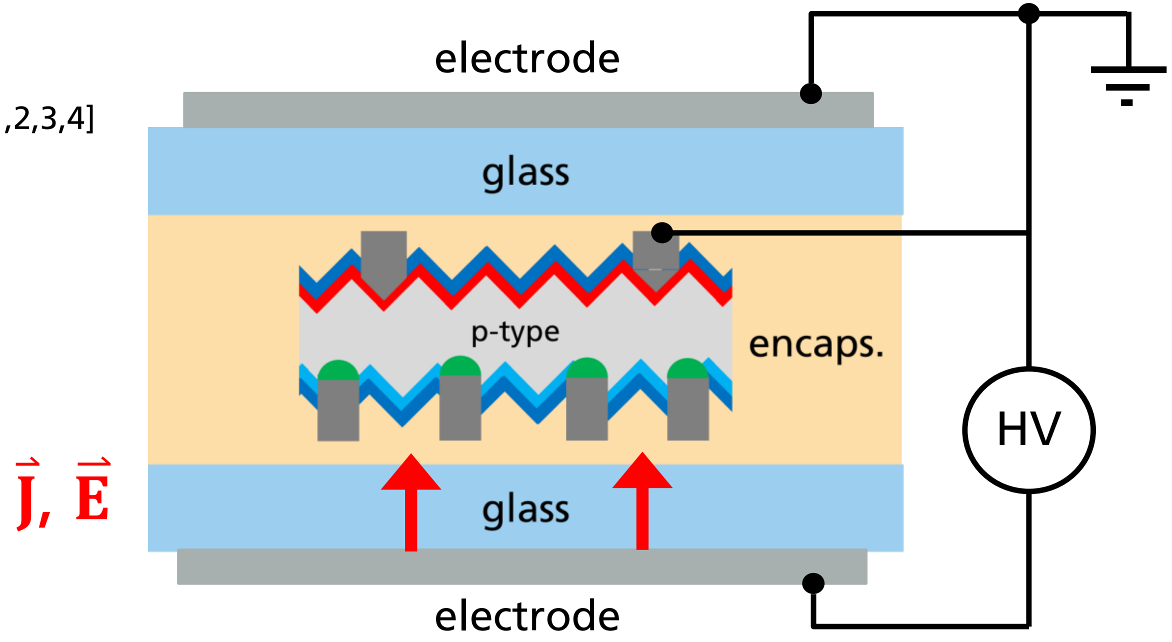
Rear side PID tests

High voltage stress applied to the rear side only

- Voltage U = 1 kV
- High voltage is only applied to the rear side [1,2,3,4]

Different test conditions

- Temperature:
  40 °C [1], 50 °C [2], 60 °C / 85 °C [3,4]
- Duration: 24 h [2,3,4], 40 h [1]



[1] Luo, W. et al., IEEE Journal of Photovoltaics 8.5 (2018): 1168-1173

[2] Luo, W. et al., Progress in Photovoltaics: Research and Applications (2018).

[3] Sporleder, K. et al., RRL 2019, DOI10.1002/pssr.201900163

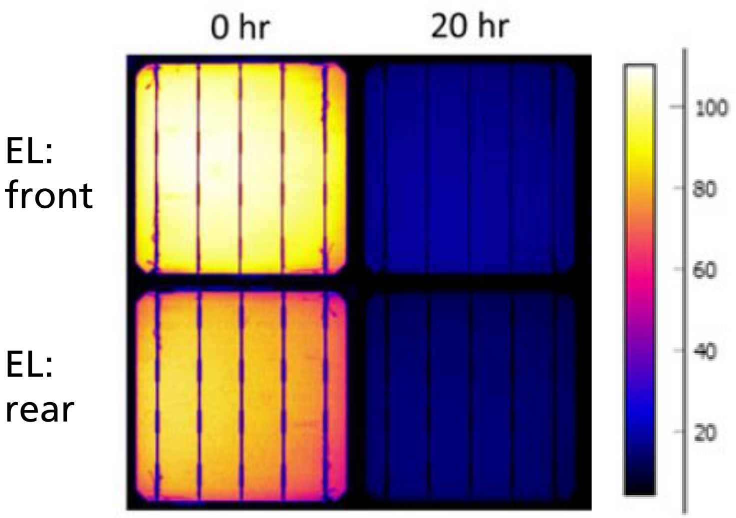
[4] Sporleder, K. et al., SOLMAT 201 (2019): 10.1016/j.solmat.2019.110062

Next slides refer to rear side PID tests

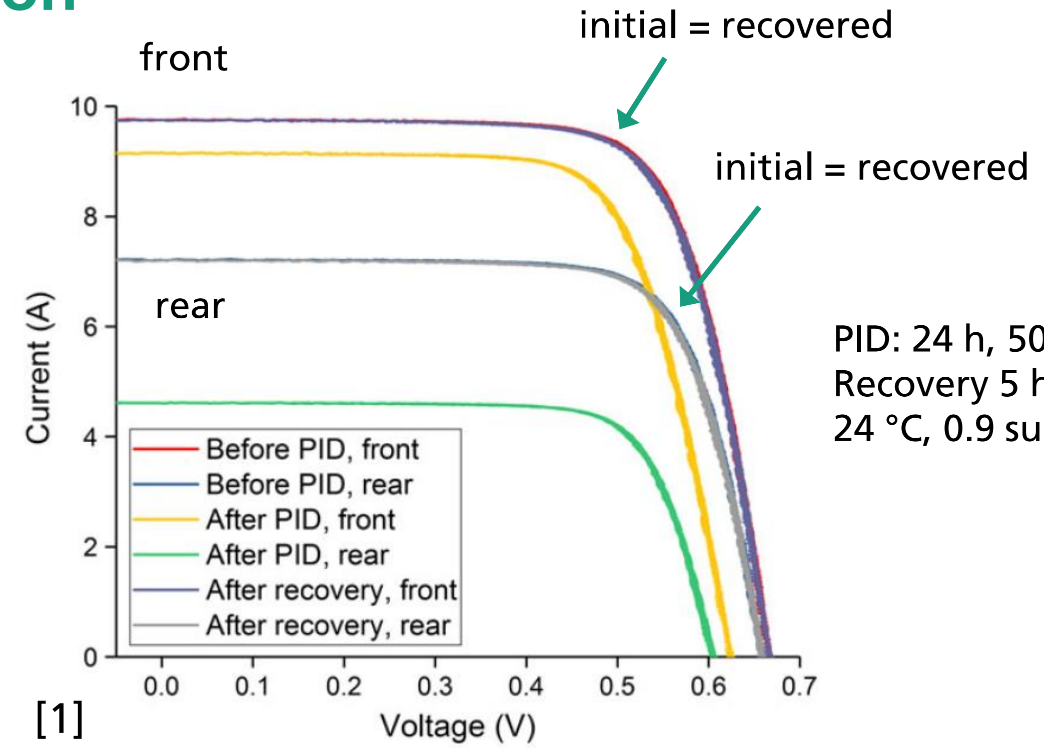
Potential induced degradation of bifacial PERC

Laterally homogenous rear side degradation

- Current and voltage loss
- No shunting of p-n junction
- FF is not the dominating loss factor
- Full recovery achieved after illumination (unlike PID of the shunting type, PID-s)



Electroluminescence images [1]



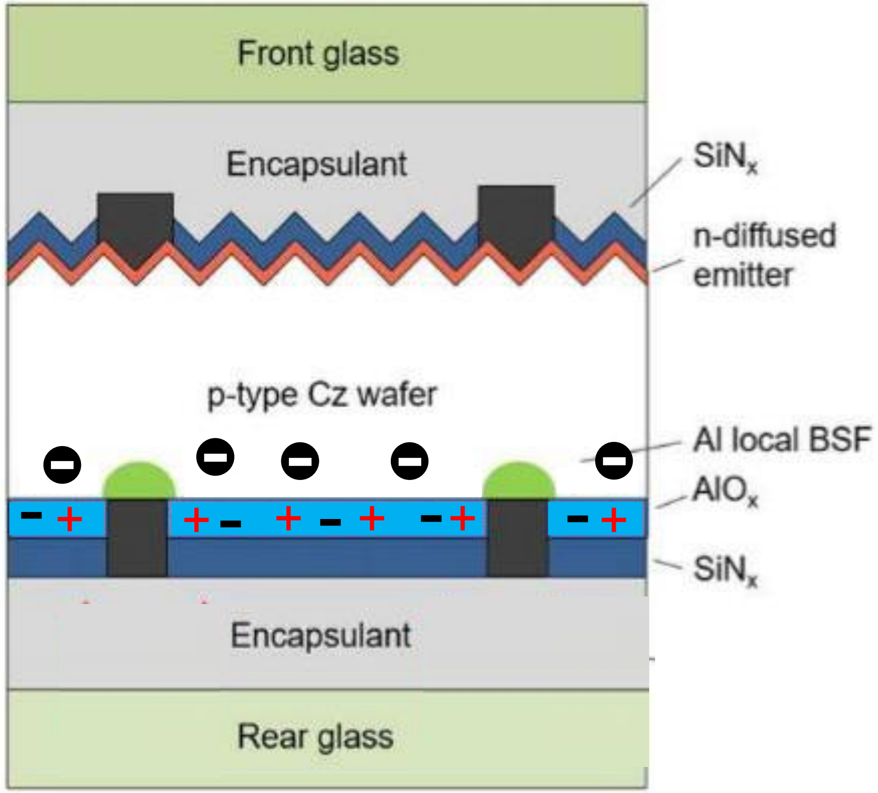
PID: 24 h, 50 °C
Recovery 5 h, 24 °C, 0.9 suns

- Lateral homogenous degradation, unlike PID-s
- Present mechanism: de-polarization PID (PID-p)

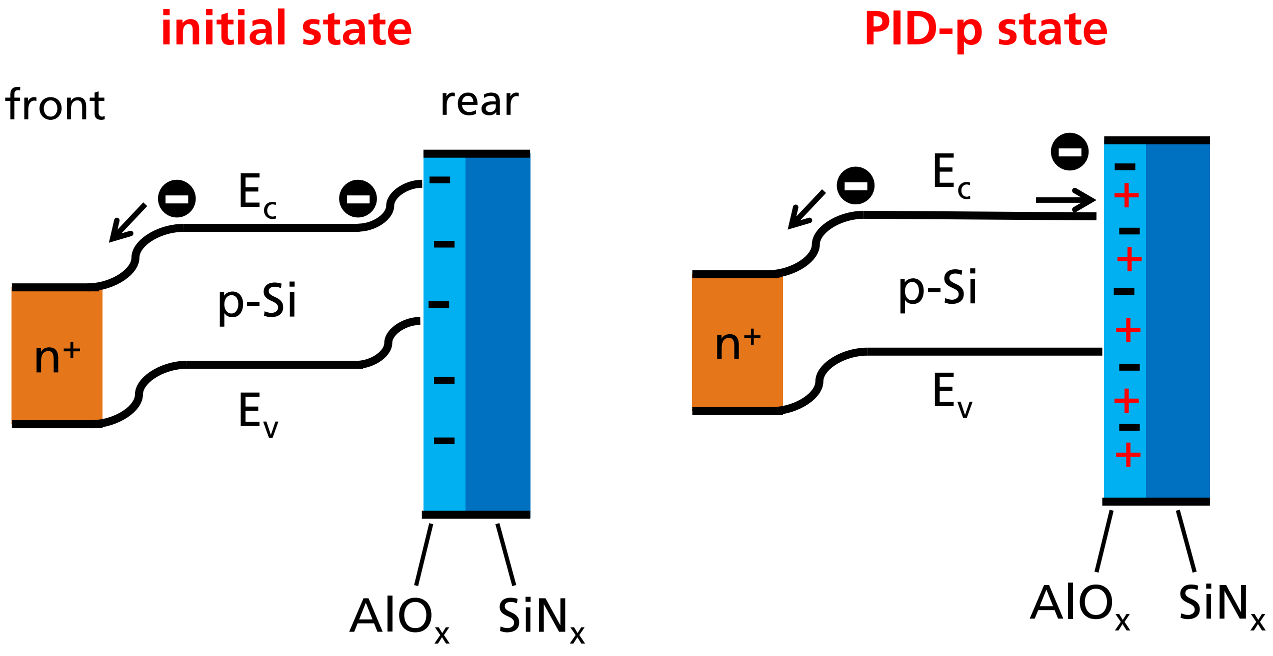
[1] Luo, W. et al., Progress in Photovoltaics: Research and Applications (2018).

Potential induced degradation of bifacial PERC

De-polarization of charges in AlO_x passivation layer (PID-p)



[1]



- De-polarization ~ compensation of field effect passivation [1,2]

[1] Luo, W. et al., Progress in Photovoltaics: Research and Applications (2018).

[2] Swanson, R. et al., 15th PVSEC. Shanghai, China, 2005.

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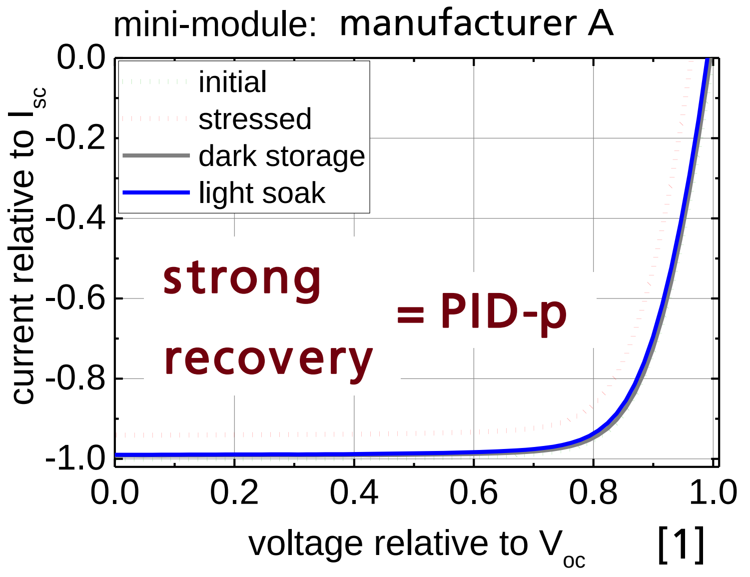
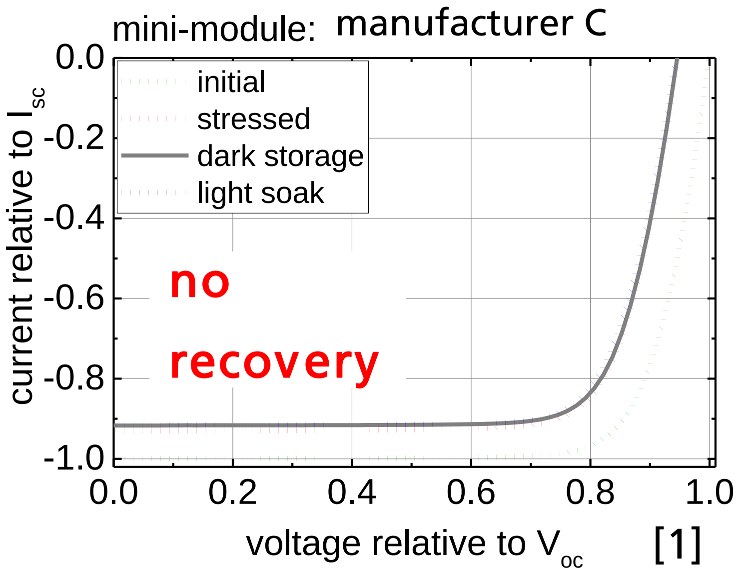
Efficiency losses due to PID at the rear side

Different PID mechanisms at bifacial PERC cells

Rear side PID test at industrial cells [1]

- PID test 60°C, 1000 V, 24 h
- Dark storage: 220 days
- Light soak: 4 h @ 1000 W/m²
- All cells are
  - p-type mono
  - bifacial PERC
  - but from different manufacturers





Power losses (relative to initial state)

	A	C
PID test	-9.7%	-12.7%
dark storage	-0.8%	-13.9%
light soak	-2.1%	-14.7%

- New PID-type → not PID-p
- Different PID behavior for the same cell type
- **Manufacturers need to know the critical process steps**

[1] K. Sporleder et al., SOLMAT 201 (2019): 110062.

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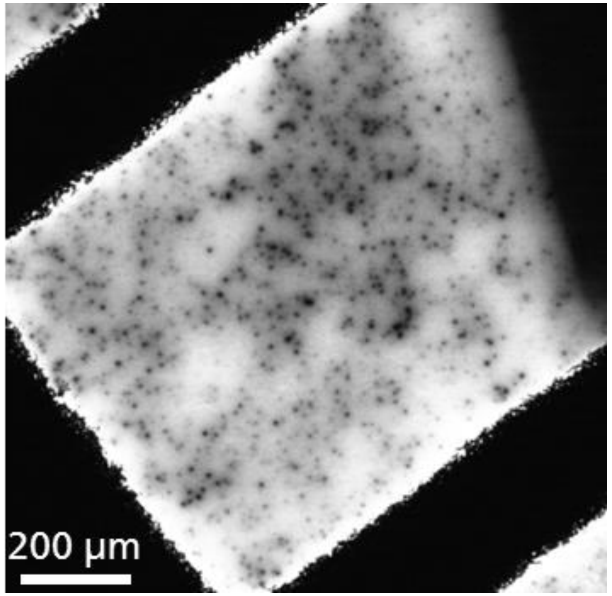
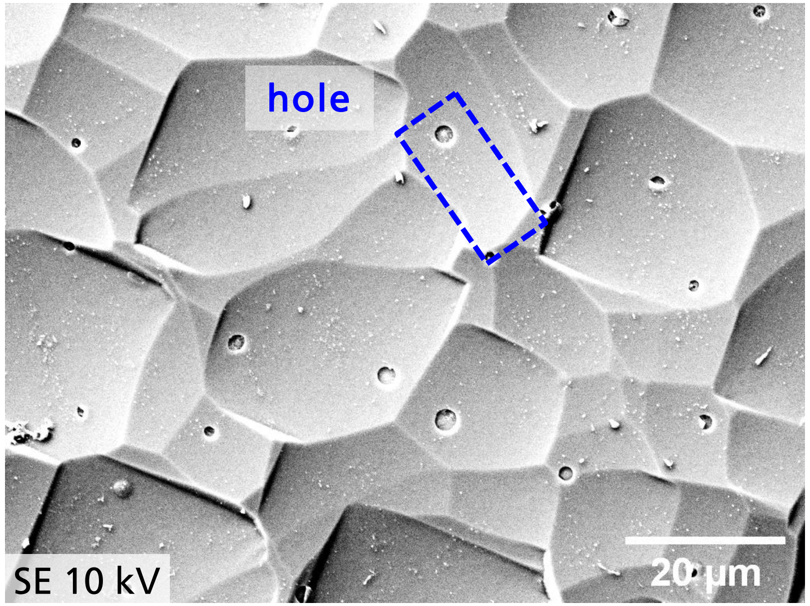
Investigation of the microstructure
Structural defects at the rear surface

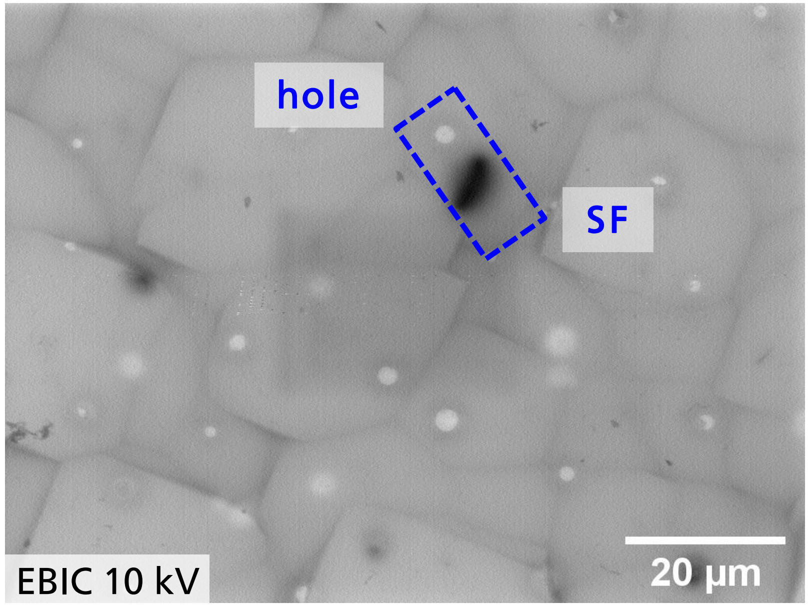
Cell type C:



LBIC, 555 nm [1]



SEM at rear surface: topography [2]



Electron Beam Induced Current measurement [2]

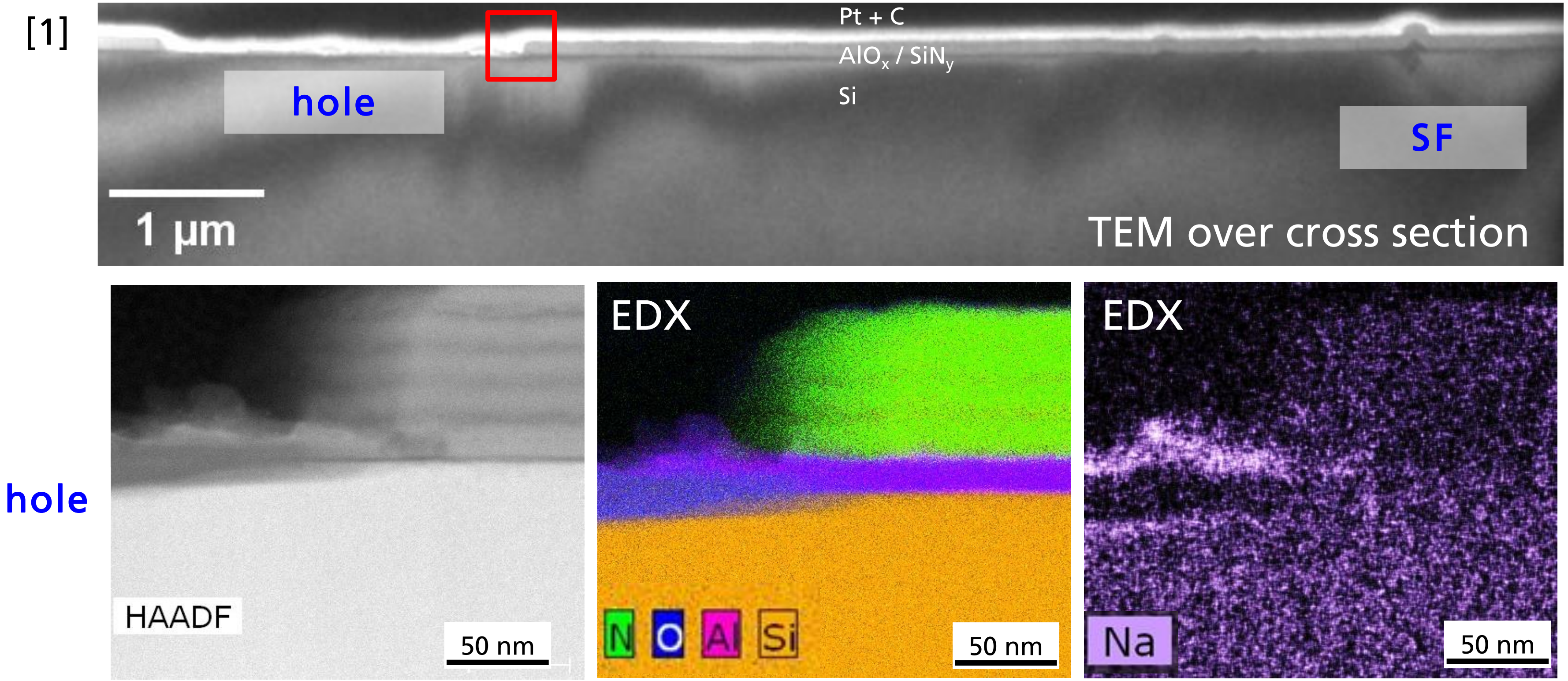
- Lateral inhomogeneous recombination at PID sample after PID test (85°C, 1000 V, 24 h)
- Topography: circle shaped damages of passivation layer → holes → "PID of the corrosion type (PID-c)"
- EBIC reveals independent sub-surface defects → stacking-fault (SF)

[1] K. Sporleder et al., RRL 2019, DOI 10.1002/pssr.201900163
[2] K. Sporleder et al., SOLMAT 201 (2019): 110062.

Cross section through PID defective area

Hole-like defects due to a corrosive PID type (PID-c)

[1]



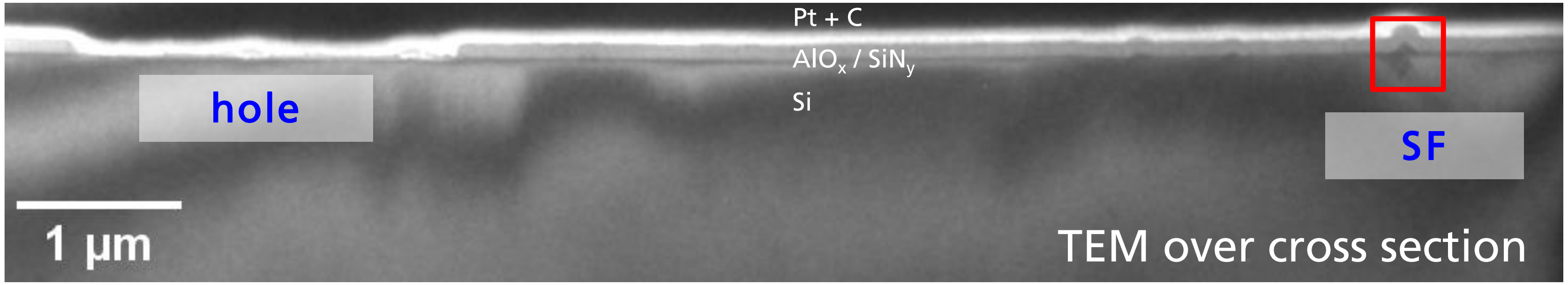
- Local SiO_2 formation at Si / AlO_x interface (30 nm thickness, no native oxide)
- Alkali metal impurities found (Na, K, Ca)

[1] K. Sporleder et al., SOLMAT 201 (2019): 110062.

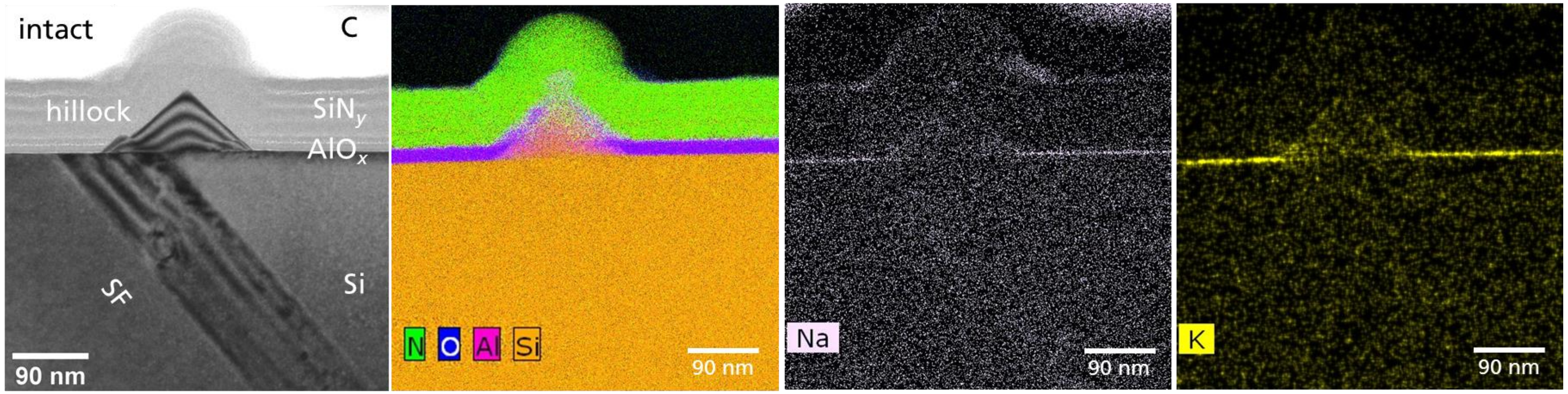
Cross section through PID defective area

In addition: Increased concentration of alkali metals at the Si-interface

[1]



SF



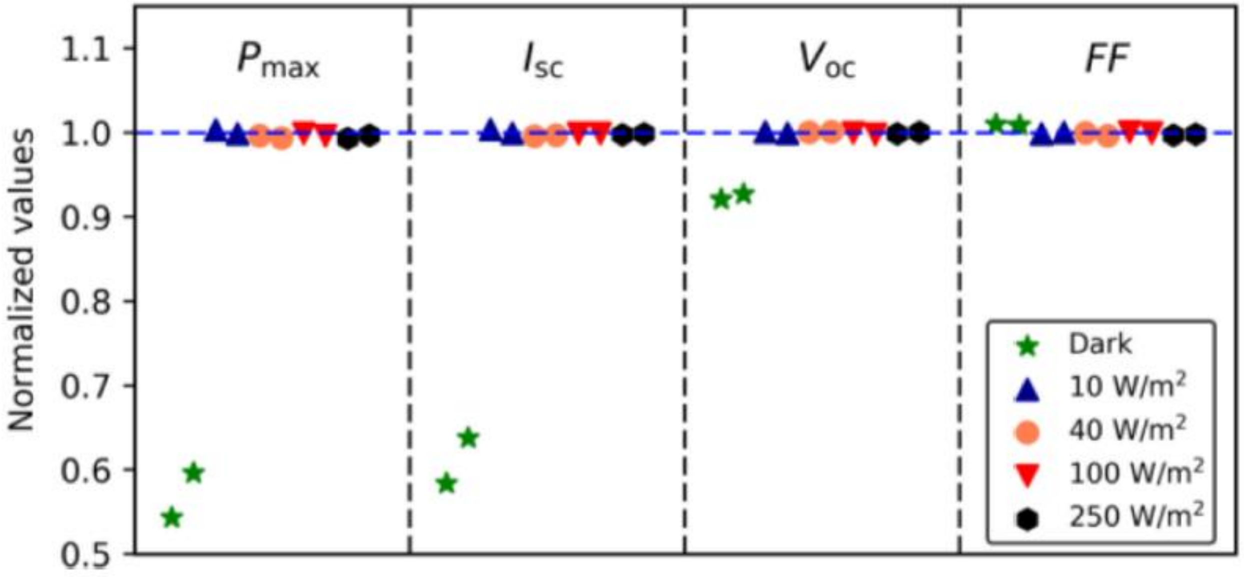
- Recombination active stacking fault (lower EBIC signal)
- Alkali metal impurities at Si / AlO_x interface, probably also inside stacking-fault (SF)

[1] K. Sporleder et al., SOLMAT 201 (2019): 110062.

PID at the rear side

The role of illumination during the PID test

- W. Luo et al. [1] show that illumination can prevent PID on bifacial p-type PERC cells
- 10 W/m² are sufficient to suppress PID



[1]

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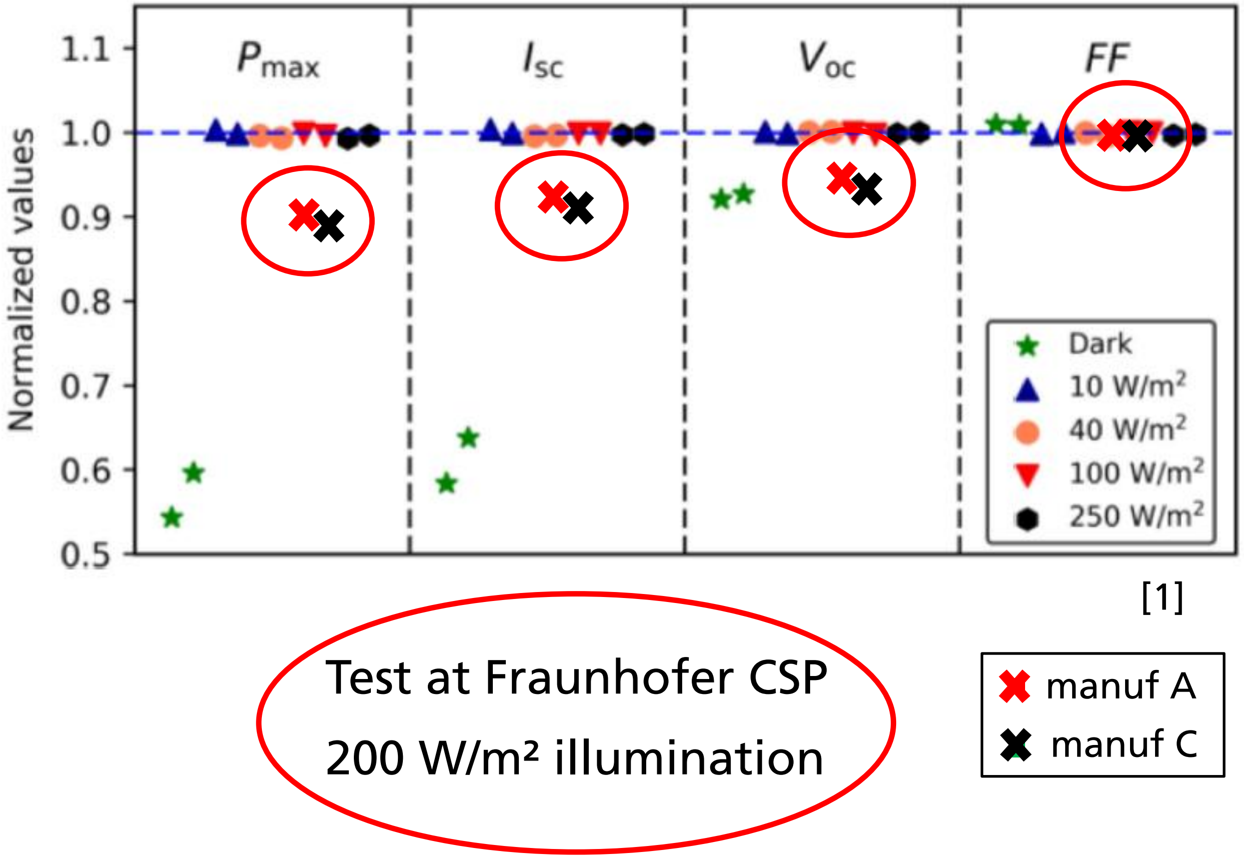
PID is relevant under field conditions

- Our experiments [2] show that industrial PERC+ suffer from PID even under illumination



[1] W. Luo et al., IEEE Journal of Photovoltaics 8.5 (2018): 1168-1173.

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- PID cell tester 'PIDcon' adopted for bifacial PID testing
- Discrimination between PID-p and PID-c
- Later version with simultaneous illumination

PIDcon (Freiberg Instruments)

https://www.freiberginstruments.com/pid/pidcon.html | www.pidcon.com

[1] W. Luo et al., IEEE Journal of Photovoltaics 8.5 (2018): 1168-1173.
[2] K. Sporleder et al., Potential induced degradation of bifacial PERC solar cells under illumination, IEEE Journal of Photovoltaics (2019), accepted

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Summary

1) PID-p and PID-c can harm the rear side of bifacial silicon solar cells

2) Susceptibility to PID at the rear side depends on the cell process for the same technology

3) Manufacturers need to know the critical cell process

4) Meaningful rear side PID tests need simultaneous illumination to predict yield losses

Acknowledgements

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Federal Ministry for Economic Affairs and Energy

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