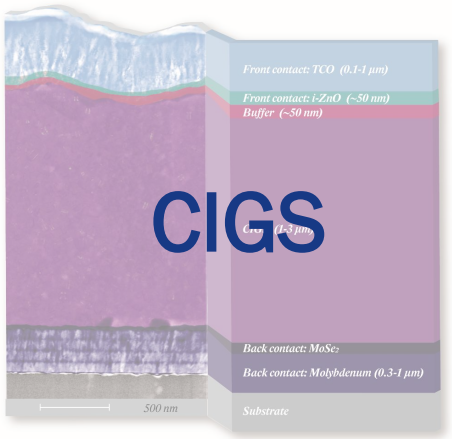
TNO innovation for life

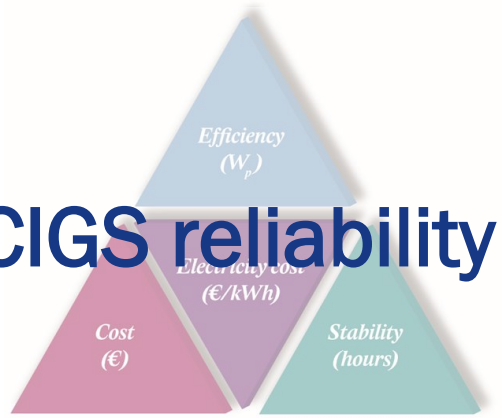
DEGRADATION MECHANISMS IN CIGS DEVICES

MIRJAM THEELEN

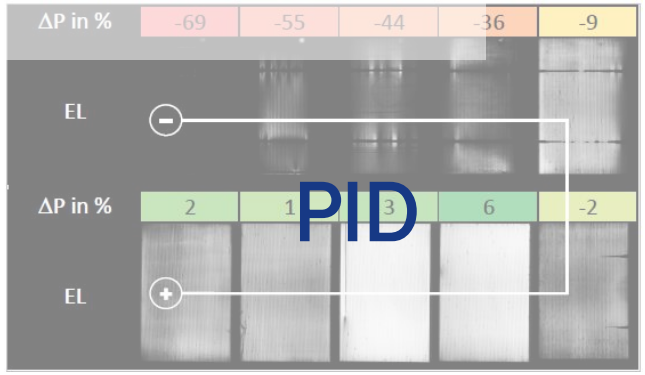
OUTLINE



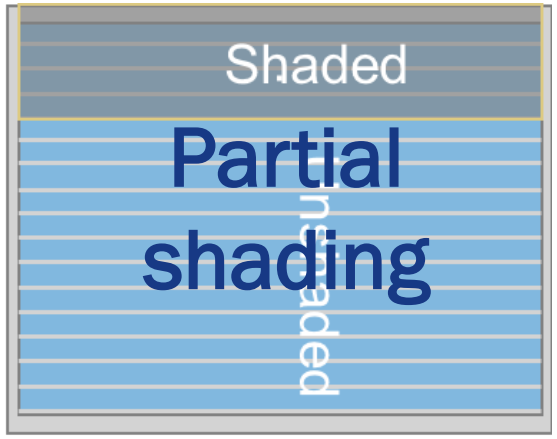
CIGS



CIGS reliability



PID



Partial shading

Humidity ingress

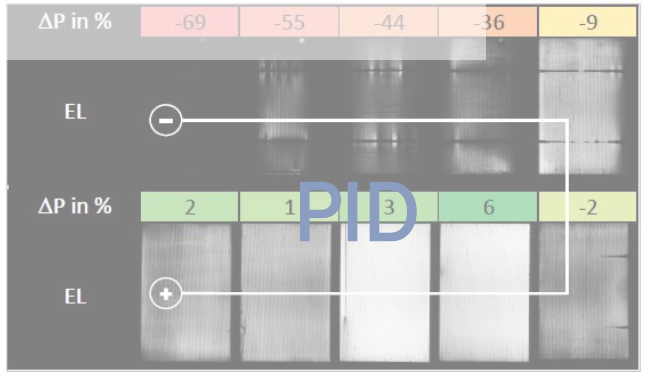
Conclusions

SOLLIANCE

OUTLINE

CIGS

CIGS reliability



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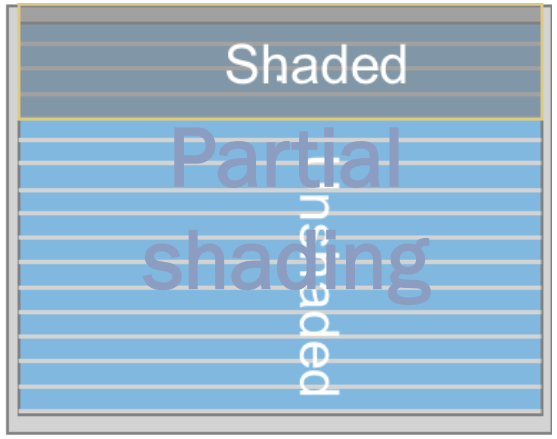


Partial shading

Humidity ingress

Conclusions

SOLLIANCE

Thin Film CIGS

Flexible, black, low material usage, esthetic, free form, low CO_2 footprint
Perfect for integration

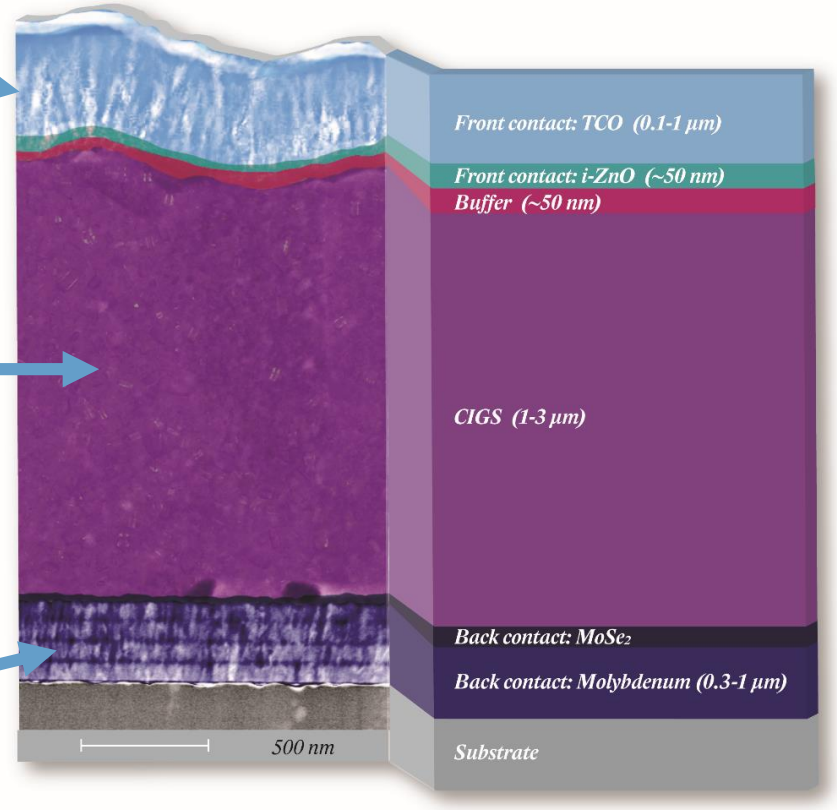
Feurer et al., PiP 25 (7) (2017) 645

CIGS CELL STACK

Front contact:
Conductive and transparent

Absorber:
Light into electrons

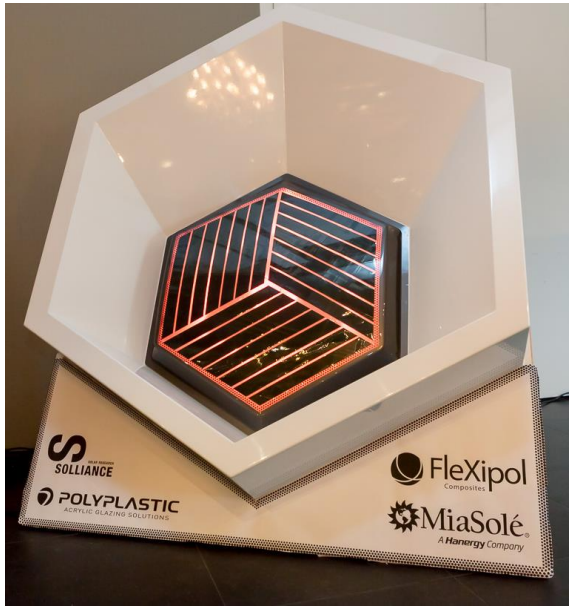
Conductive
back contact

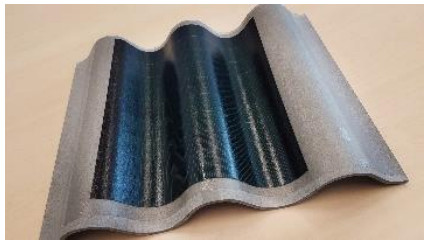


3-5 µm

Thin film $Cu(In,Ga)Se_2$

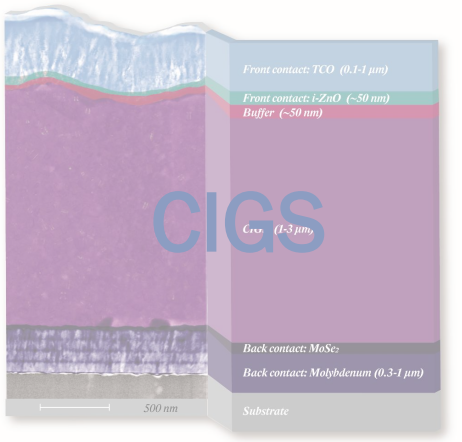
MANY NEW APPLICATIONS AND POSSIBILITIES





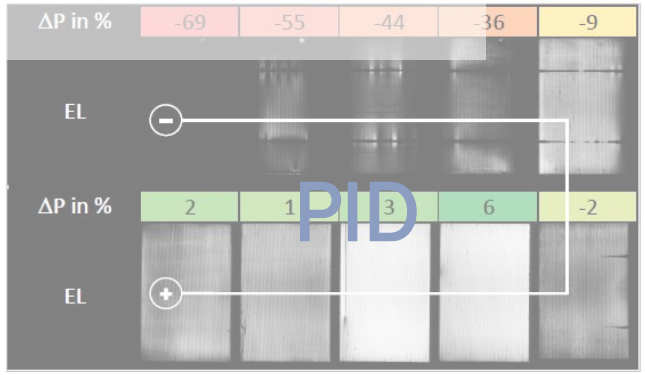
Goal: Highest performance for lowest price

OUTLINE



CIGS

CIGS reliability



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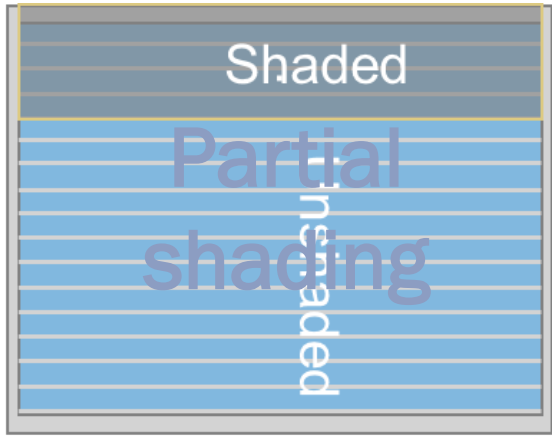


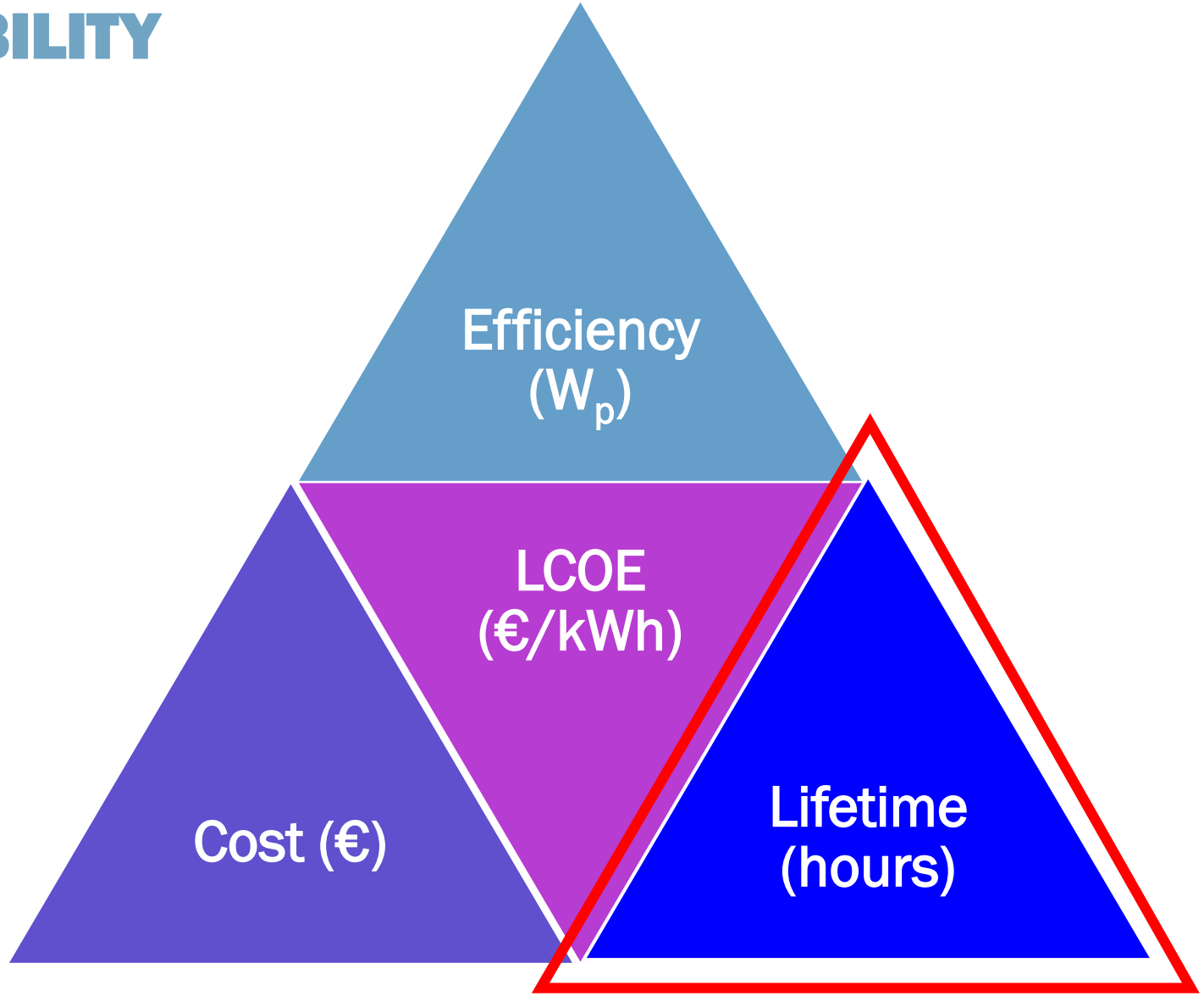
Partial shading


Humidity ingress

Conclusions

SOLLIANCE

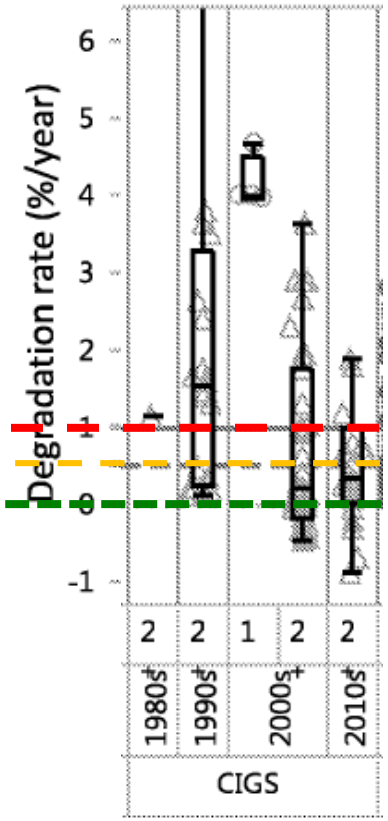
PV RELIABILITY



CIGS COMPARED TO OTHER TECHNOLOGIES

80% after 20 years

No degradation

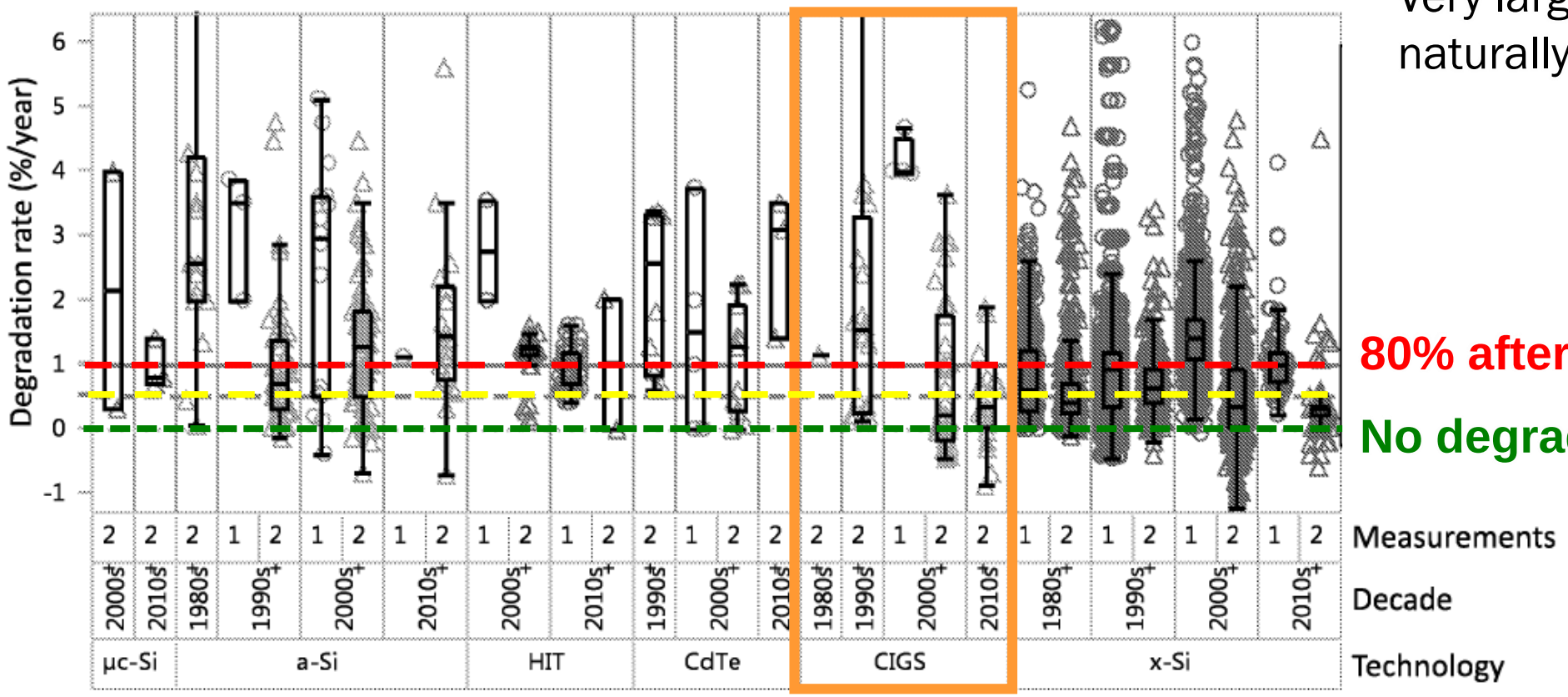


Ideally:

- All modules under yellow (or green?) line
- No early failures

Jordan et al., PiP 24 (7) (2016) 978-989

CIGS COMPARED TO OTHER TECHNOLOGIES



Very large data set, but naturally incomplete

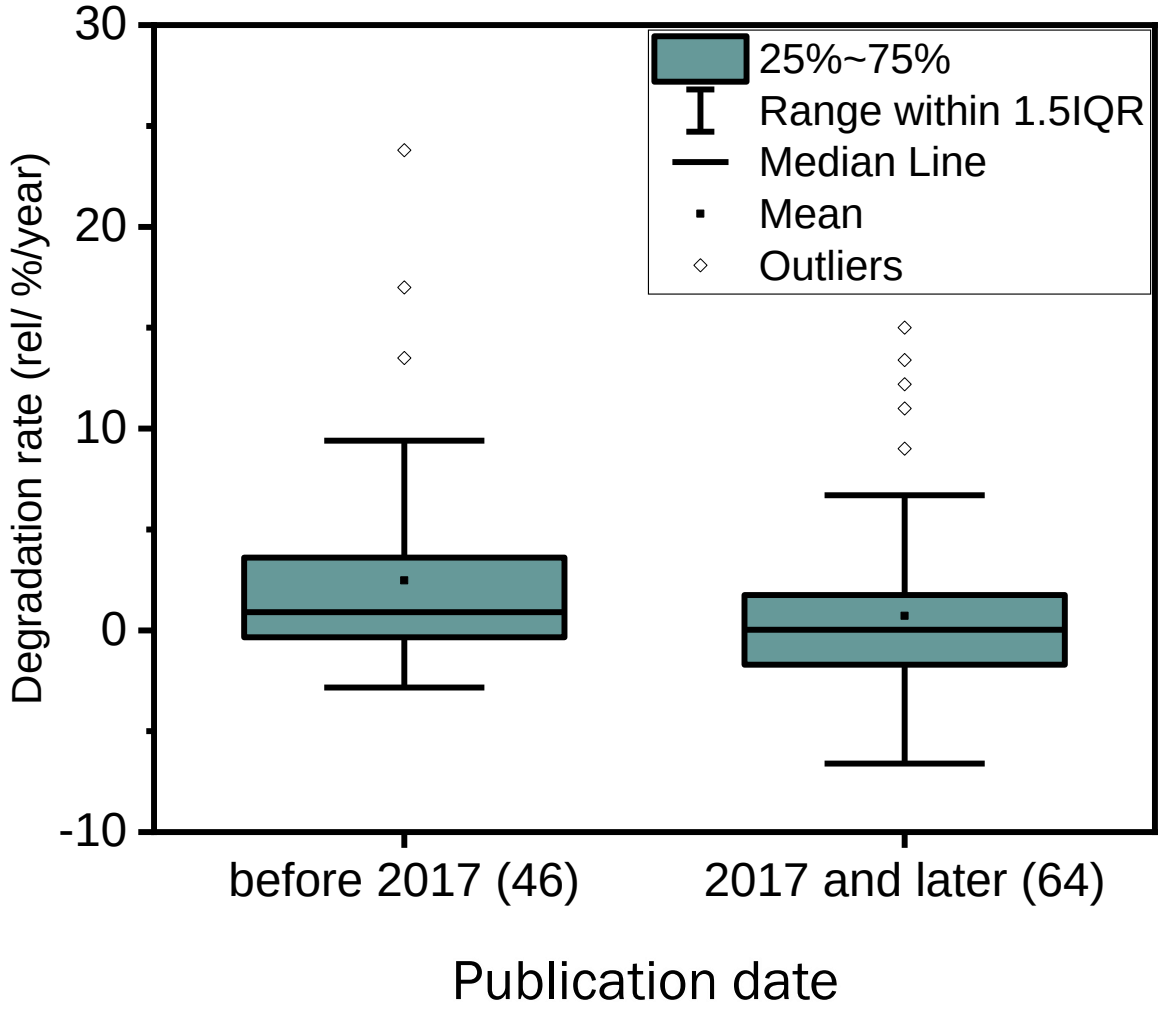
80% after 20 years

No degradation

CIGS is doing well ☺

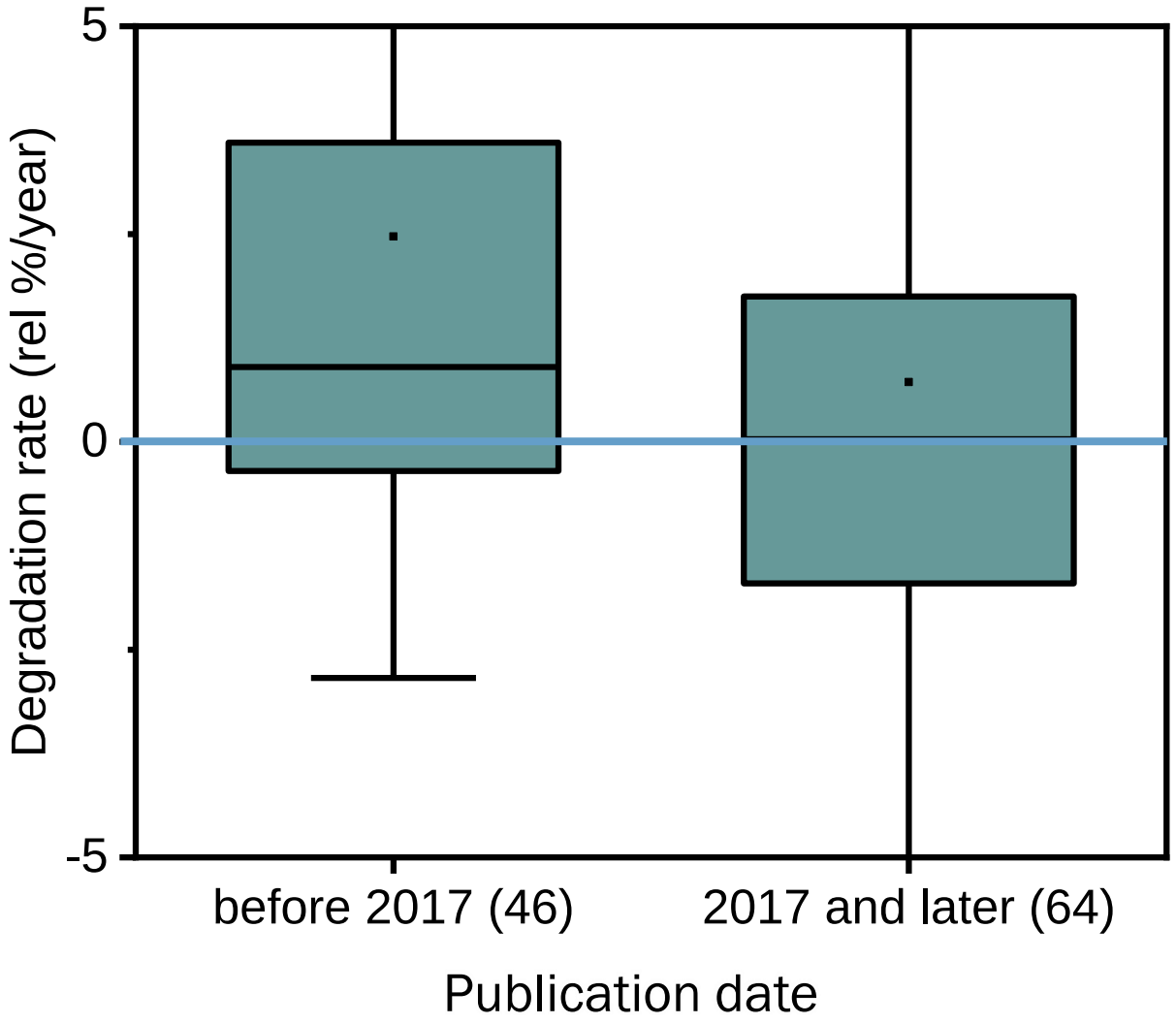
Jordan et al., PiP 24 (7) (2016) 978-989

OUR OWN LITERATURE STUDY



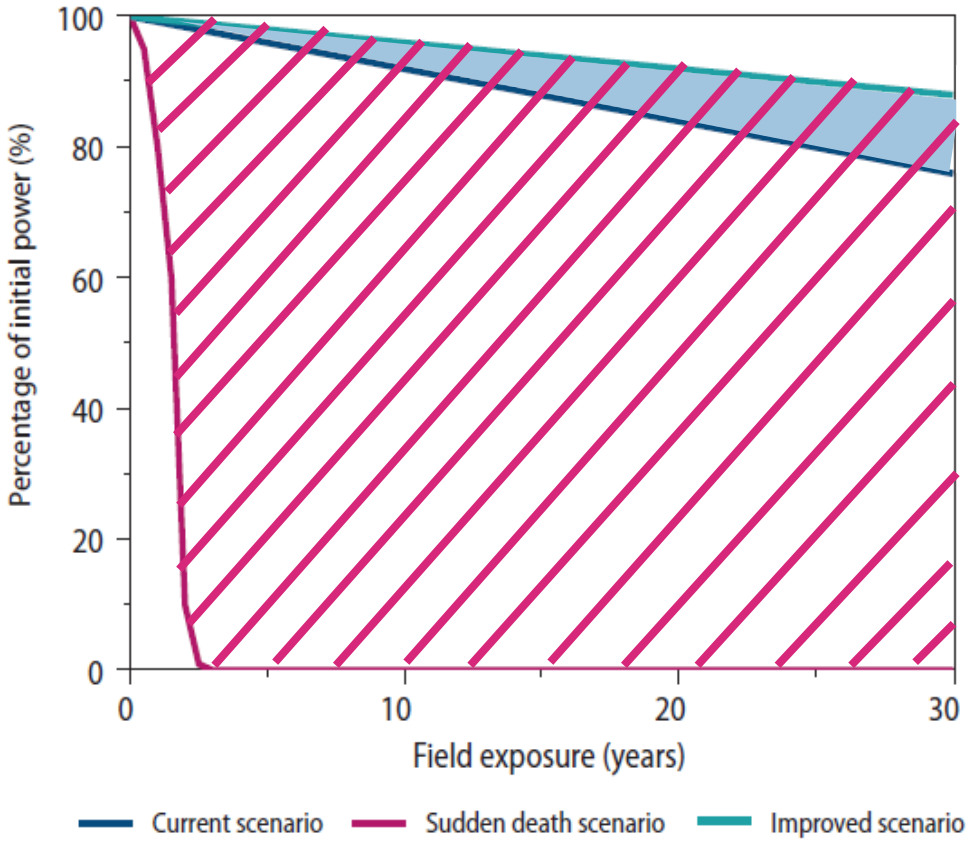
CIGS modules in literature

OUR OWN LITERATURE STUDY: ZOOMED IN

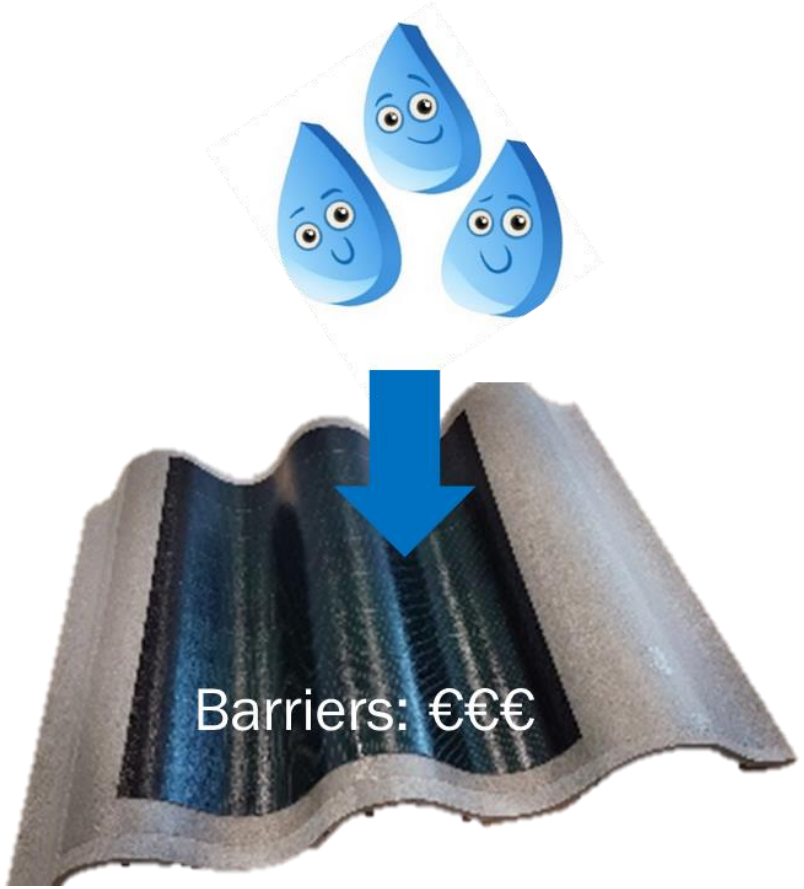


- Median degradation rate (after 2017): 0% per year ☺
- Some modules degraded and many became better
- Mind: publications often include ‘outliers’

WHY FINDING DEGRADATION MECHANISMS?

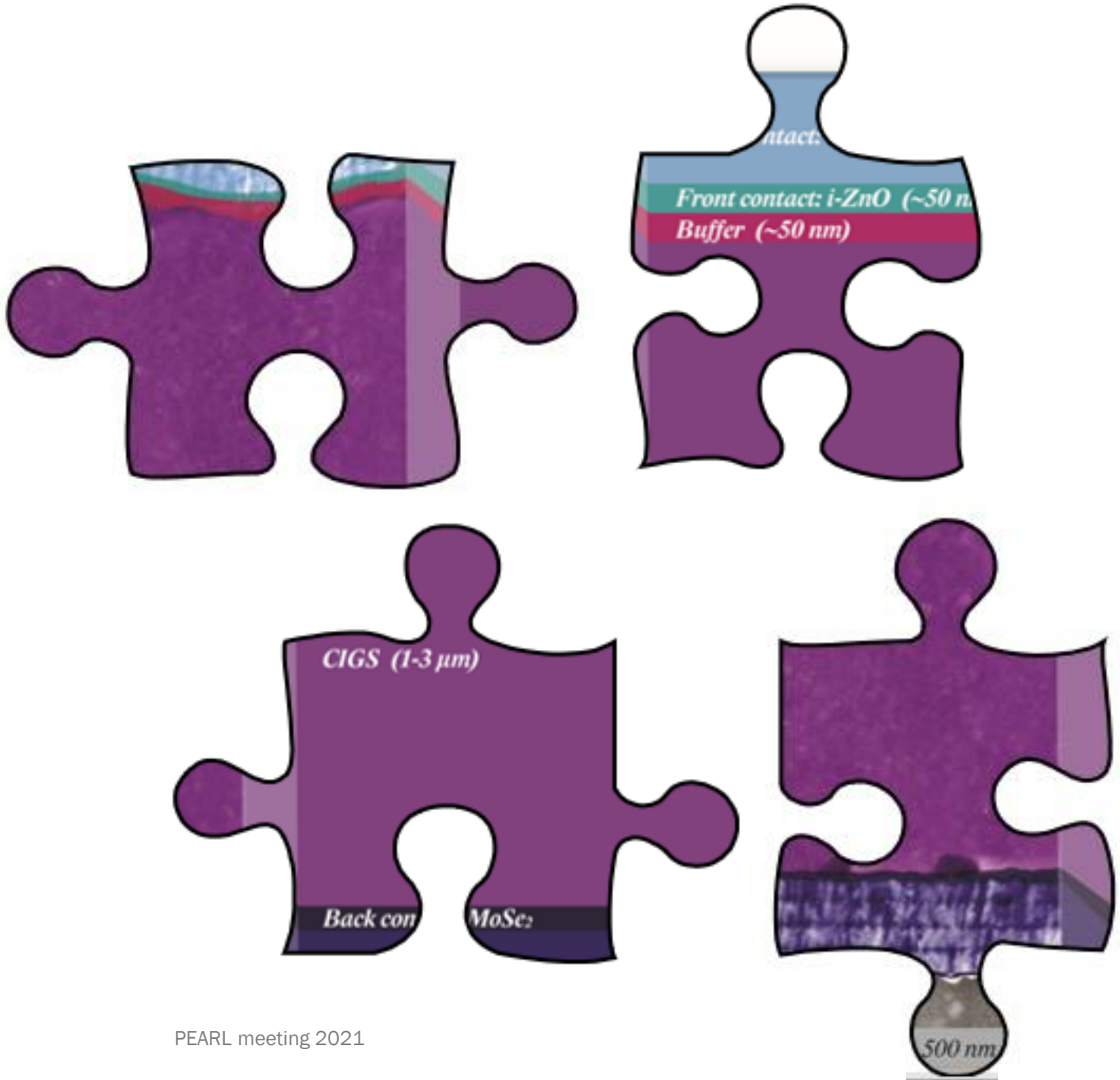


Improve yield and predictibility

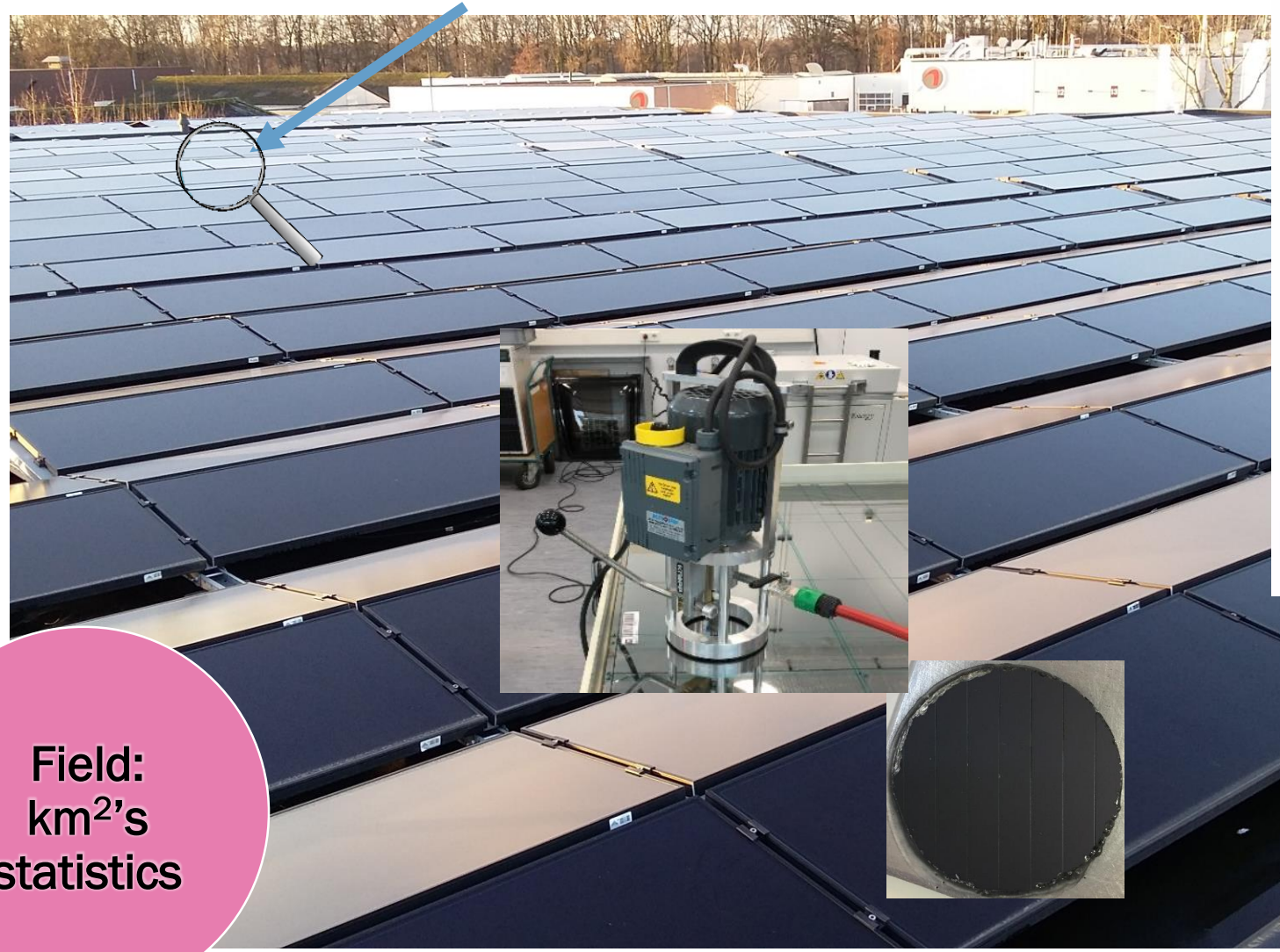


Many degradation effects can be avoided, but add costs to modules or systems

SOLLIANCE


Front contact: i-ZnO (~50 n
Buffer (~50 nm)
CIGS (1-3 µm)
Back con
MoSe2
500 nm

RESEARCH IN FIELD AND LAB



Field: km²'s statistics

Lab: nm scale analysis

SOLLIANCE

THREE MECHANISMS FOR CIGS

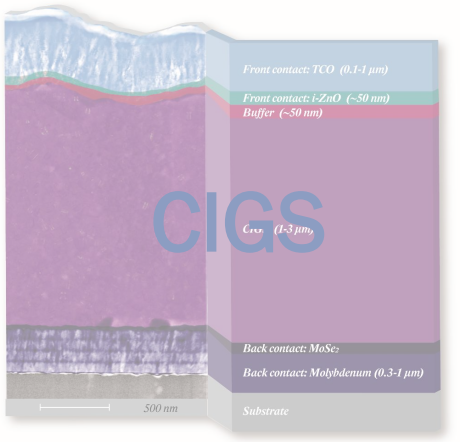
Potenti[illegible]radation

Worst case scenarios

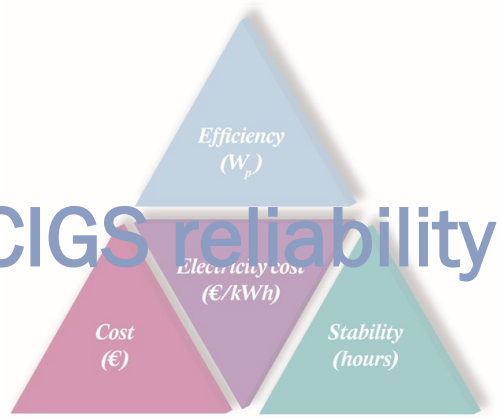
Partial shading

Humidity ingression

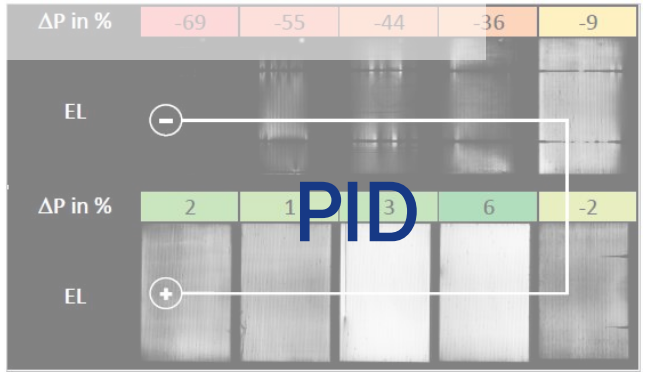
OUTLINE



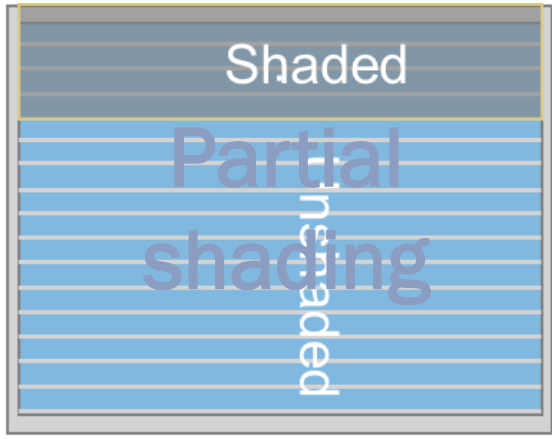
CIGS



CIGS reliability



PID



Partial shading

Humidity ingress

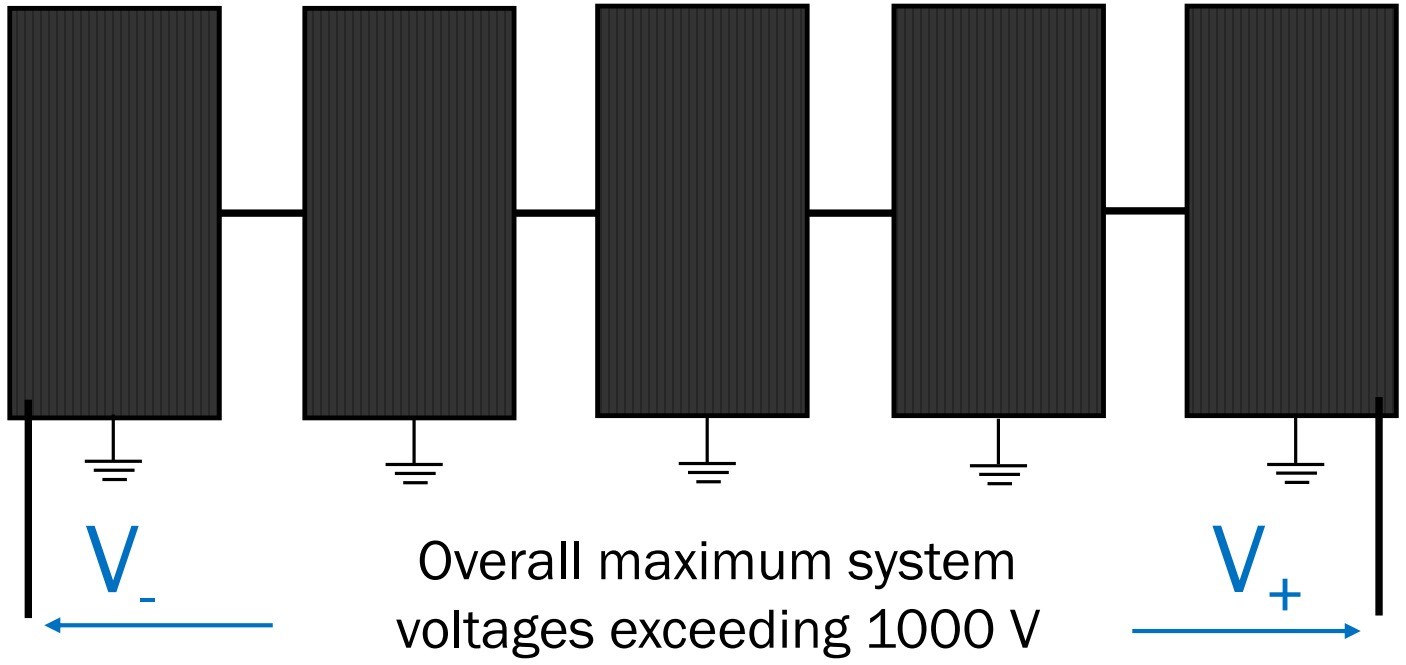
Conclusions

SOLLIANCE

POTENTIAL INDUCED DEGRADATION

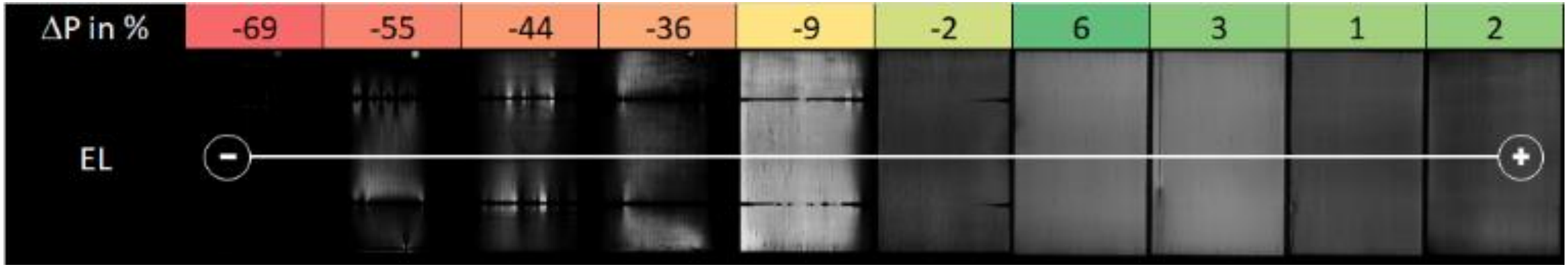
Potential Induced Degradation upon exposure to high voltage stress in the field

Large strings



POTENTIAL INDUCED DEGRADATION

- Limited appearance for CIGS
- Only found for one old batch of one manufacturer



Negative end string ☹

Positive end string ☺

Overall maximum system voltages can exceed 1000 V

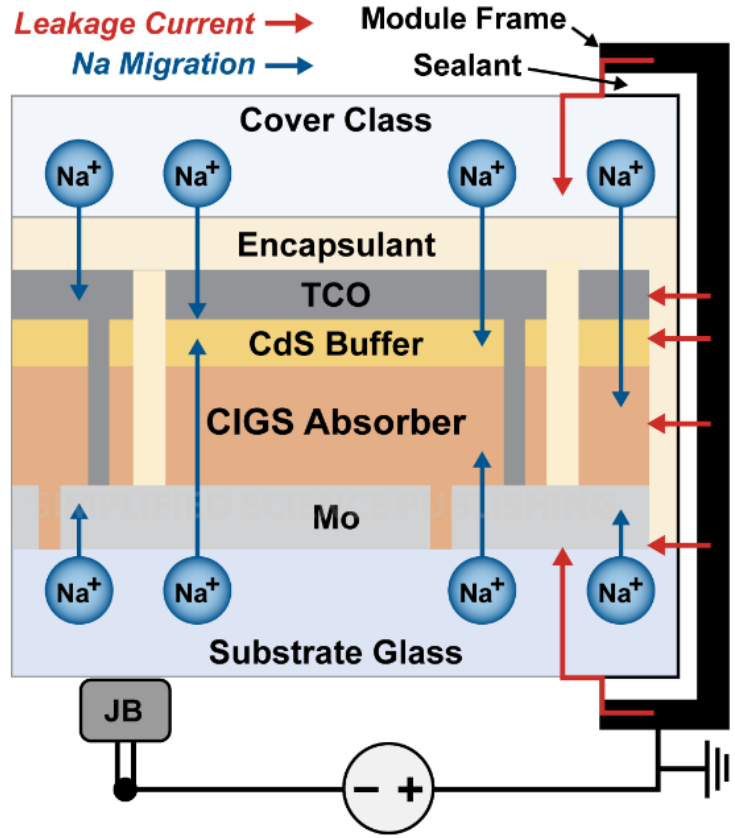
- No clear visual effects

Weber et al., Proc. 33rd EUPVSEC 2017

SOLLIANCE

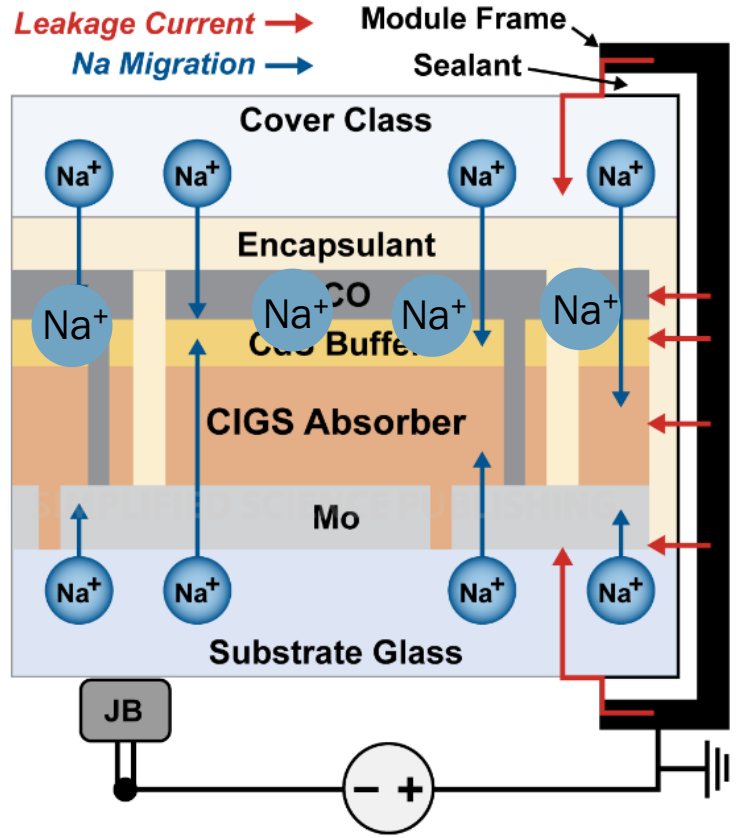
ION MIGRATION

- Potential mechanism: Ion migration from front and back glass
- CIGS contains Na^+, therefore CIGS likely is not often sensitive to PID

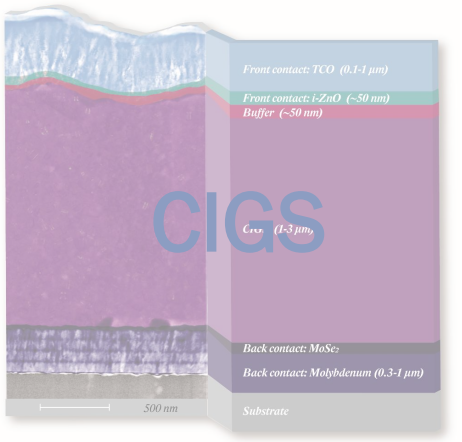


ION MIGRATION

- Potential mechanism: Ion migration from front and back glass
- CIGS contains Na^+, therefore CIGS likely is not often sensitive to PID
- If too many ions in pn-junction, then degradation

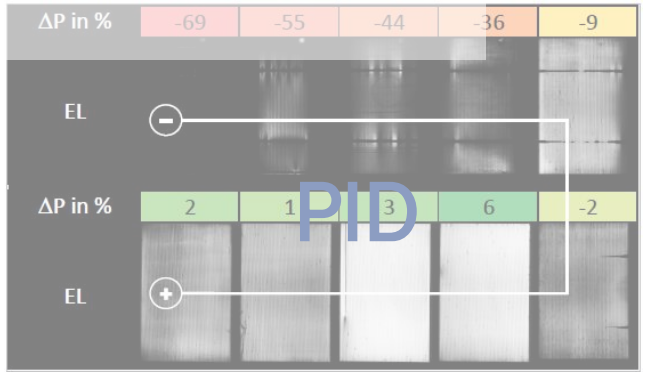


OUTLINE

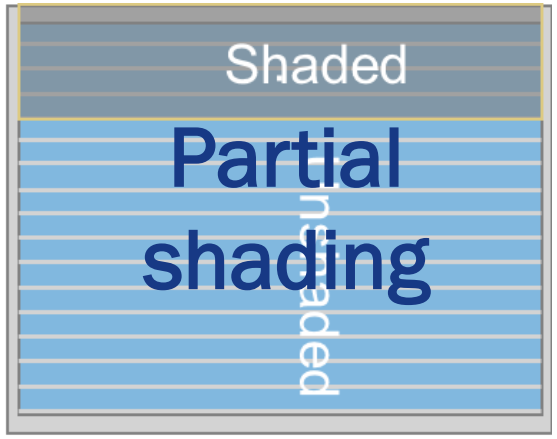


CIGS

CIGS reliability



PID

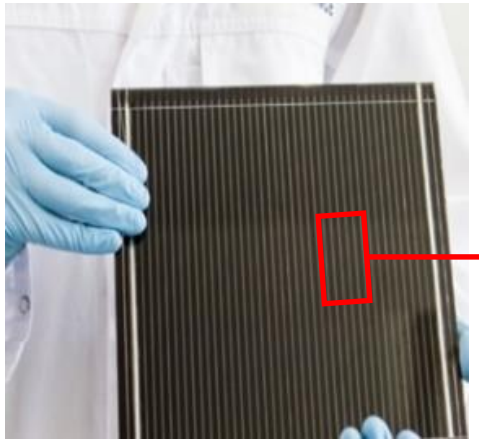


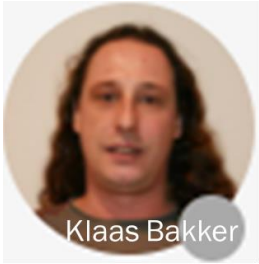
Humidity ingress

Conclusions

SOLLIANCE

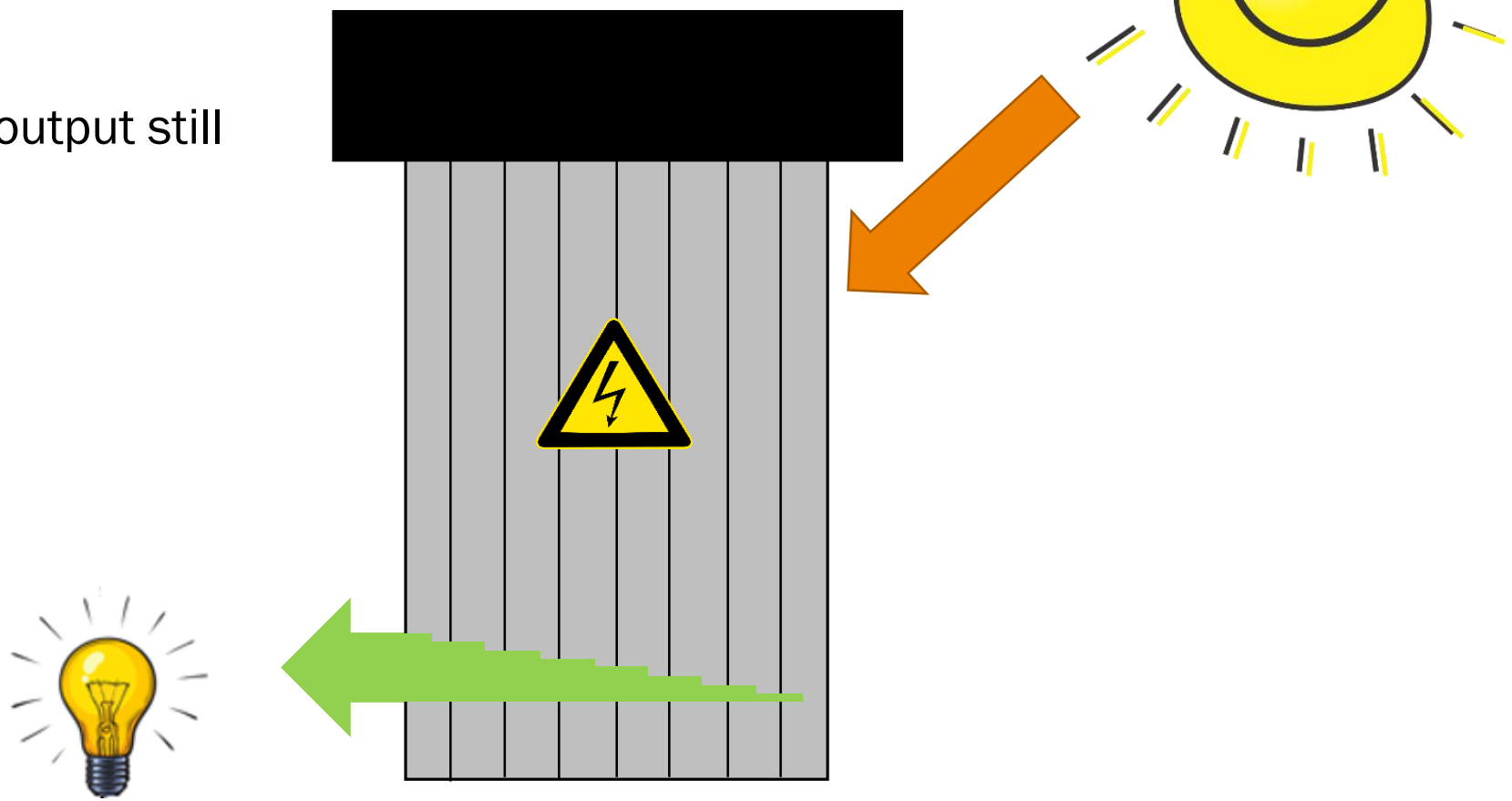
CIGS MODULE OPERATION: NO SHADOW





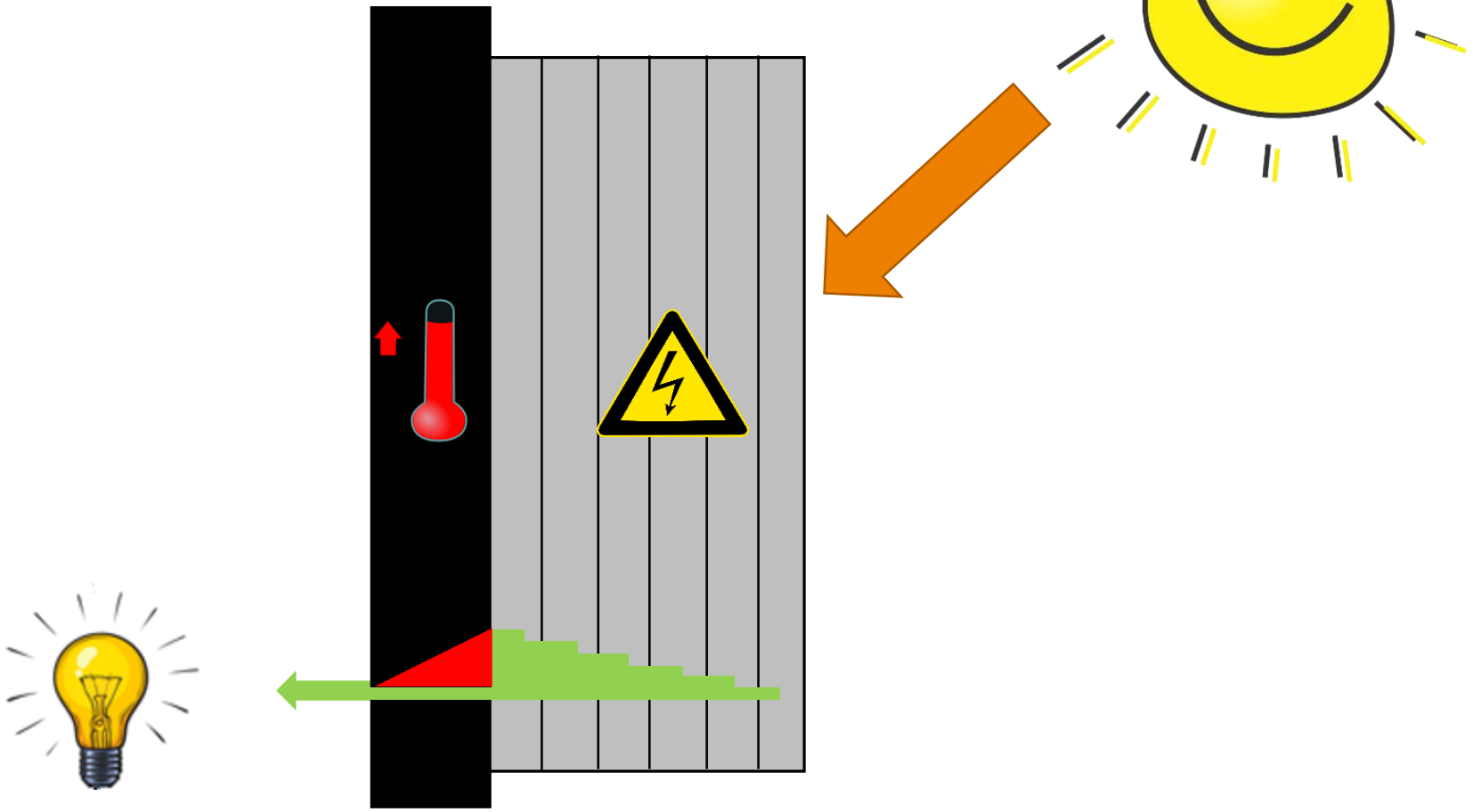
LANDSCAPE SHADING

- Equal power generation
- Less output power, but output still high ☺
- No risk for damage ☺



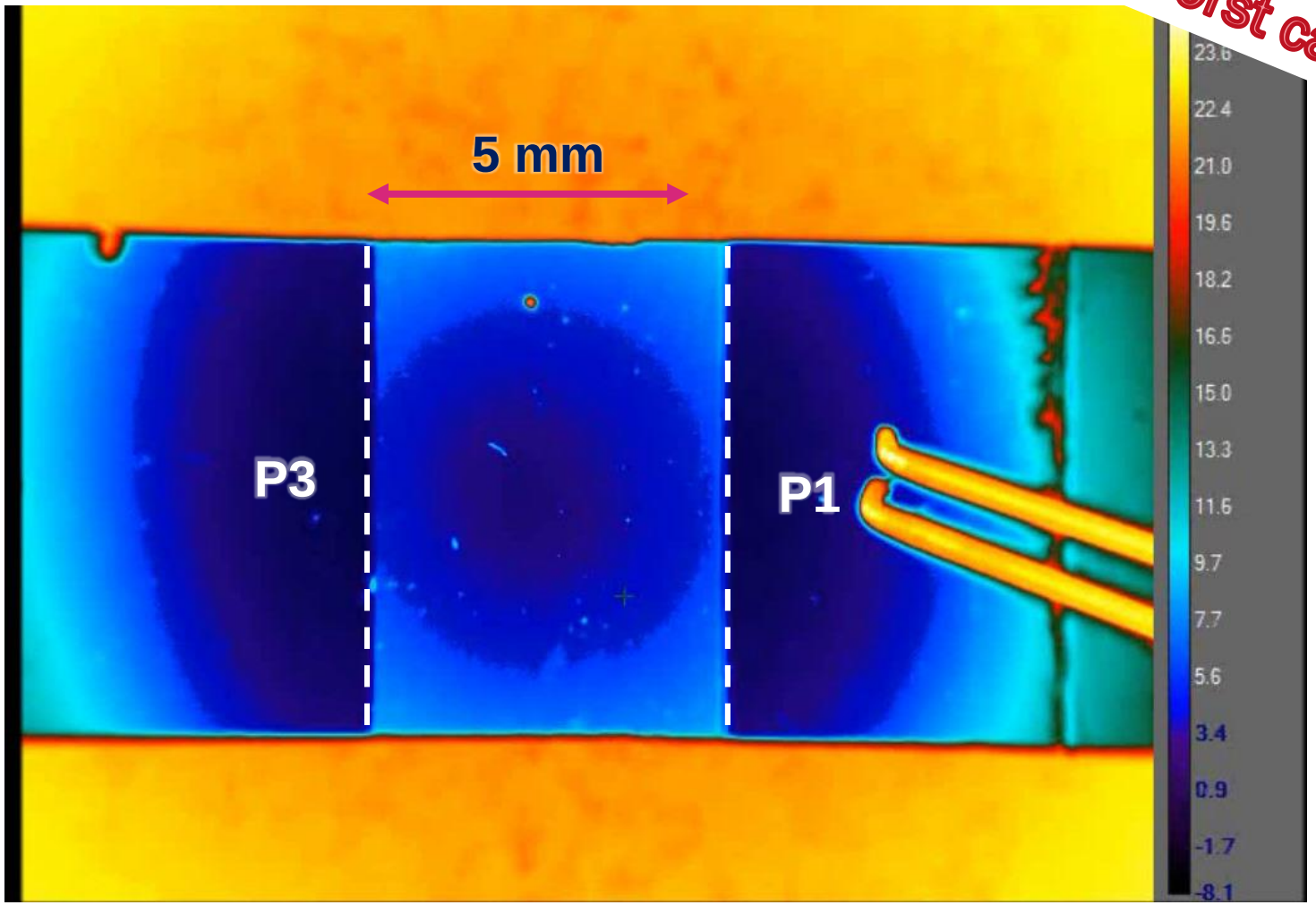
CIGS REVERSE BIAS

- Reverse power flow
- P = V * I
- Reverse voltage ☹
- Lower module output ☹
- Risk for damage ☹



DEFECT FORMATION: WORM FORMATION

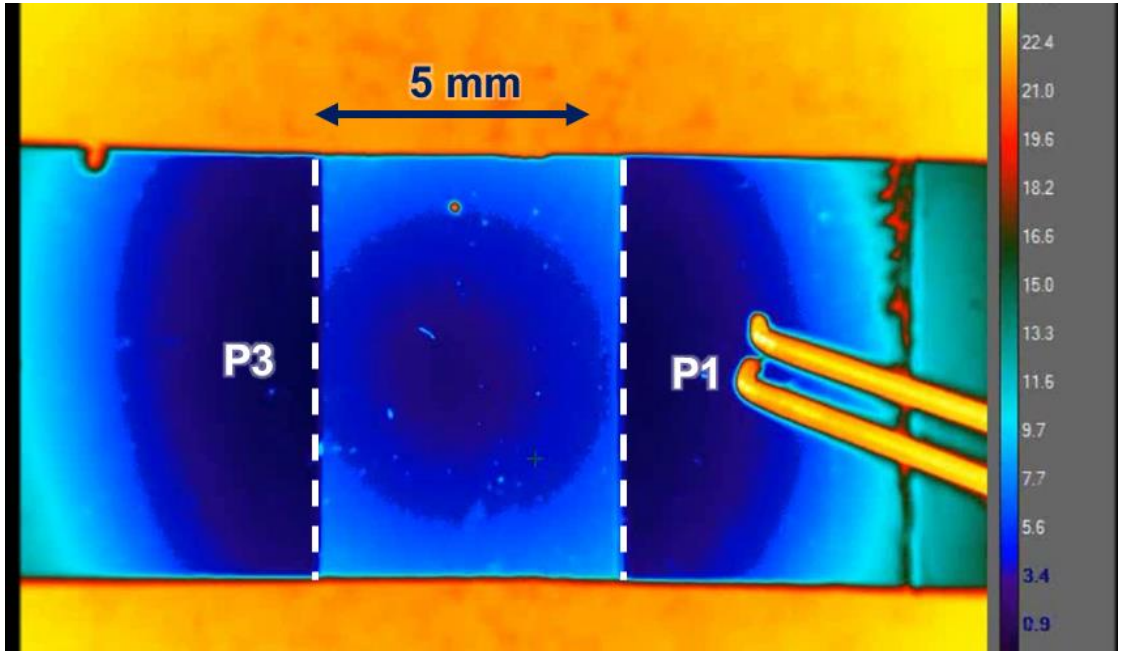
Worst case scenarios



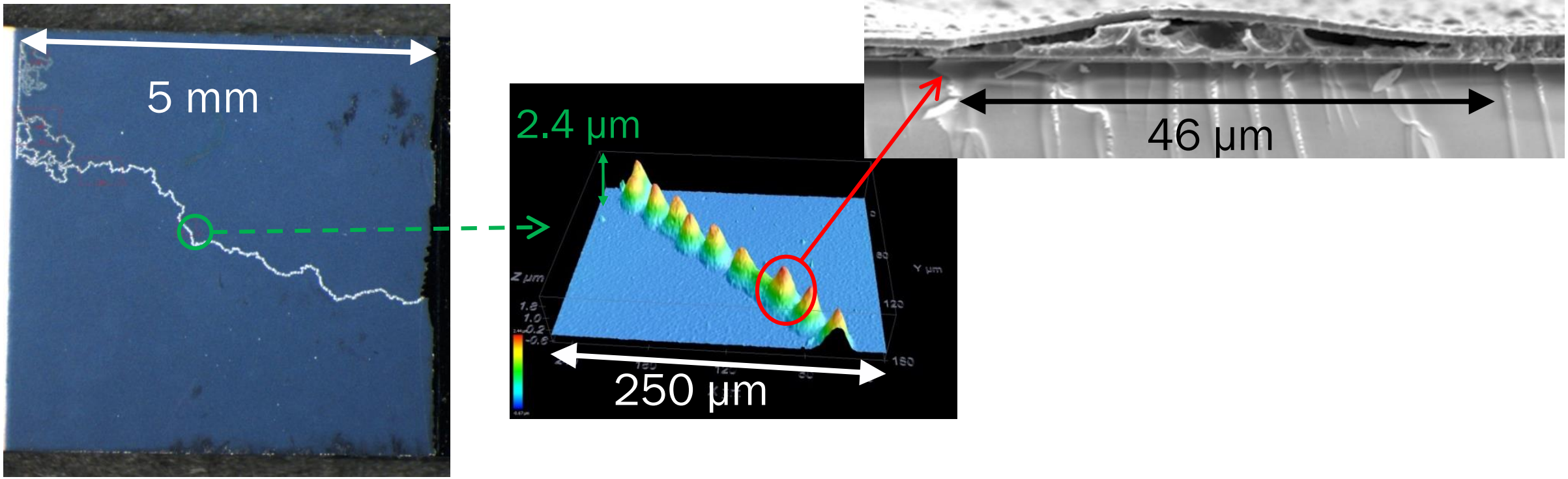
Real time IR movie

REVERSE BIAS

- After worm formation:
  - Cells are shunted
  - No power output anymore
- Also other effects (partly reversible)



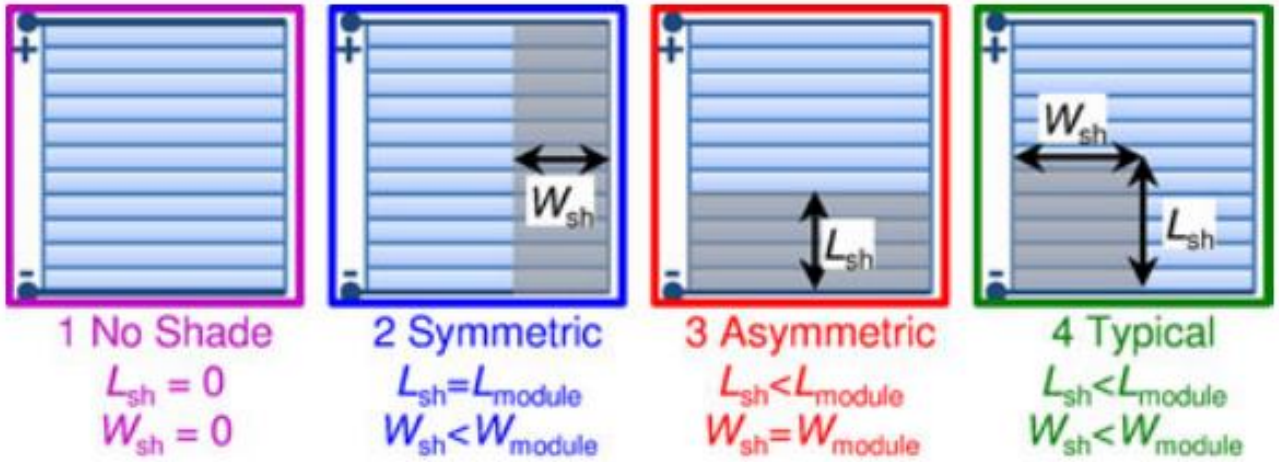
WORMLIKE DEFECTS IN DEPTH



K. Bakker et al., Solmat 205 (2020) 110249

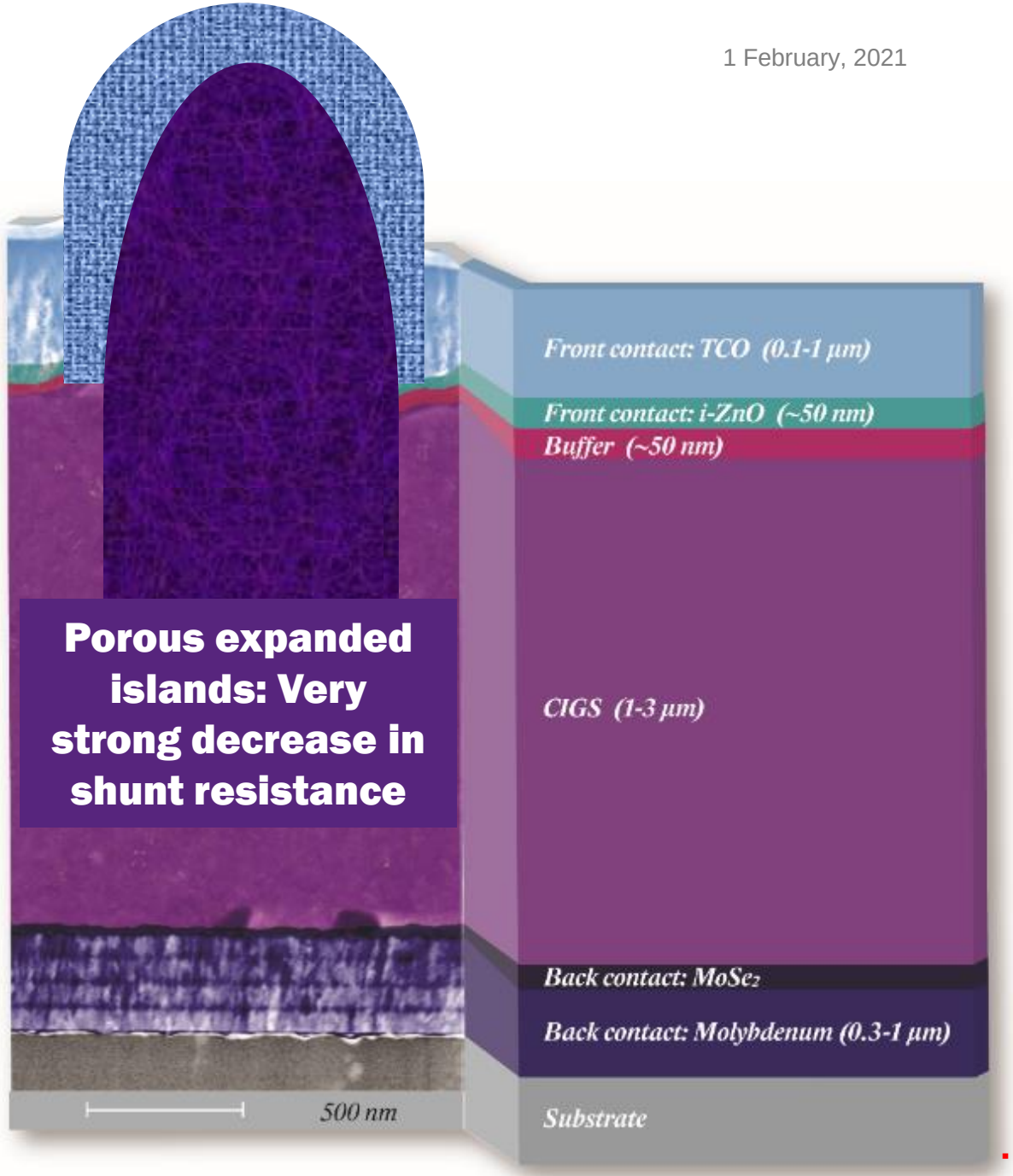
FACTORS INFLUENCING DAMAGE

- Shape and intensity of shading
- Composition of cells
- Geometry of cells
- Presence of bypass diodes

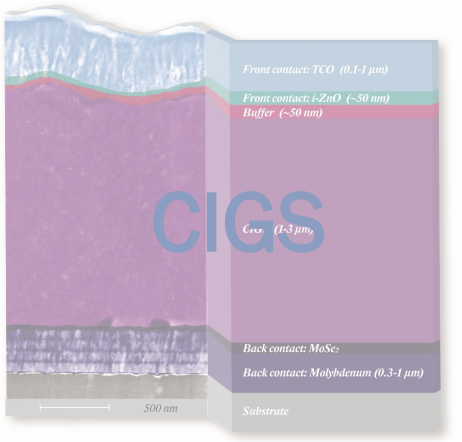


Dongaonkar et al., IEEE JPV 3 (2013) 1367-1375

REVERSE BIAS

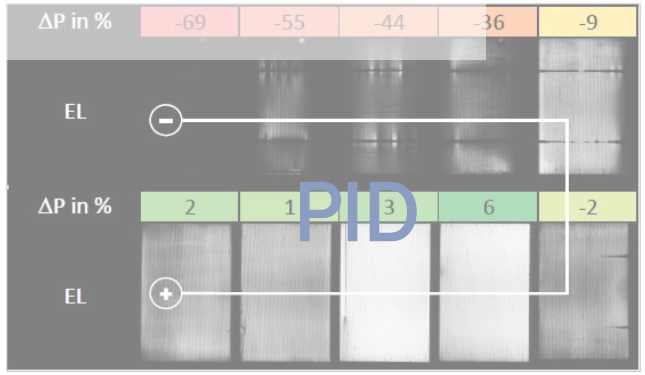


OUTLINE

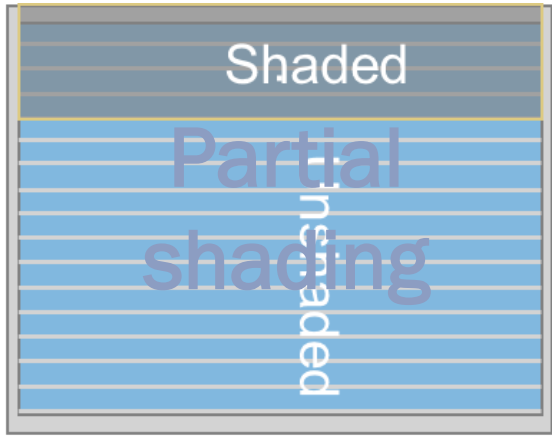


CIGS

CIGS reliability



PID



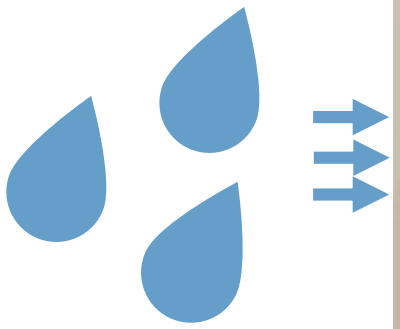
Partial shading

Humidity ingress

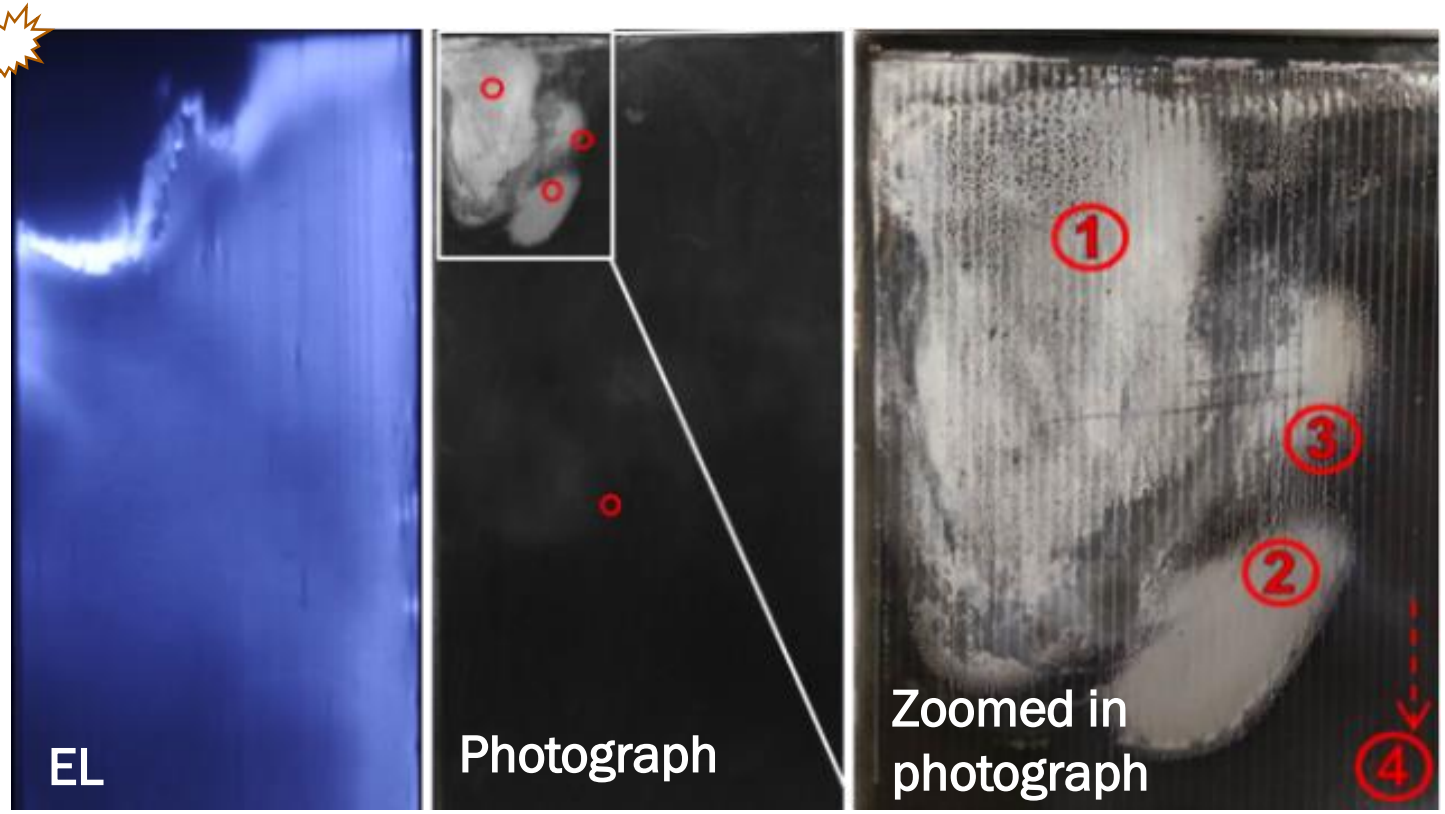
Conclusions

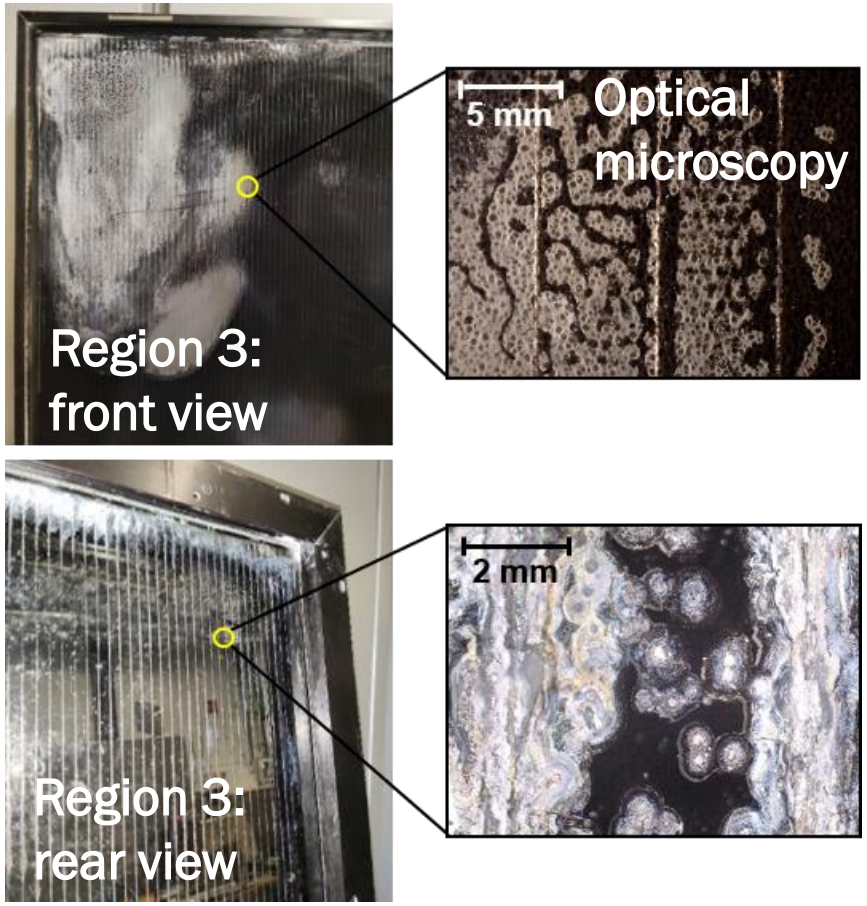
SOLLIANCE

SOMETIMES DEGRADATION IS VISIBLE



HUMIDITY INGRESS

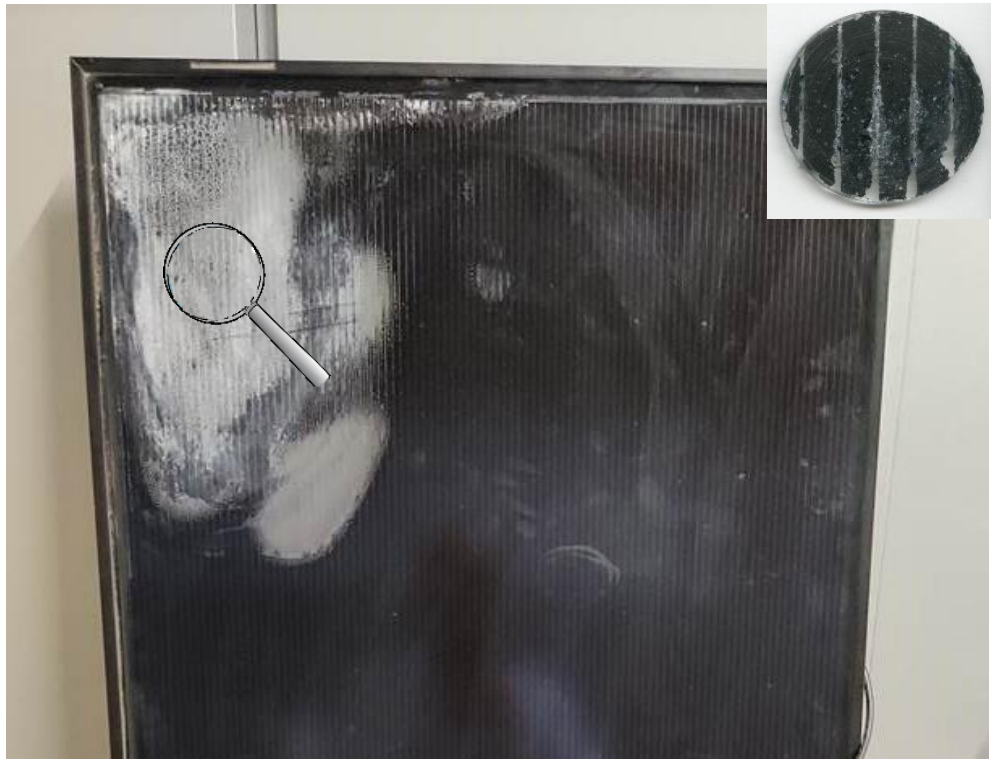




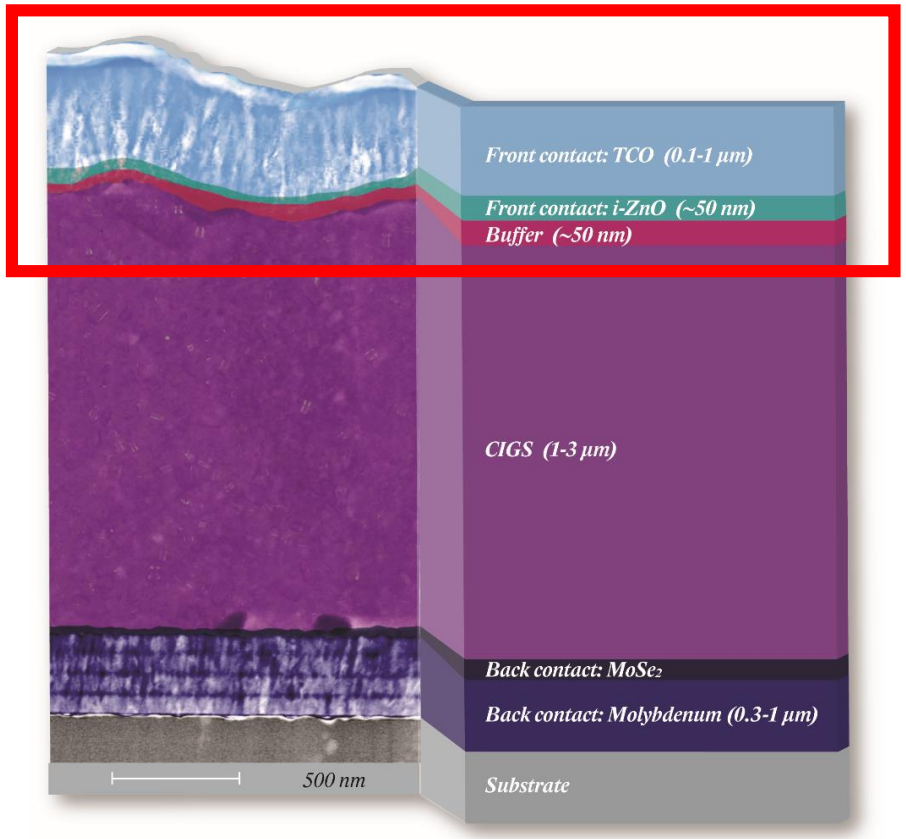
eigenenergie.net

SOLLIANCE

HUMIDITY INGRESS: MECHANISMS



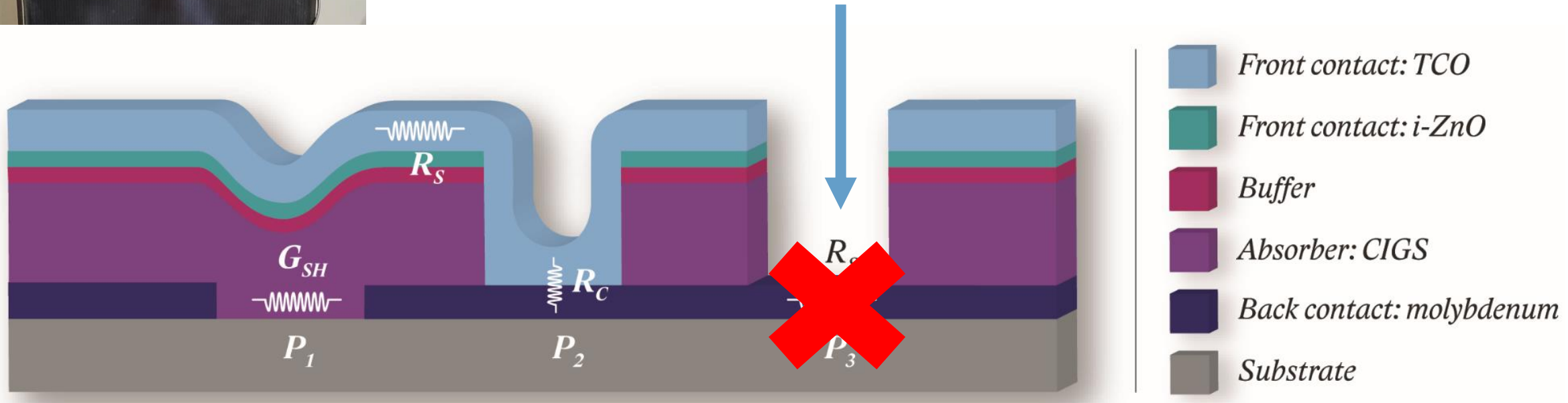
TCO degradation: R_s



SOLLIANCE

HUMIDITY INGRESS: MECHANISMS

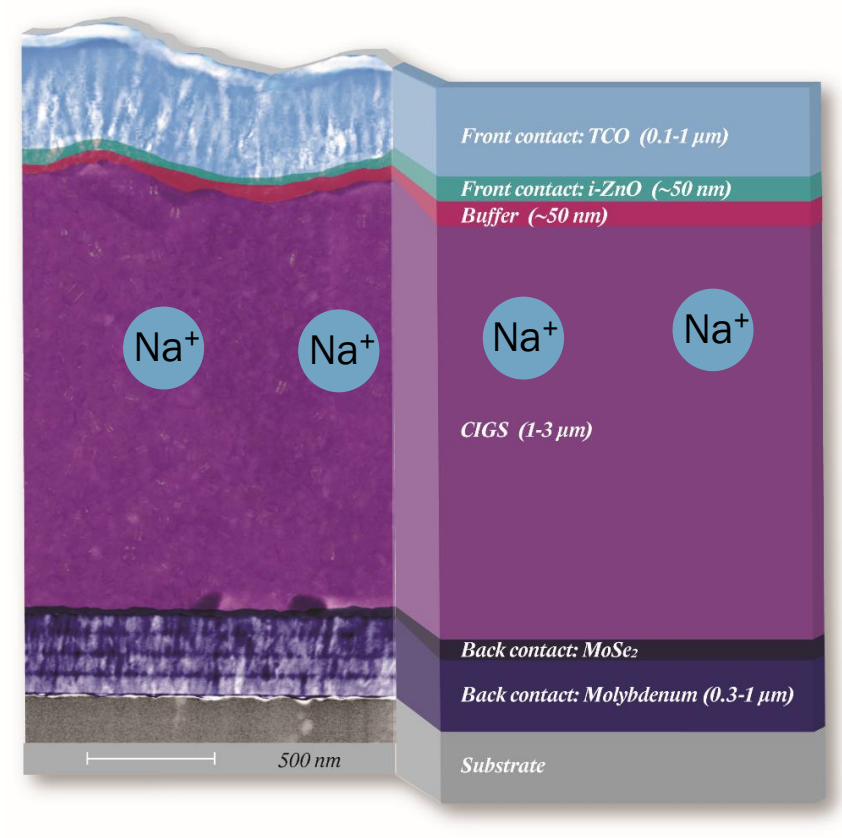
Interconnection loss between cells:
complete performance loss



Theelen and Daume, Solar Energy 133 (2016) 586–627

SOLLIANCE

HUMIDITY INGRESS: MECHANISMS

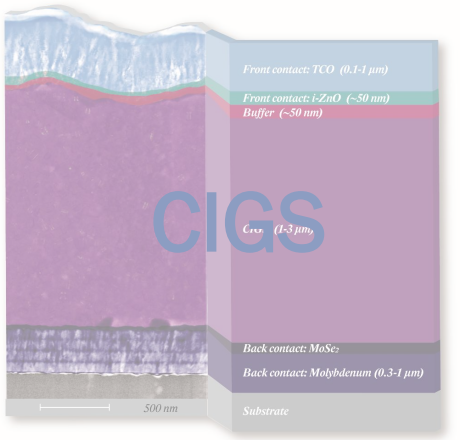


Often migration of alkali-elements in absorber: Decrease R_{sh}

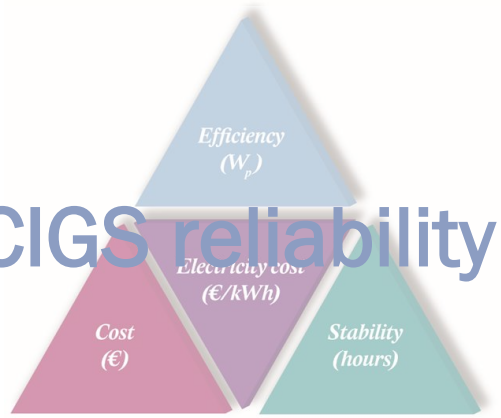
(Measured in ALT damp heat + illumination)

SOLLIANCE

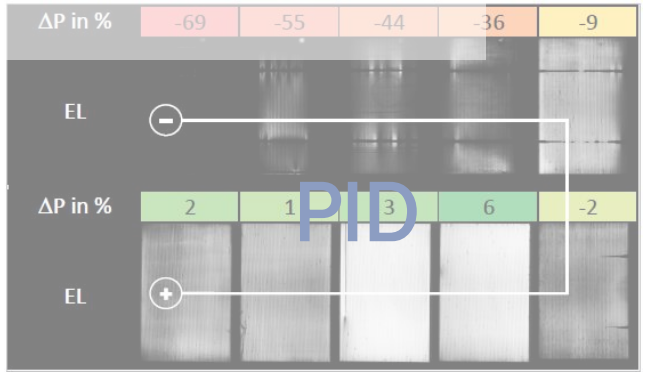
OUTLINE



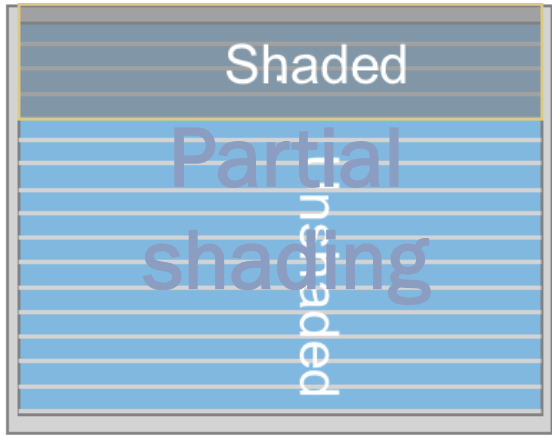
CIGS



CIGS reliability



PID



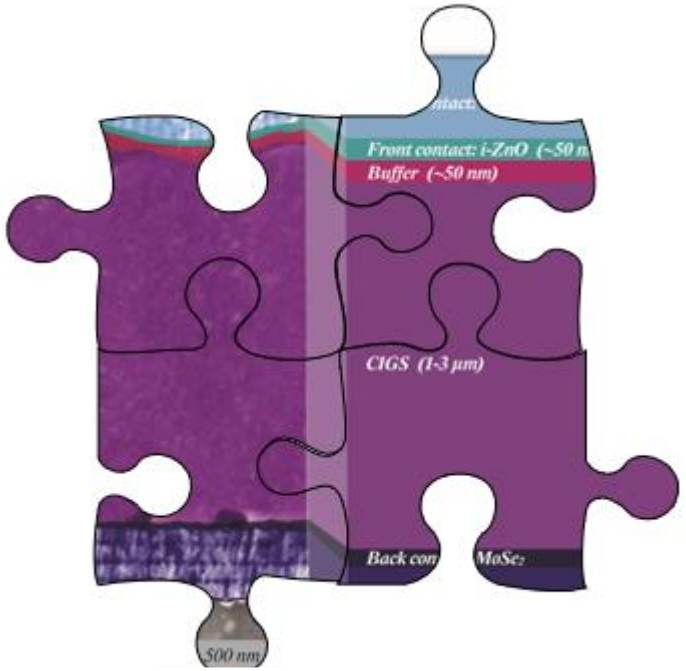
Partial shading

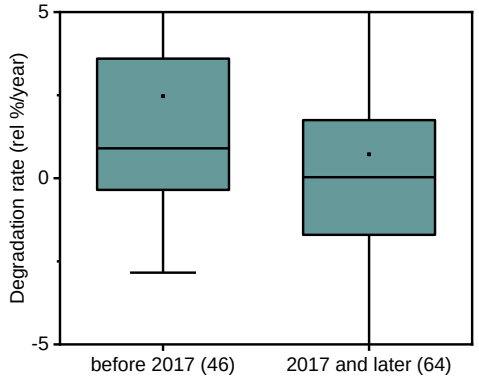
Humidity ingress

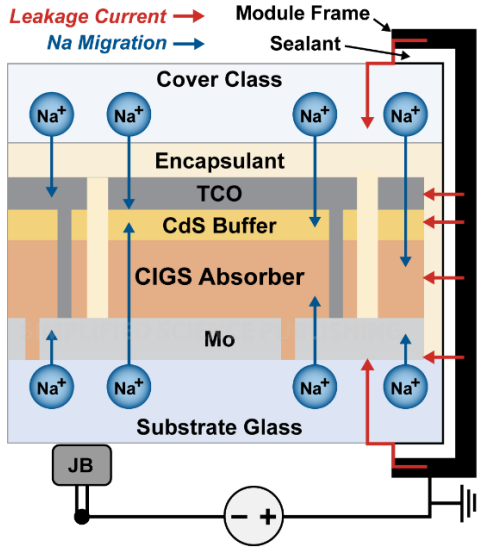
Conclusions

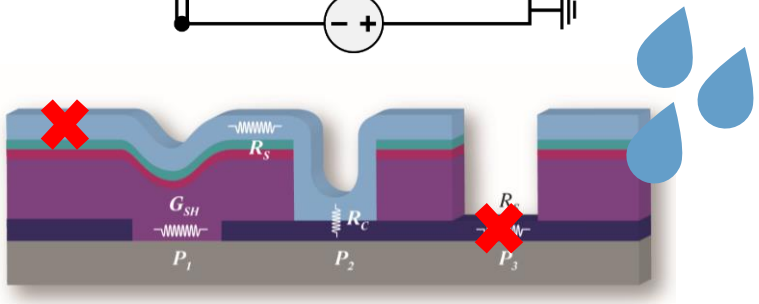
SOLLIANCE

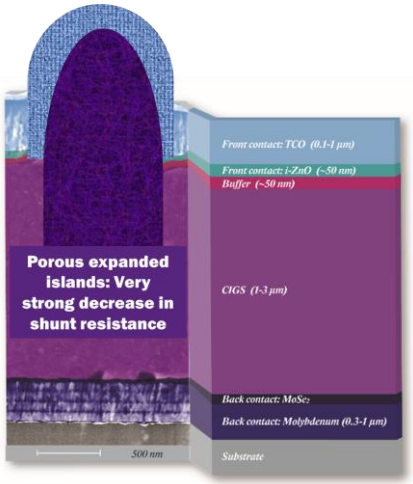
CONCLUSIONS











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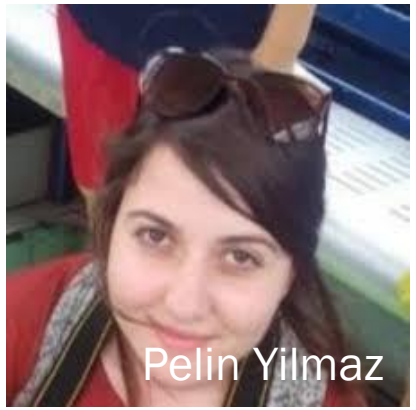
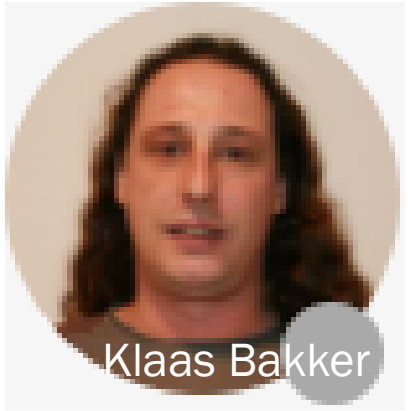
THANKS TO





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AND TO YOU FOR LISTENING!

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THANKS FOR
YOUR ATTENTION
QUESTIONS
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