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M10 Solar Equipment

pv magazine webinars

Minimizing partial shading yield losses

12 December 2023

4:00 pm – 5:00 pm | CET, Berlin

10:00 am – 11:00 am | EST, New York City

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Welcome!

Do you have any questions? ❓

Send them in via the Q&A tab. 👉 We aim to answer as many as we can today!

You can also let us know of any tech problems there.

We are recording this webinar today. 📹

We‘ll let you know by email where to find it and the slide deck, so you can re-watch it at your convenience. 👀 💡

Shading in PV systems – a short field report

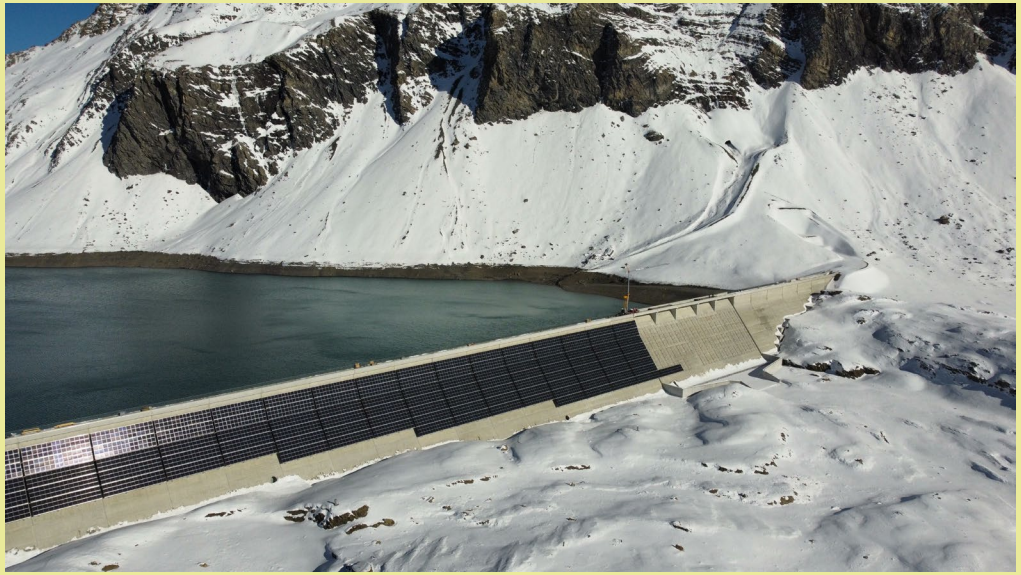
Planeco GmbH

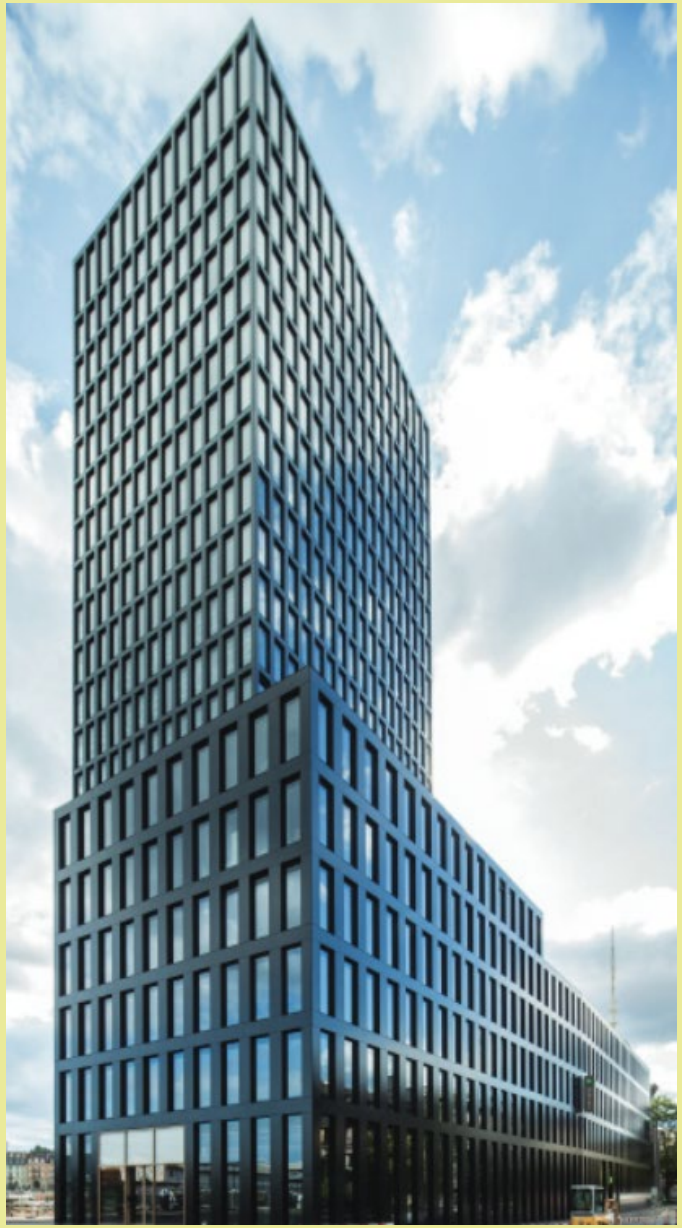
Planeco was founded in 2011 by Roman Brunner and Claudius Bösiger
and is located in Arlesheim, Switzerland.

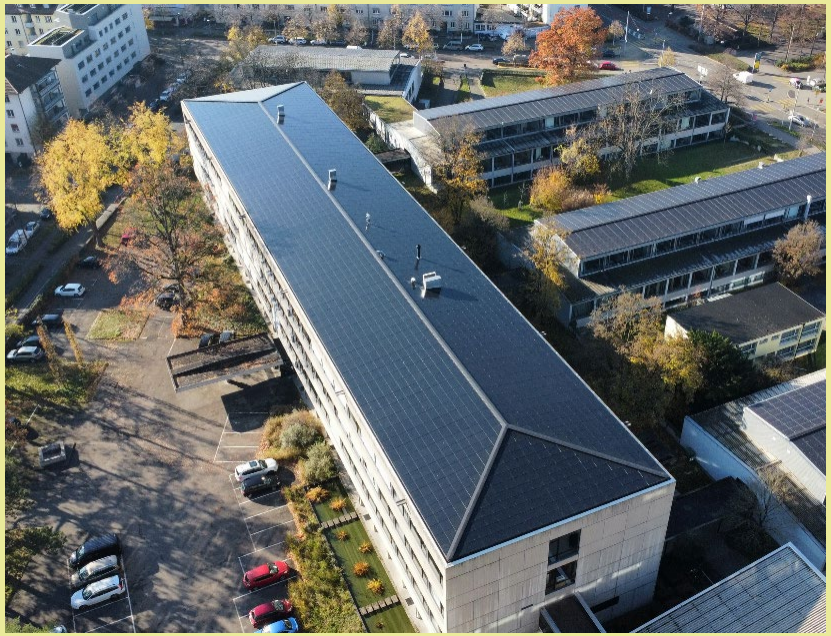
Planeco specializes in the planning and construction of photovoltaic power plants.
We are one of the market leaders in Switzerland, particularly in the field of
building-integrated photovoltaics.

Since 2020 our local energy provider IWB holds a 60% stake in Planeco.
Planeco currently has a total of 90 employees.

Planeco - Website
Planeco - YouTube
Planeco - LinkedIn







References

PLANECO SOLAR

What are the main reasons of shading in PV systems?

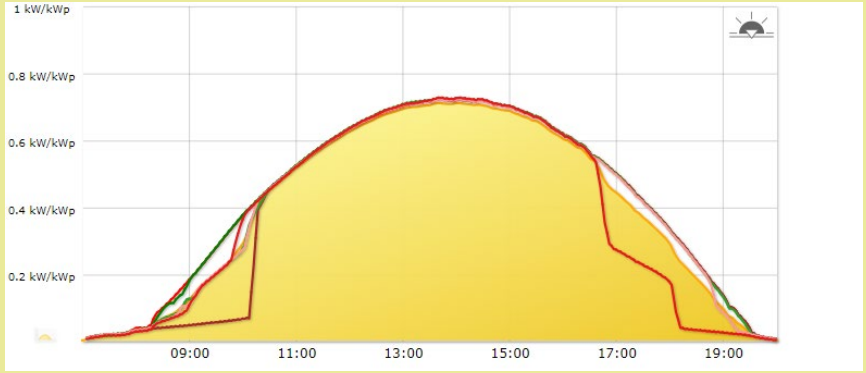
What damage can occur

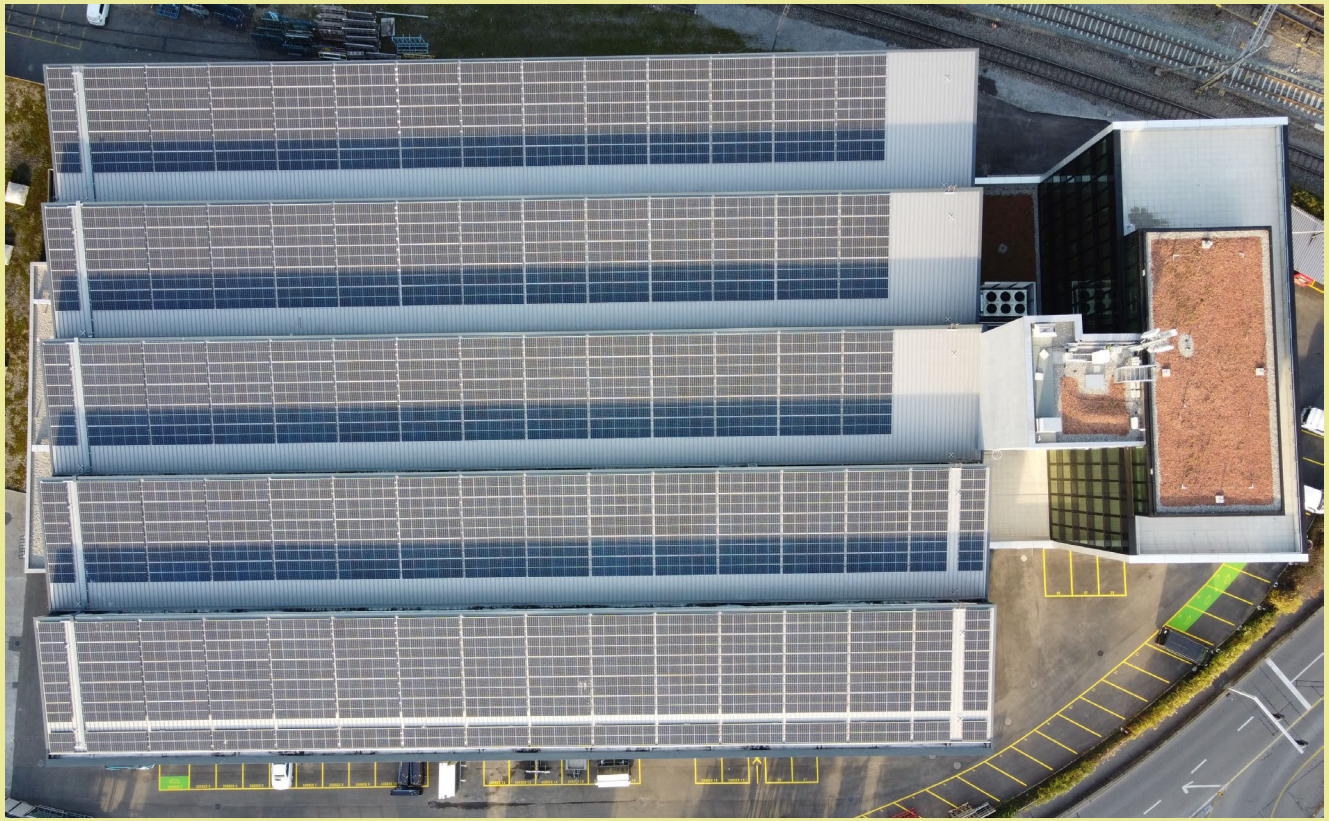
PLANECO SOLAR

How losses can be minimized

PLANECO SOLAR

Morning





Afternoon

How losses can be minimized

PLANECO SOLAR

Installing additional modules, even if they are partially shaded, …

… maximizes the energy production on a given roof/facade/area.
… shortens the energy payback time of the system.
… is cost-effective as it reduces the price per kWp and kWh.

Modules that are more resilient to partial shading could …

… further minimize yield losses.
… maximize profitability (depending on the project and the module production costs).
… contribute significantly to operational safety of PV systems.

Thank you

PLANECO SOLAR

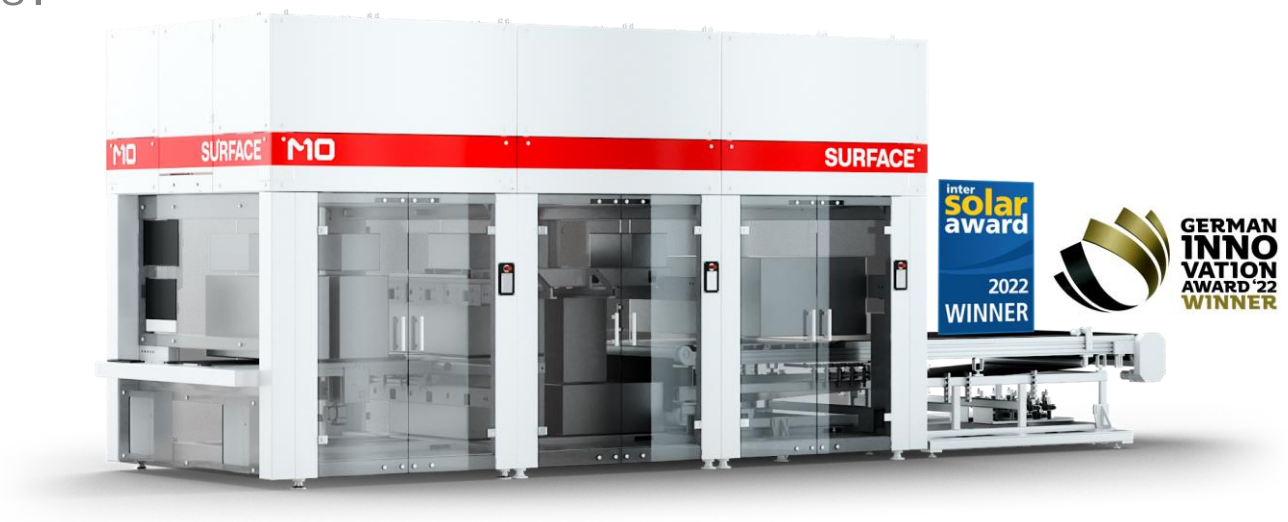
Shading Resilience of Shingle Matrix Modules

Nils Klasen, Philipp Zahn, Marco Saladin

12.12.2023
PV Magazine Webinar

Lead Questions for today‘s Webinar

1. What‘s the issue with *Partial Shading*?
2. Why are we convinced the *Shingle Matrix Interconnection* offers superior partial shading properties?
3. How can *Shading Resilience* be quantified?



Examples for Partial Shading

Small shaded areas already have a huge impact on power output!


[1]


[2]


[3]

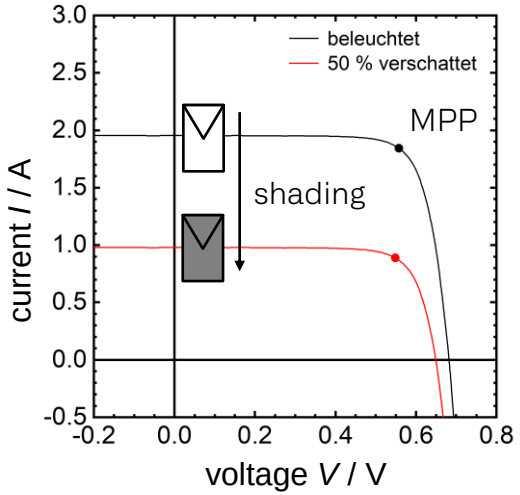
[1] Contribution of AE Solar
[2] Taken on my way to work
[3] Taken during a hike

What‘s the issue with Partial Shading?

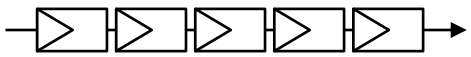
In two words: current mismatch

Shading of Solar Cells

- Reduction of irradiation ➔ Reduction of photocurrent I_{ph}



- Electrical **serial interconnection** ➔ current conservation



$$I_1 \overset{!}{=} I_2 \overset{!}{=} \ldots \overset{!}{=} I_n$$ ← 1st Kirchhoff law

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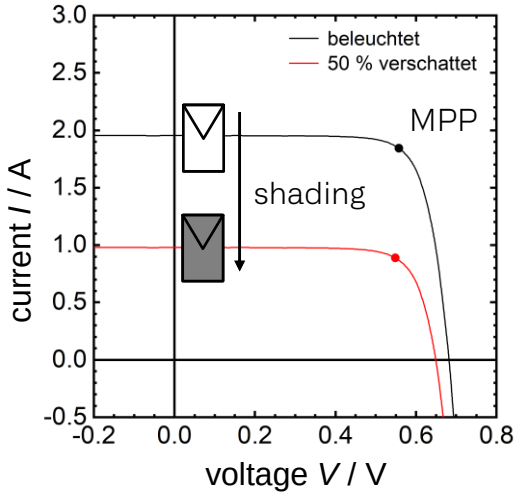
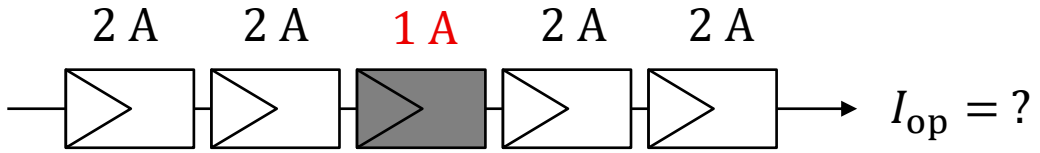
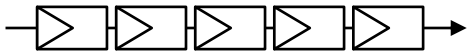




current mismatch $\Delta I = 1\ \mathrm{A}$

- Electrical **serial interconnection** ➔ current conservation



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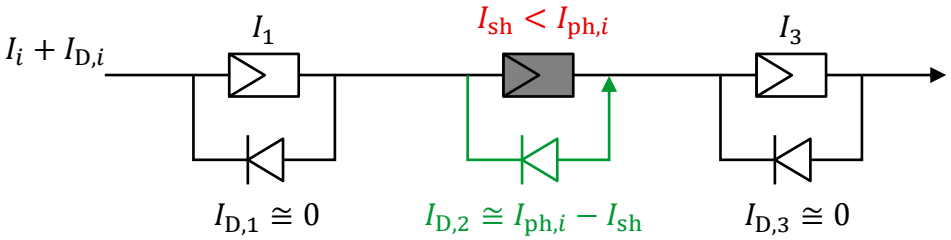
What‘s the issue with Partial Shading?

Counter measures for current mismatch

Bypass Diodes

- Difference in generated current **bypasses** the solar cell through the **diode**



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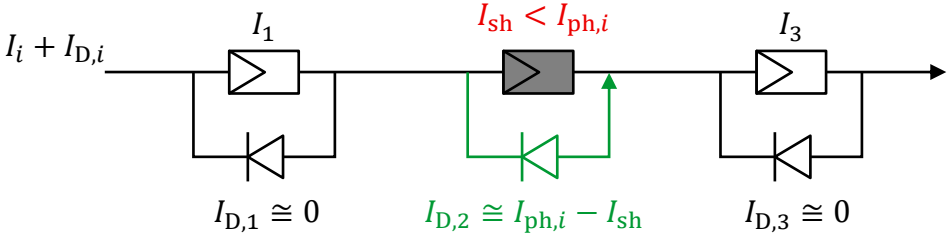

Full Parallel Module Layout

- No current mismatch „possible“
- Challenge:
  - $V_{module} = V_{cell} \cong 0.65\ V$
  - $I_{module} = n \cdot I_{cell} \cong 600\ A$
- If just V_{cell} could be $\cong 30\ V$ …

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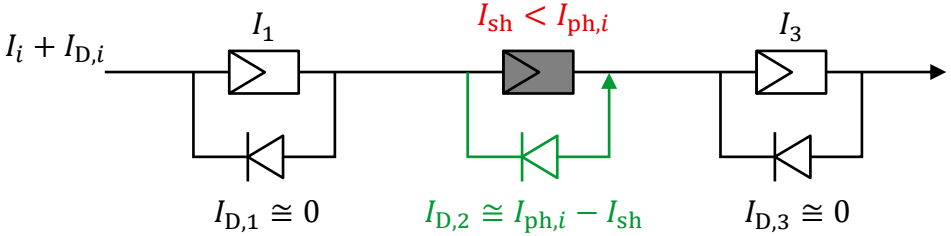

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Mitigation of Current Mismatch

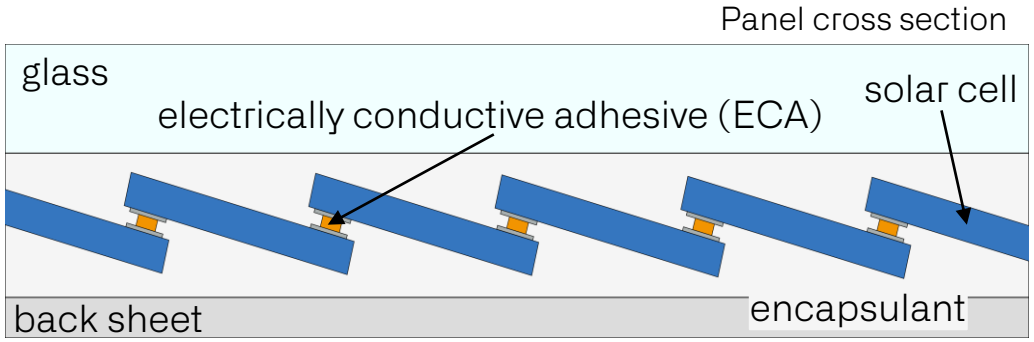
- Shingle Matrix Interconnection

Evolut[10]n

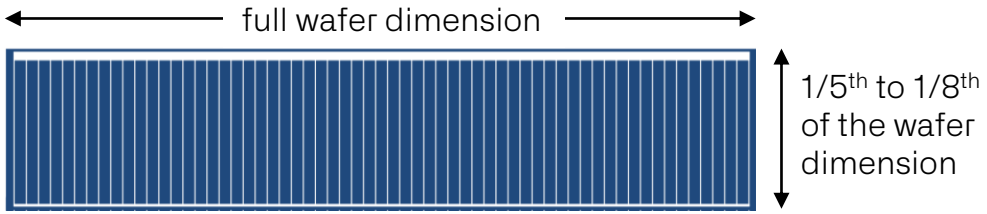
Shingle Matrix Interconnection

Shingle Interconnection Technology [1]

- **Remove:** ribbons / wires / solder
- **Add:** overlapping solar cells / ECA



- Requires special solar cell format



[1] Donald C. Dickson Jr., US patent, S 2938938 A, 1960

Evolut[10]n

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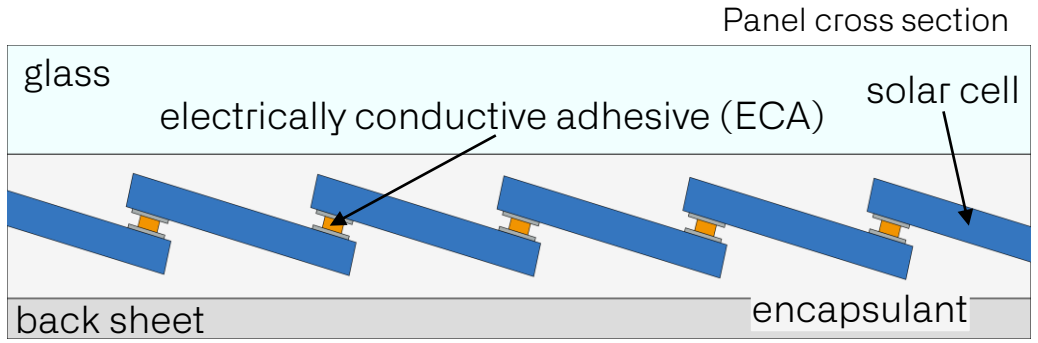

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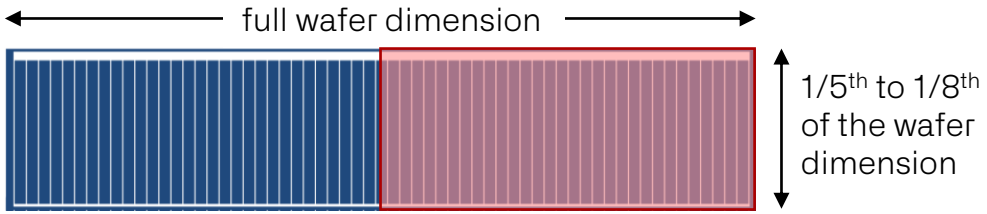
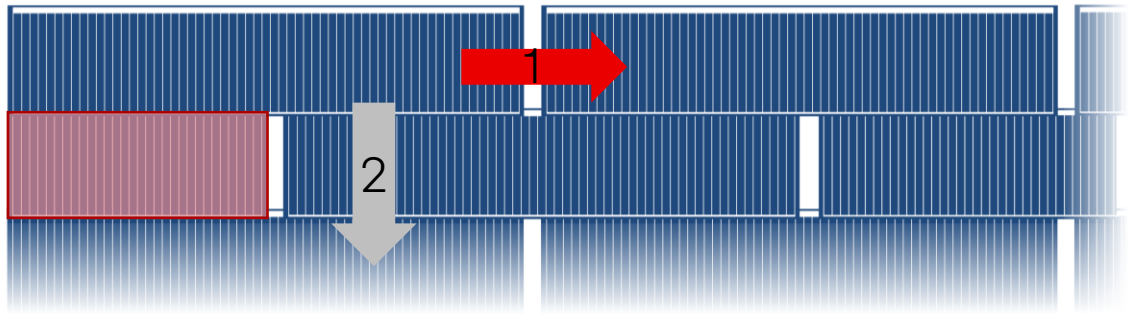


Shingle Matrix Layout

- Introducing: half-cut shingle solar cells
- Creation of masonry-like structure

1. Parallel interconnection of solar cells in one row
2. Serial interconnection of rows forming the panel



- Current / voltage characteristics similar to standard PV modules

[1] Donald C. Dickson Jr., US patent, S 2938938 A, 1960

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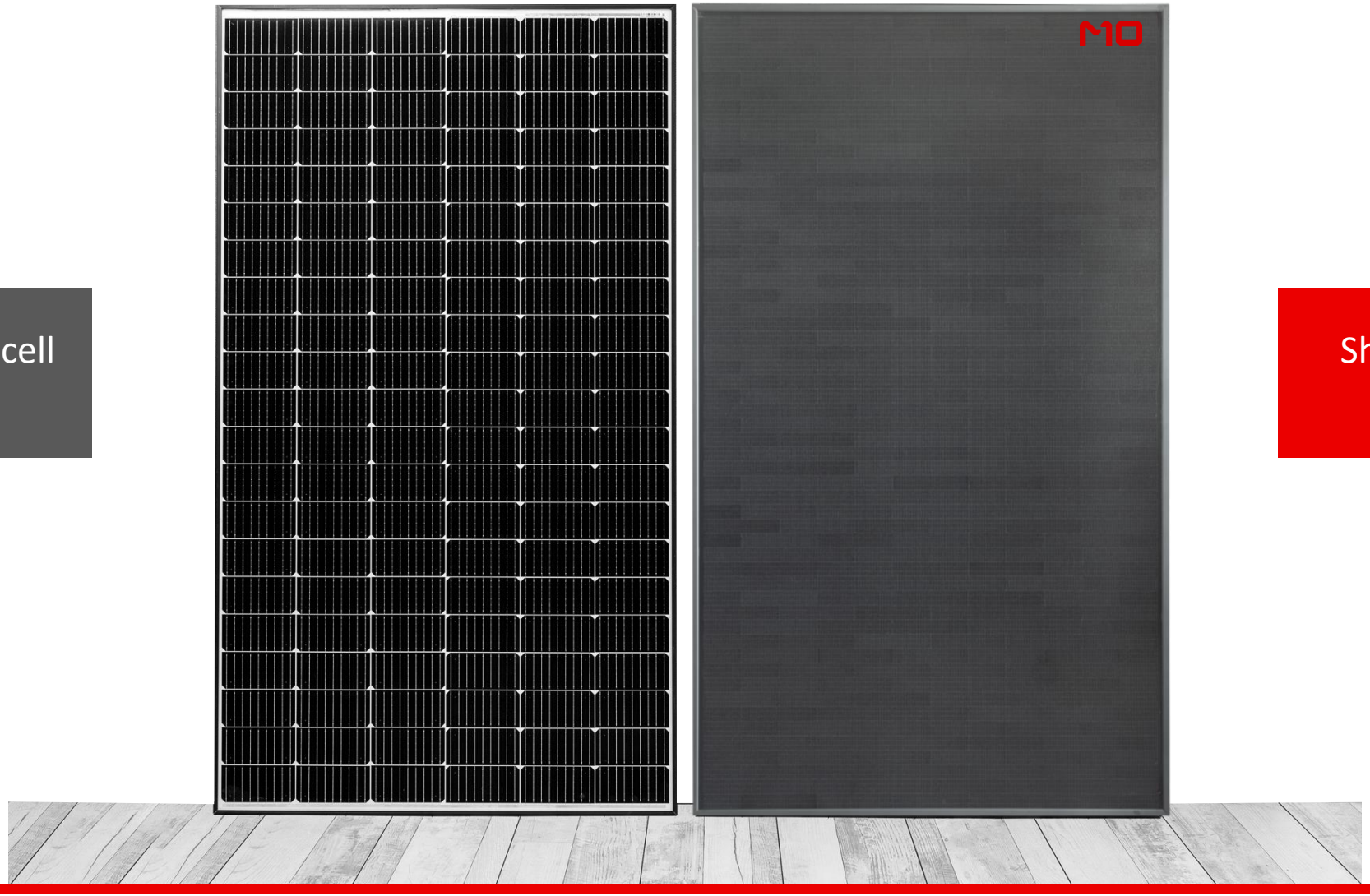
Shingle Matrix Modules

A unique way of Solar Cell Interconnection

Half-cut solar cell module



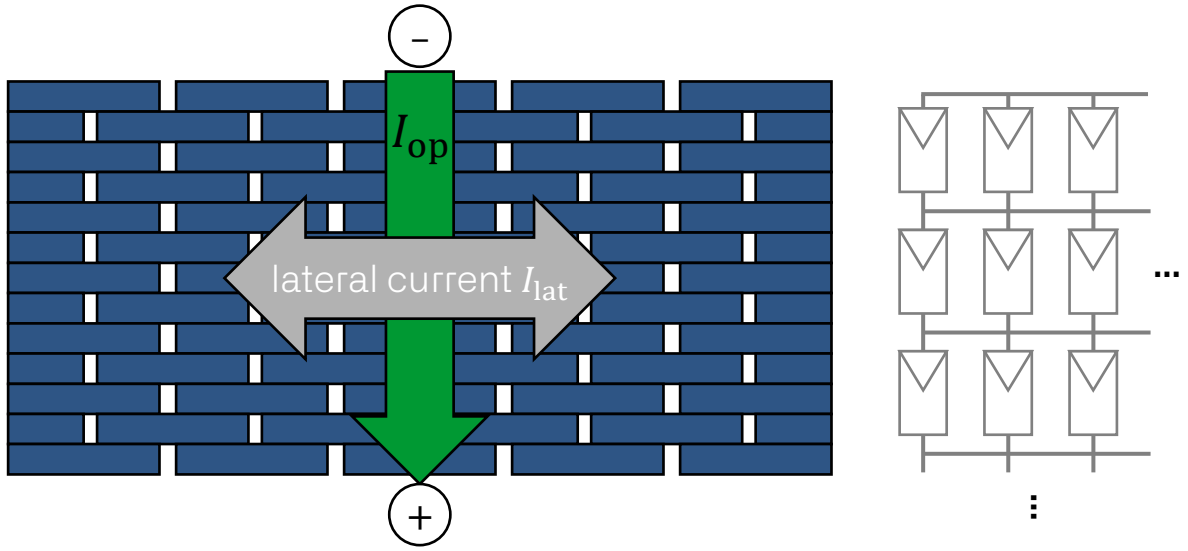
Shingle matrix module

Current Mismatch Mitigation

Lateral Currents

- „Lateral currents“, I_{lat}: perpendicular orientation to currents in normal operation

Current flow in normal operation



Current Mismatch Mitigation

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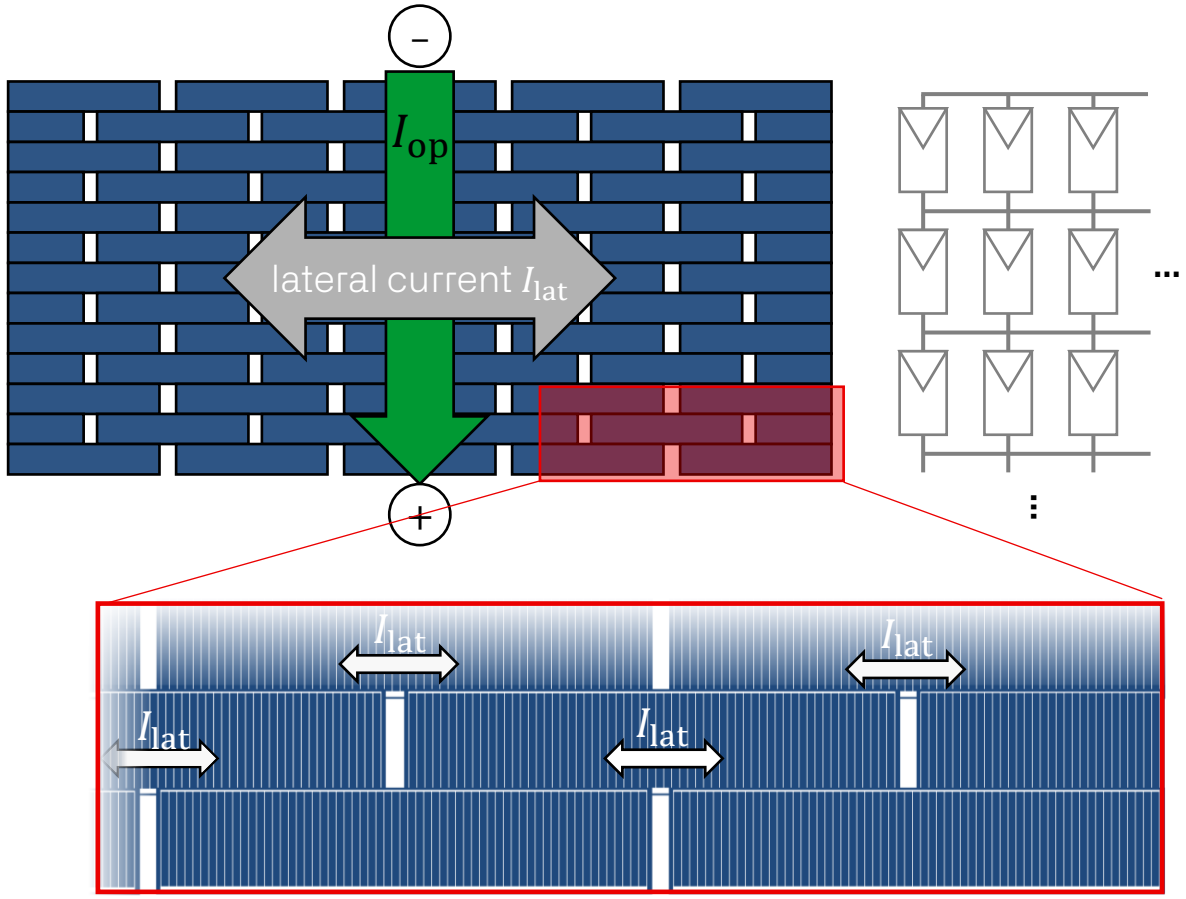

Current Mismatch Mitigation

Lateral Currents

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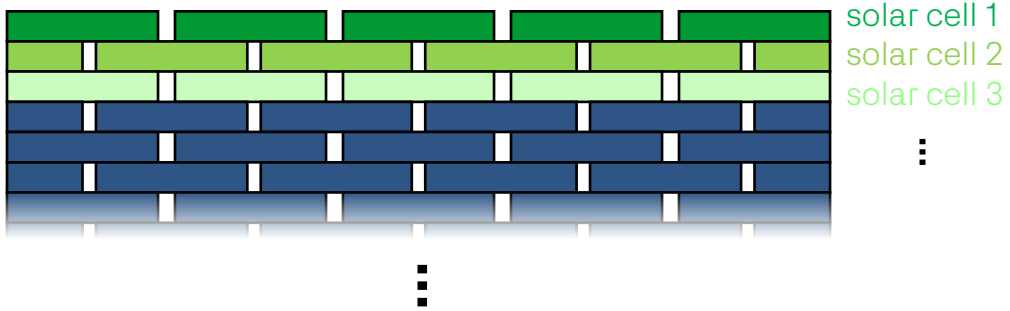
- Solar cells in a row behave like one large solar cell



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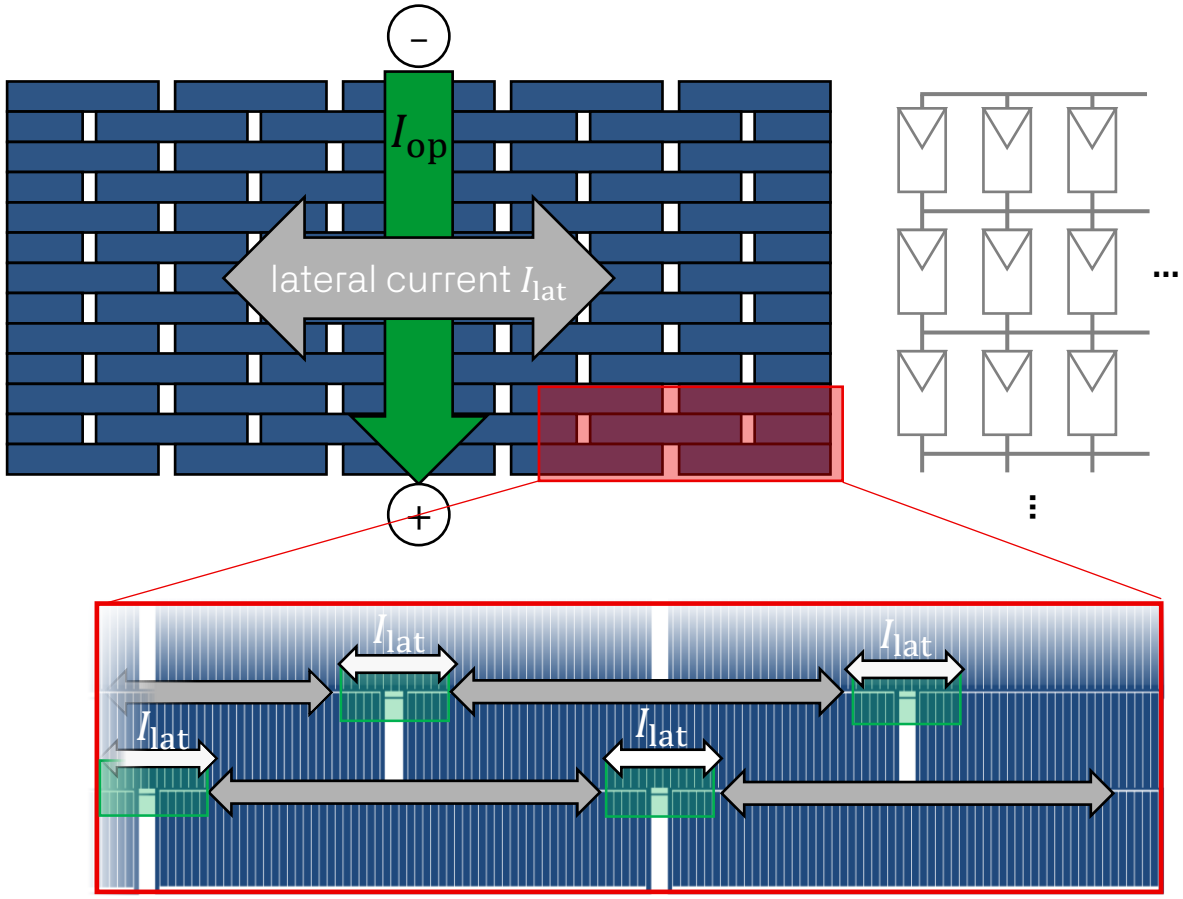
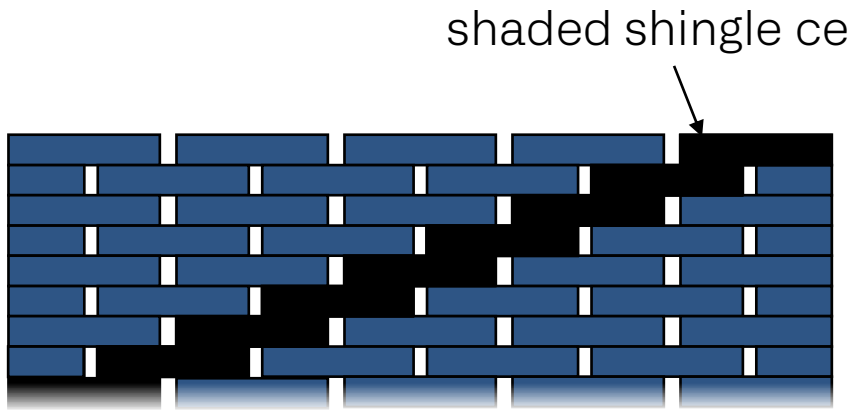


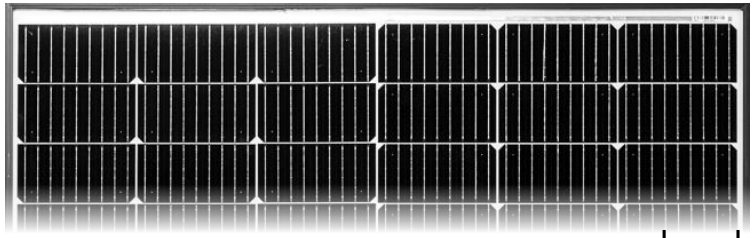
Current Mismatch Mitigation

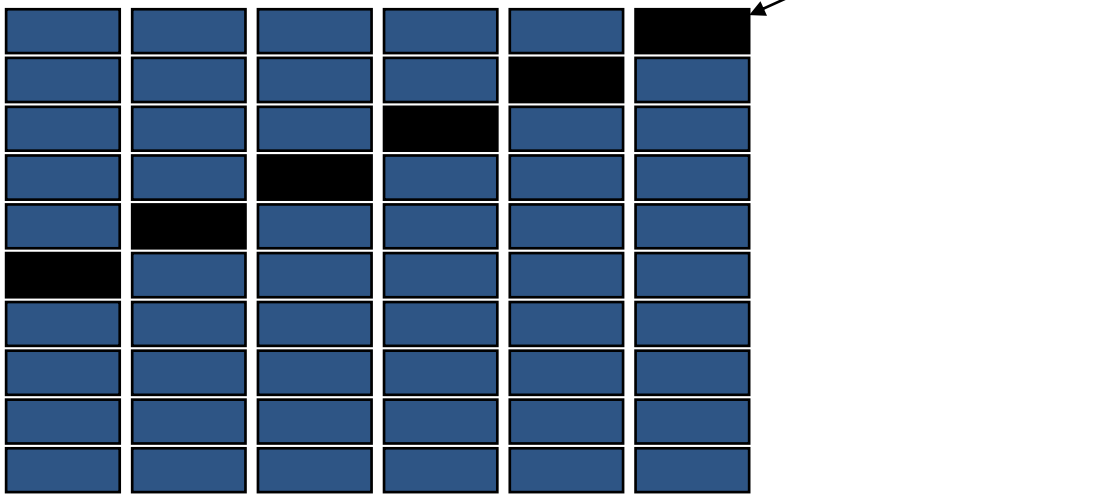
A Shading Example

Shingle Matrix Module



Half-cut Solar Cell Module



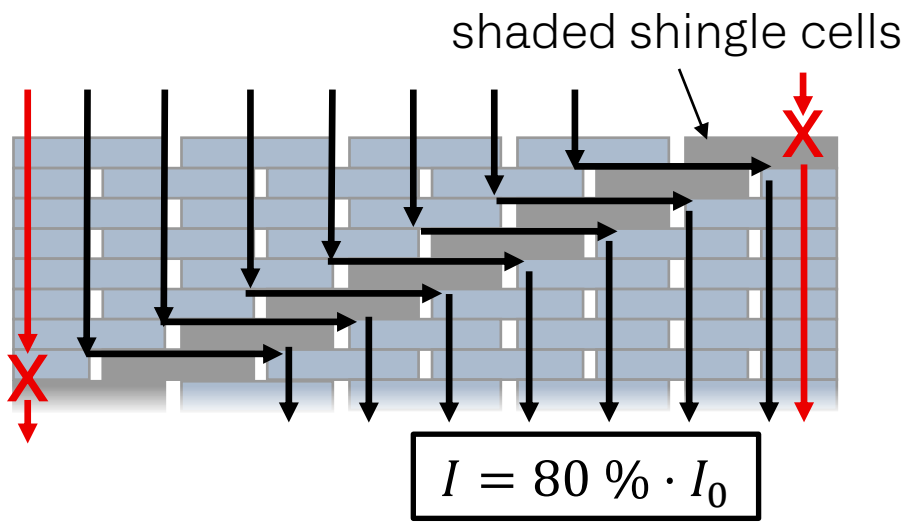


Current Mismatch Mitigation

A Shading Example

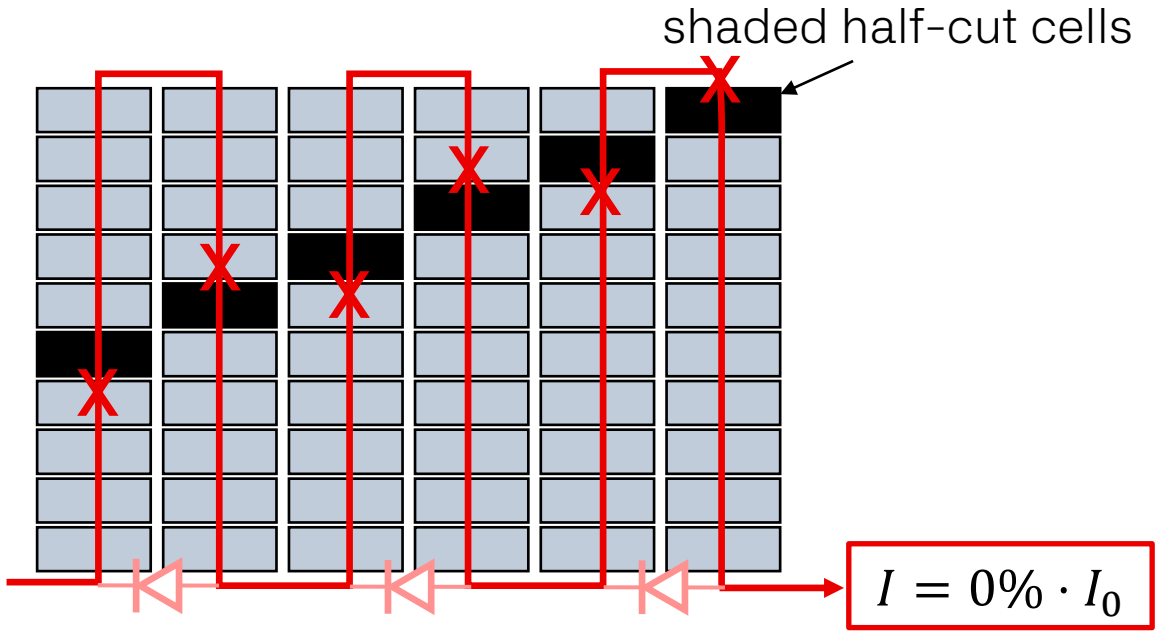
Shingle Matrix Module

- 4 out of 5 solar cells per row operate as usual
- Lateral currents **bypass** the shade [1]
- Current reduction to $0.8 \cdot I_0$



Half-cut Solar Cell Module

- In each string there are two solar cells blocking the current
- Current drops to 0 in all strings



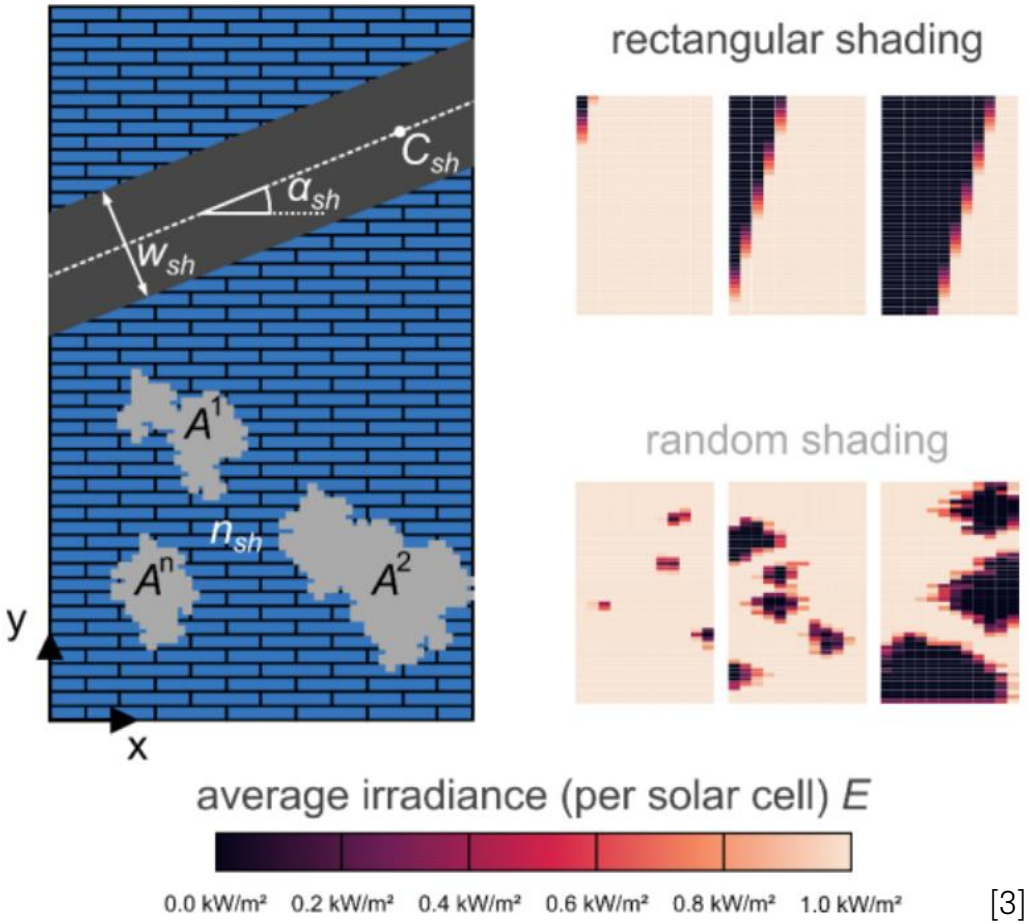
[1] Klasen *et al.*, Lateral Currents in Shingle Solar Modules Detected by Magnetc Field Imaging, IEEE Journal of Photovoltaics, 2023

How to more universally quantify Shading Resilience?

Computation of Randomized Shading Scenarios

Tackle Diversity of Shading by Statistics [1,2,3]

- Monte Carlo Method – approximation of a solution
  - Create (many) shading scenarios
  - Compute *I*-*V*-curve for different module layouts
  - Compare average results



[3]

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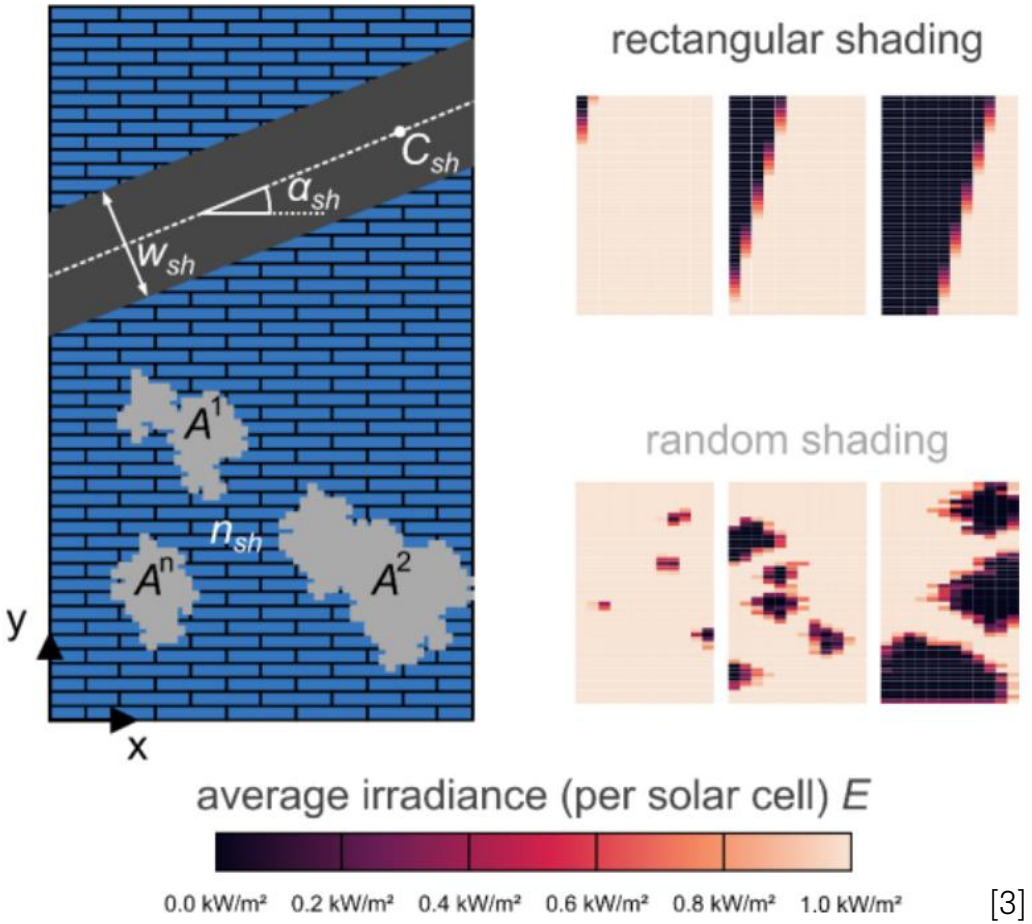
Shading Resilience = average power [1,2]

In this specific Study [3]

- Evaluation of ~1200 scenarios
- Comparison of 4 module layouts
- Focus on **current mismatch**



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Simulation Study

Spot on V_{MPP}

Current Mismatch reveals itself in V_{MPP}

- Current mismatch leads to MPPs with conductive bypass diodes ➔ voltage drop by ~ $1/n$,
  with n: number of bypass diodes

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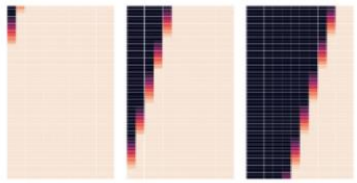
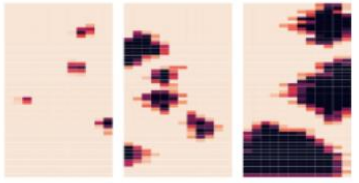
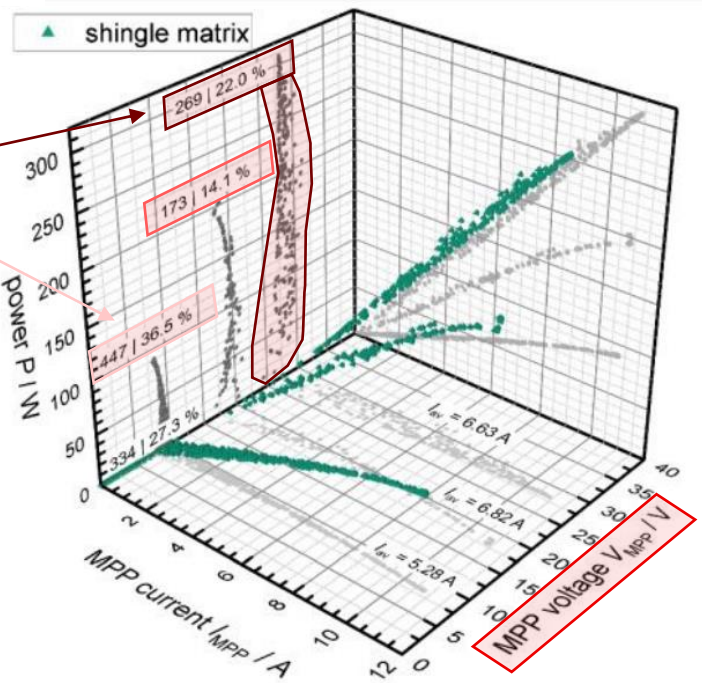
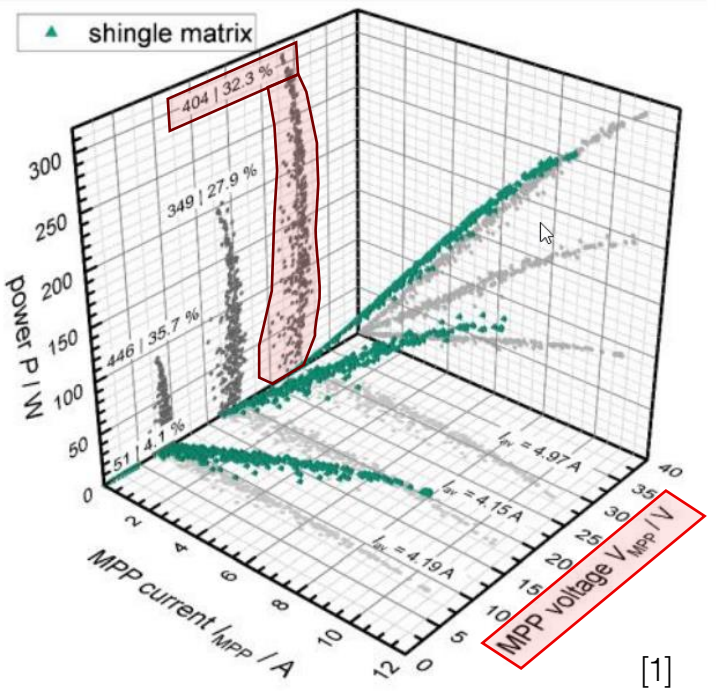




Rectangular Shading

Random Shading





[1]

Results Shingle Matrix

[1] Klasen *et al.*, Quantitative Evaluation of the Shading Resilience of PV Modules, Proceedings of the 38th EUPVSEC, 2021

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Results Monte Carlo Simulation Study

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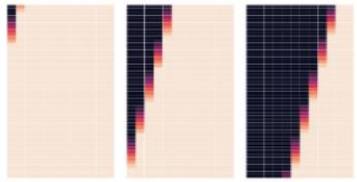

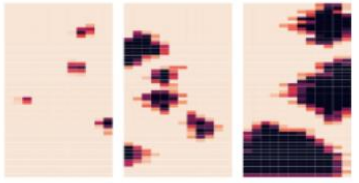

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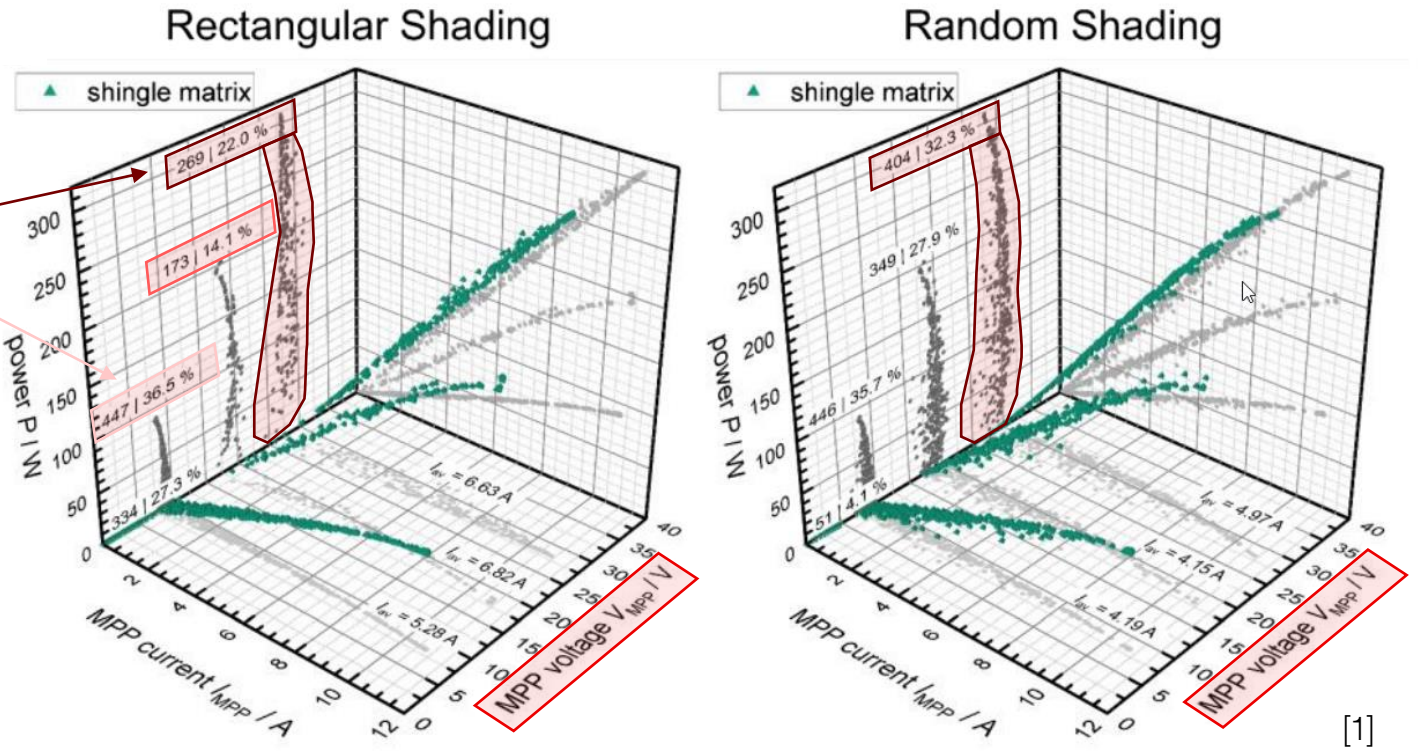
Cases without conductive bypass diode / %		
Layout	Rectangular	Random
Shingle Matrix	22.0	32.3
Shingle String	14.5	23.0
120 cell half-cut	15.0	12.6
60 cell full square	6.2	4.2



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Evolut[10]n

Thank you for your attention!

Contact us any time

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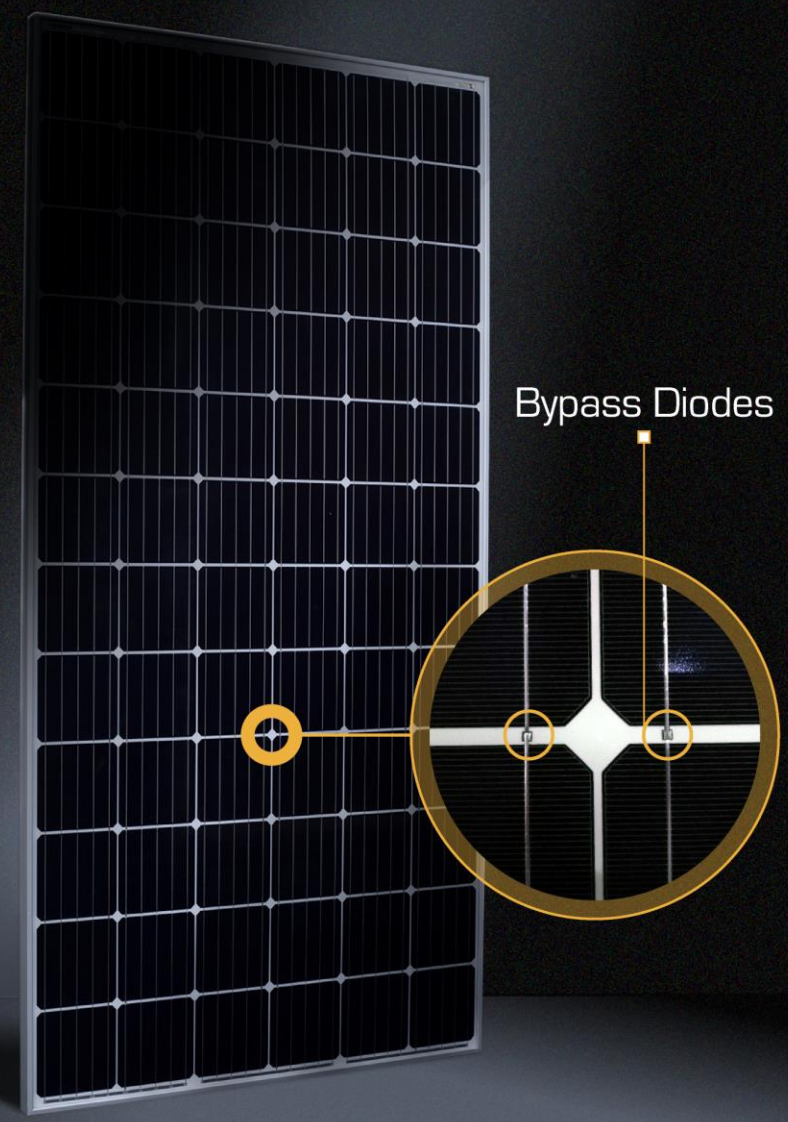
MINIMIZING PARTIAL SHADING YIELD LOSSES

SHADE-RESISTANT MODULES



Dr. Hamed Hanifi
Head of Research and Development and Technical Sales

PV Magazine webinar
December 2023

INTRODUCTION

An innovative company

- Customer-oriented company
- Tier-1 rated by Bloomberg NEF
- Present in 100+ countries

- AESOLAR received **PVEL trophy** as **TOP PERFORMER** in reliability and performance of its modules

- AESOLAR celebrated its **20 YEARS** anniversary

MOTIVATION

An overview on market segments

Two biggest PV markets in Europe

- Germany is the biggest European PV market
- 60% rooftop[1]

- Netherlands is the biggest market per capita
- Over 80% rooftop

Rooftop installations are one of the **major markets** which secures the distrbuted and renewable energy

Example of rooftop installation

[1]: Fraunhofer ISE

MOTIVATION

Challenges of rooftop PV

- PV modules are very sensitive to partial shading and lose power drastically

Bad news: You cannot avoid partial shading!

- Climate and land specifications increase the probability of partial shading:
  - Obstacles, snow , dirt, plants, etc

Obstacles

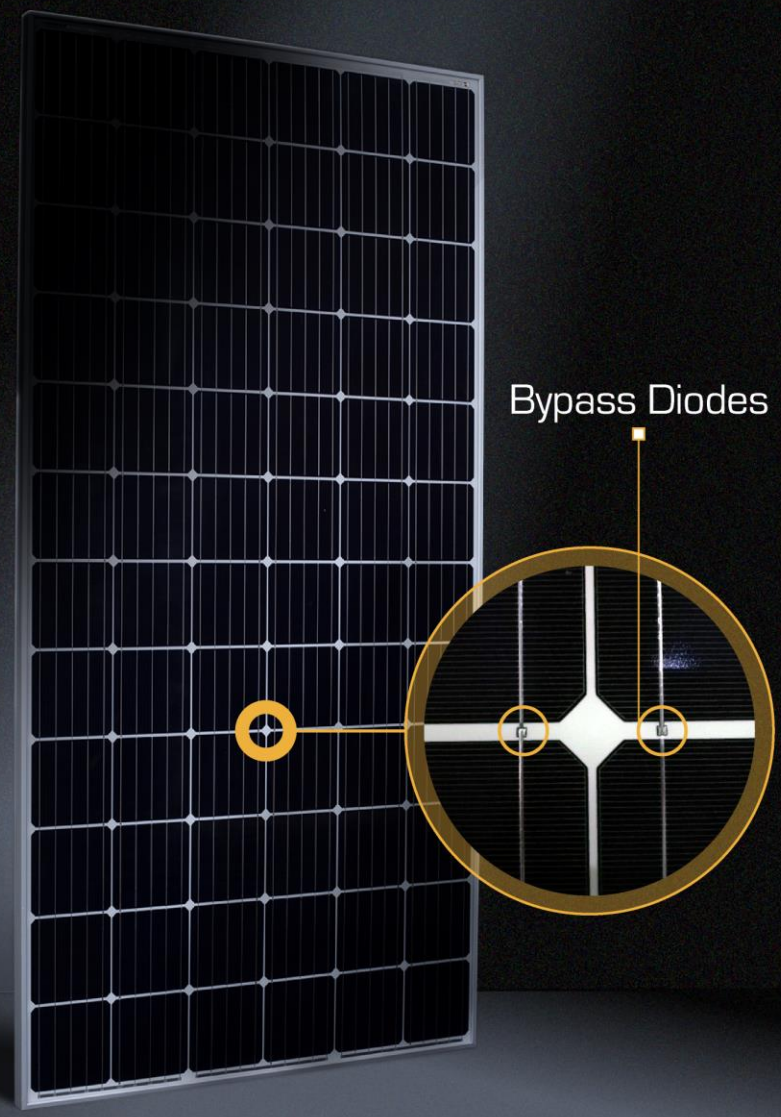
Snow

Dirt

SHADE-RESISTANT PV MODULE

Smart HSF (Hot-spot-free) PV module of AESOLAR

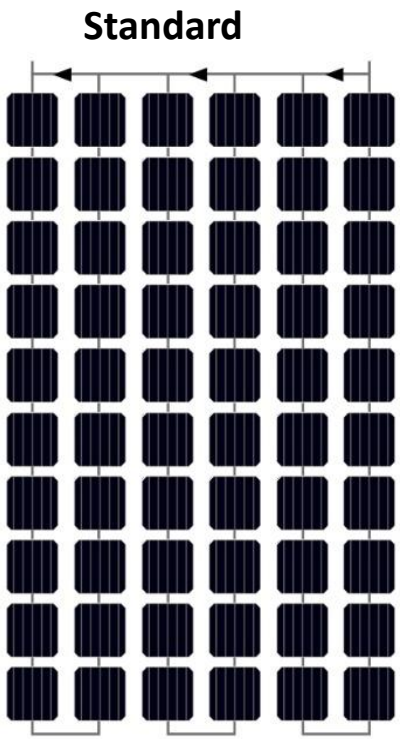
- One bypass diode for every individual solar cell
- Integrated bypass diode technology

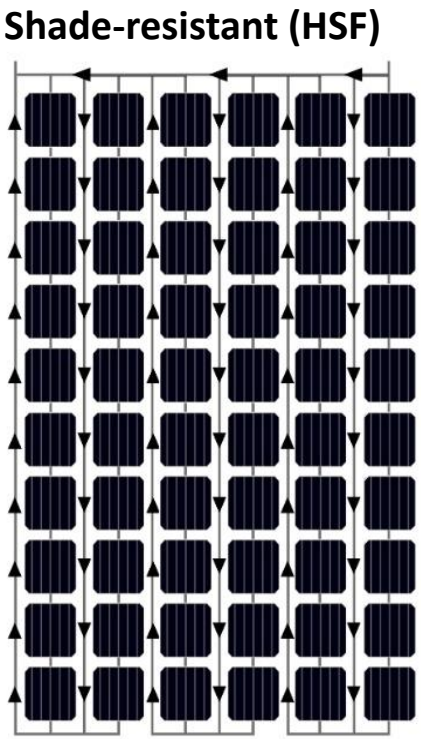


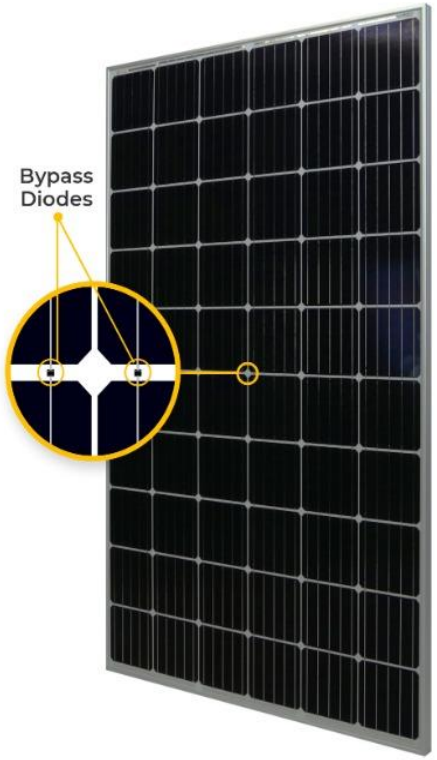
SHADING TEST

Samples and tests

- Two modules with similar bill of materials are tested under partial shading conditions
  - Shade-resistant (HSF)
  - Standard
- Partial shading test
  - Indoor test
  - Outdoor test







INDOOR PARTIAL SHADING

Shading scenarios

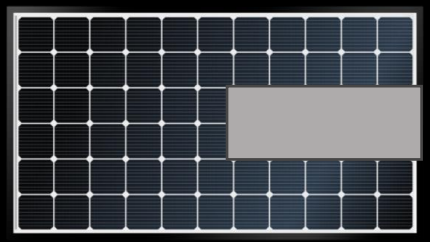
Measurement tool and setup

- Sun simulator at Fraunhofer CSP and Anhalt University of applied Sciences
- Measurement under STC

Shading scenarios

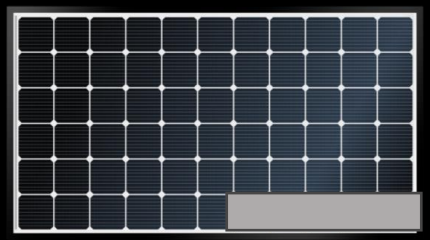
- Shading the center
- Shading the bottom row
- Shading the side row
- Shading one cell
- Shading three rows
- Shading diagonal

Shading the center



Shading one row

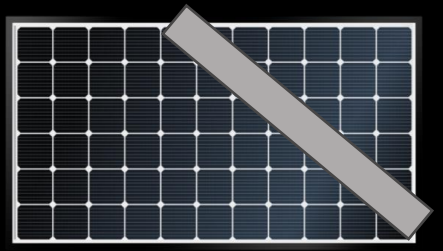
Right-side and one row



Shading one cell

Right-side and three row

Shading diagonal



INDOOR PARTIAL SHADING

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Shading scenarios

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- Shading the bottom row
- Shading diagonal

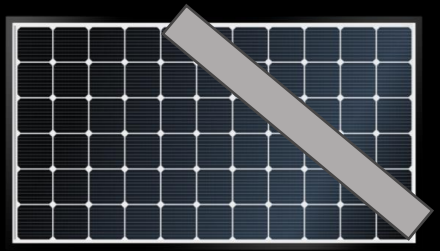
Indoor test

Shading one row

Shading one cell

Outdoor test

Shading diagonal

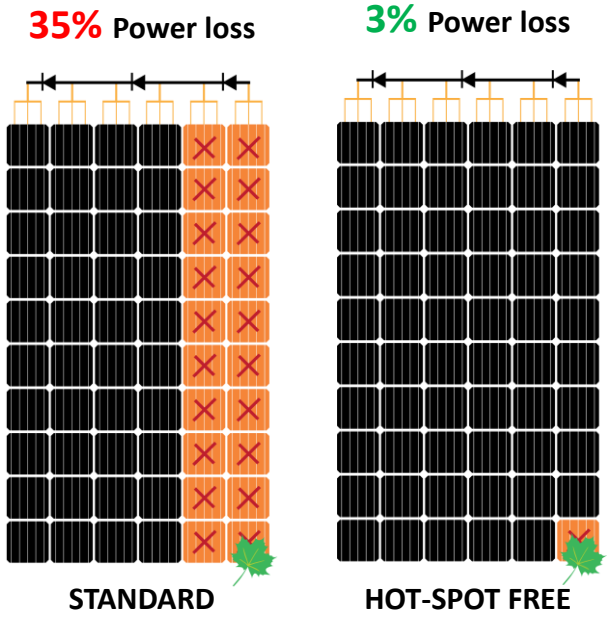


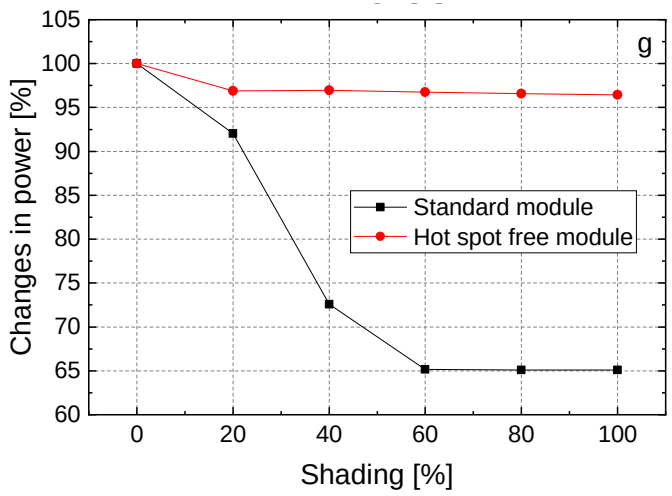
INDOOR PARTIAL SHADING

Shading of one solar cell

After shading of one cell

- **Standard module**: operates at **65%**
- **HSF module**: operates at **97%**

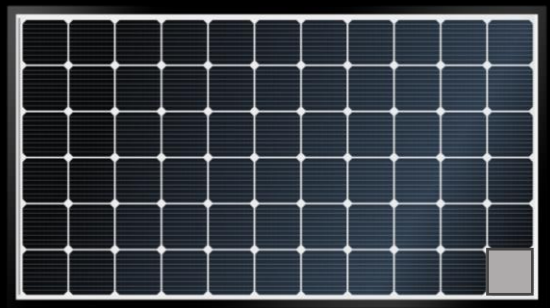


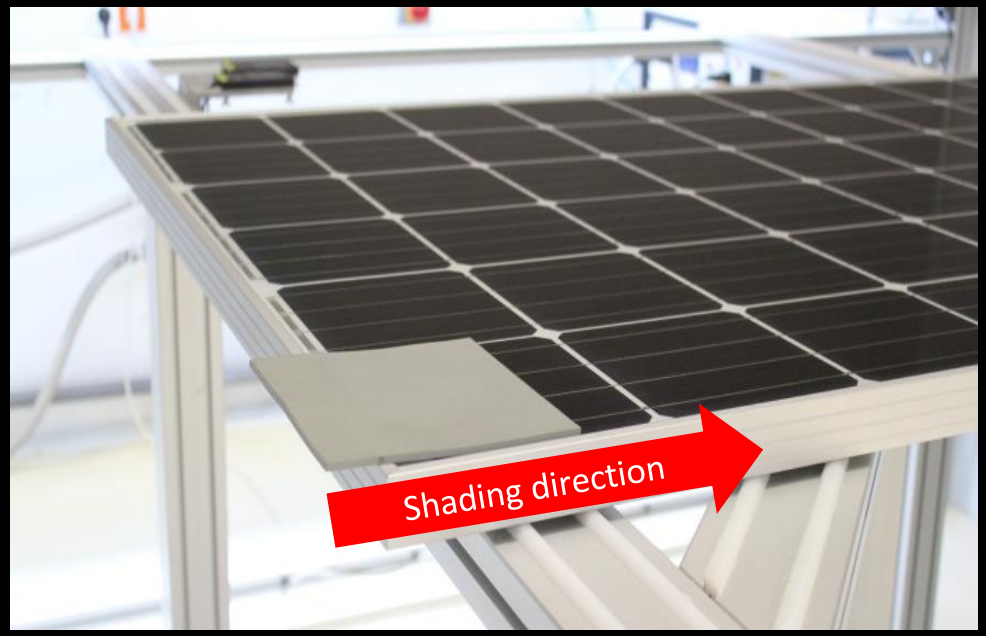


Hanifi et al, Solar Energy, 2019

Fraunhofer CSP AESOLAR

Shading one solar cell



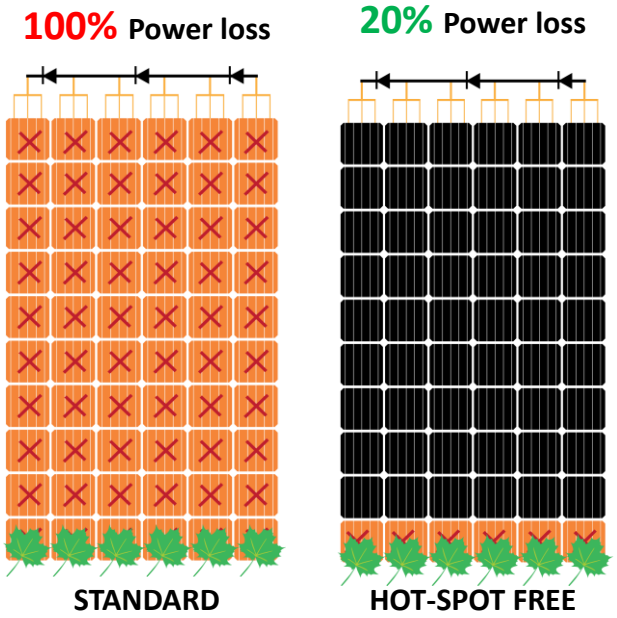


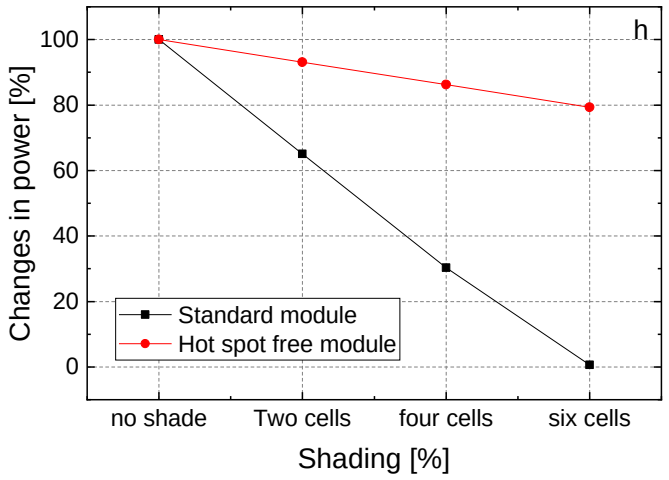
INDOOR PARTIAL SHADING

Shading of one row

After shading of one row

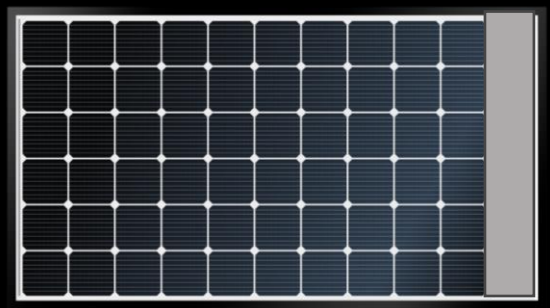
- **Standard module**: operates at **0%**
- **HSF module**: operates at **80%**





Fraunhofer CSP AESOLAR

Shading the bottom row



Hanifi et al, Solar Energy, 2019

OUTDOOR SHADING TEST

Experiment setup

Mounting in outdoor test field

- AE shade-resistant (shaded, mono-facial)
- AE standard (shaded, mono-facial)
- Reference module (unshaded, mono-facial)

Shading

- Wooden planks of 210 cm x 25 cm.

Measurement period

- 6 weeks between Oct. and Nov. 2022

Measurement tools

- All modules are connected to a SOL.Connect I-V tracer each.
- I-V curve, irradiance and backside temp. measurements are taken every 10 seconds.

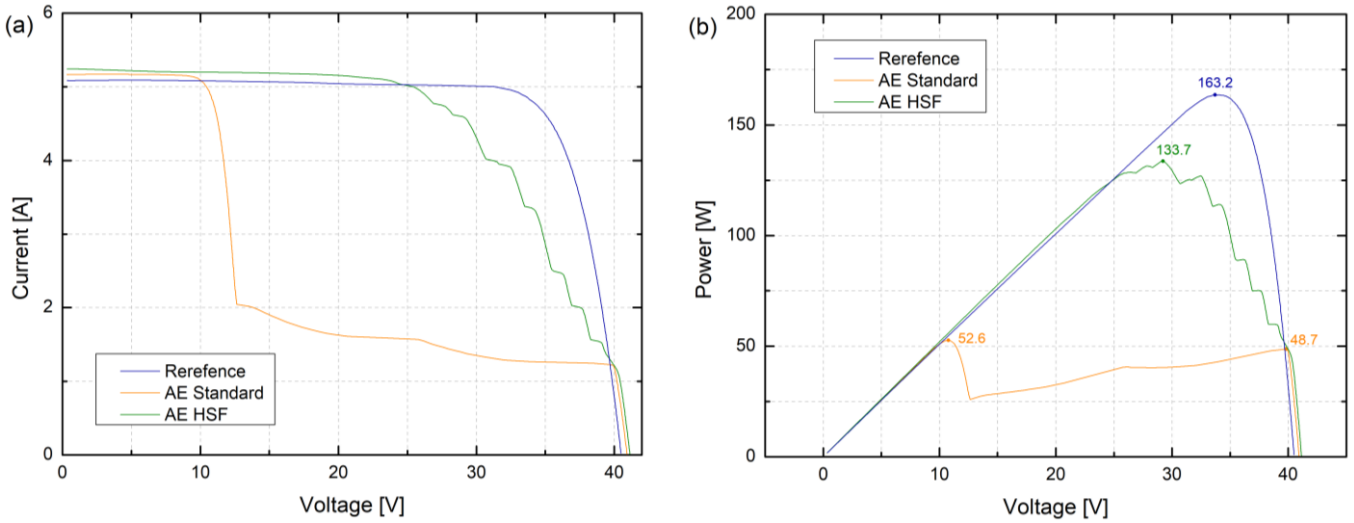
Energy yield measurement setup at the Anhalt Photovoltaic Performance and Lifetime Laboratory (APOLLO) in Bernburg, Germany

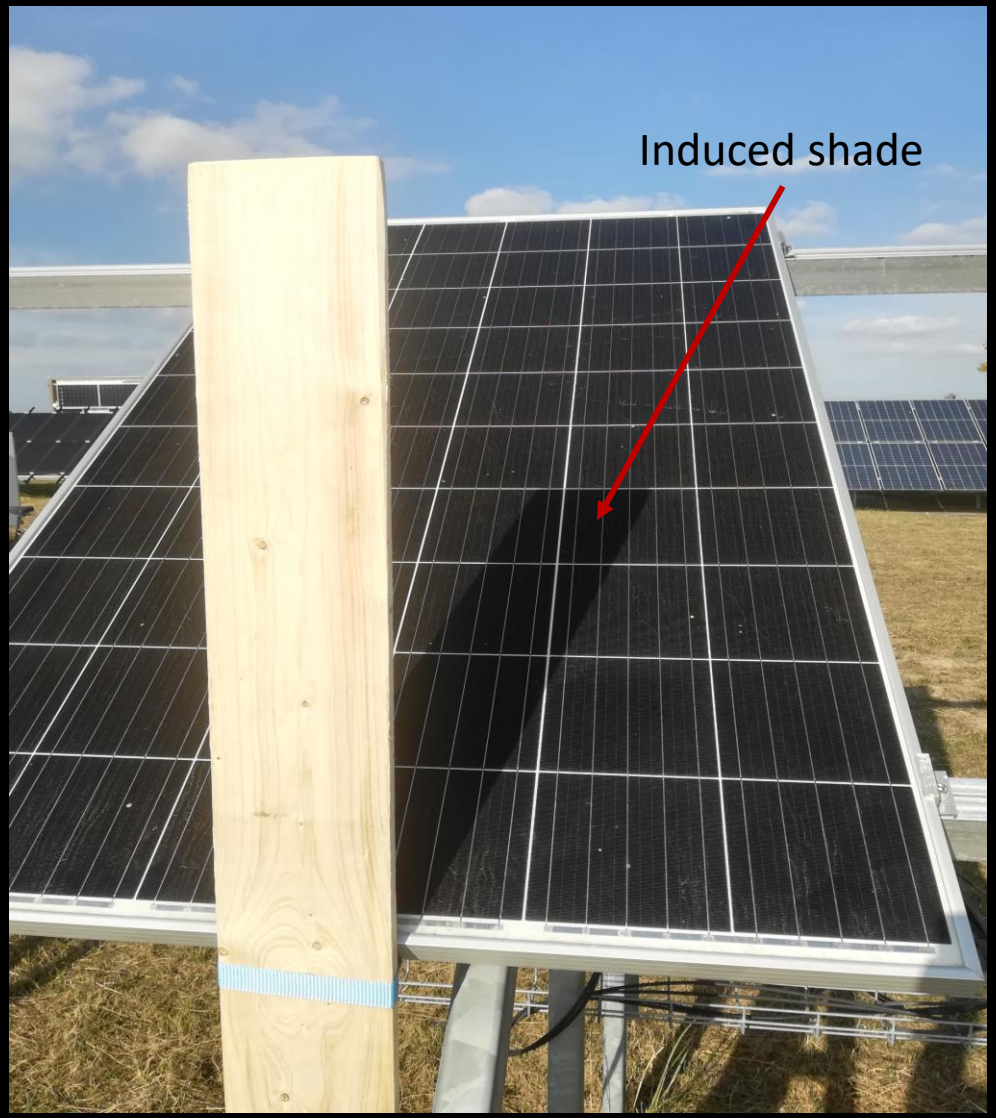
OUTDOOR SHADING TEST

Outdoor measurement

- Evaluation of IV curves in real-life scenario shows a significant advantage of HSF module over equivalent standard module

2.5 times more power relatively



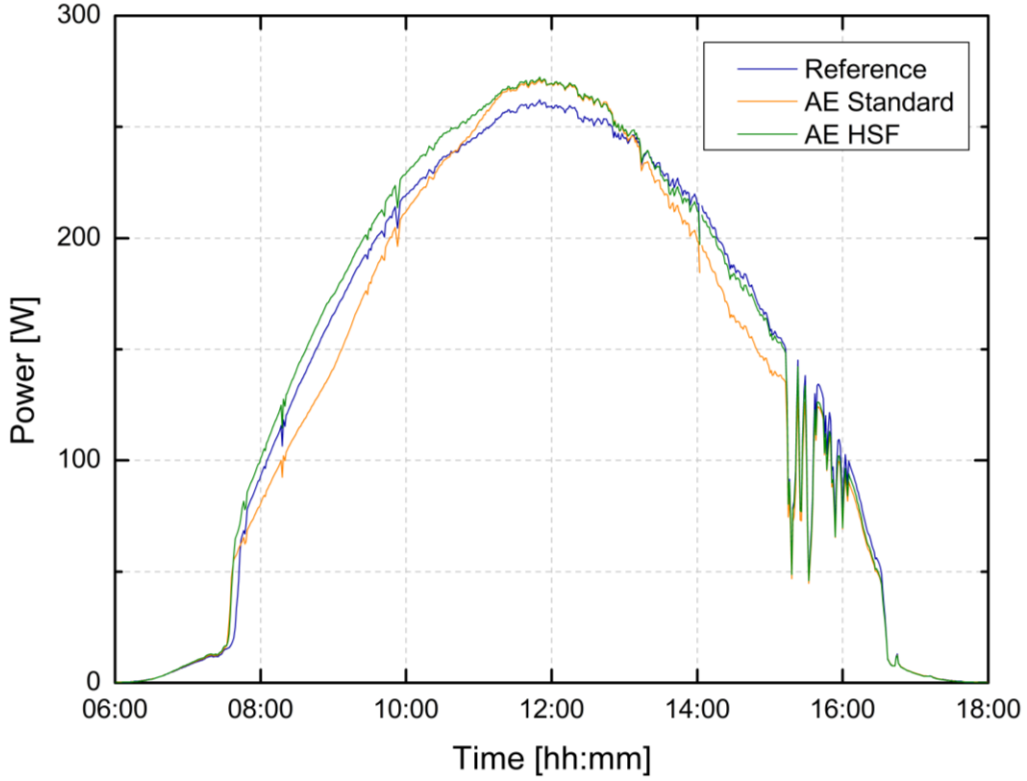


OUTDOOR SHADING TEST

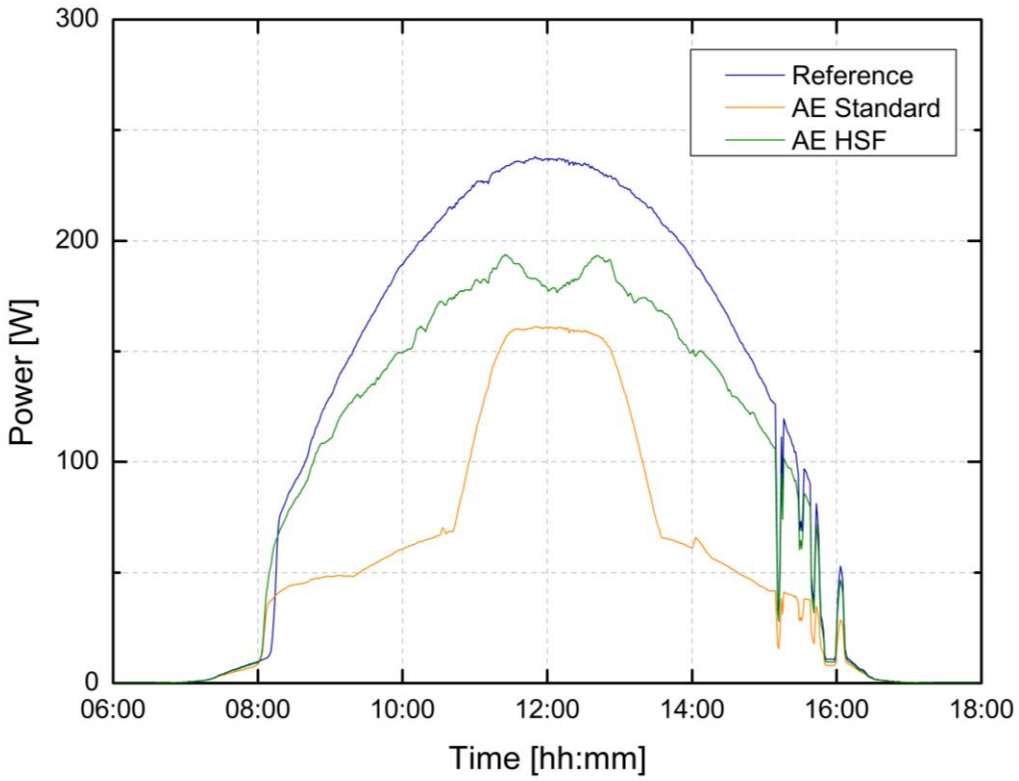
Outdoor measurement

Gain in energy yield of **+49%** compared to AE Standard

Clear day without shading



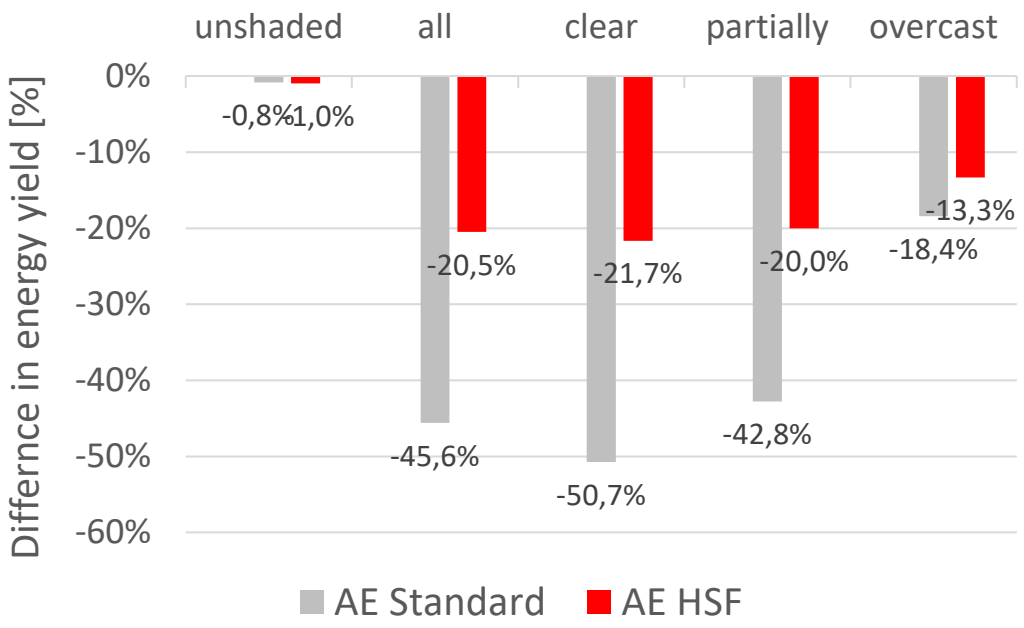
Clear day with shading



OUTDOOR SHADING TEST

Outdoor measurement

- Difference in energy yield for different day types

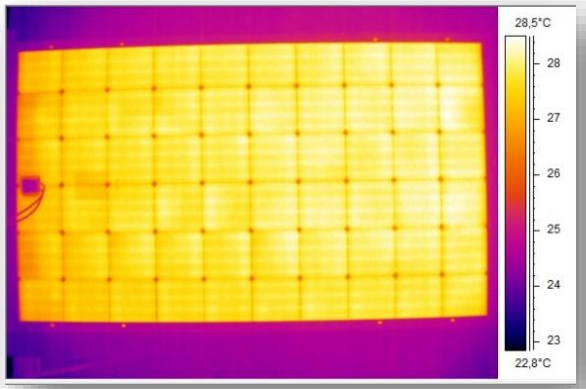


Energy yield measurement setup at the Anhalt Photovoltaic Performance and Lifetime Laboratory (APOLLO) in Bernburg, Germany

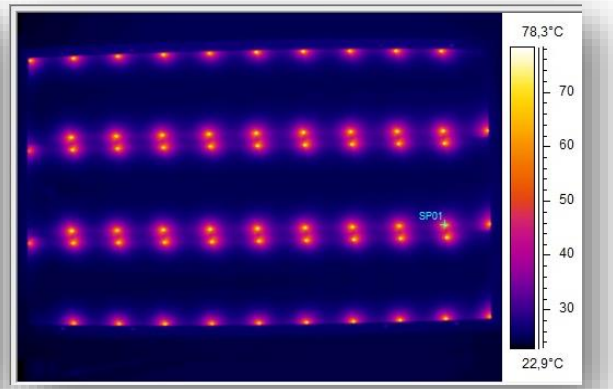
RELIABILITY

Reliability of diodes under stress test

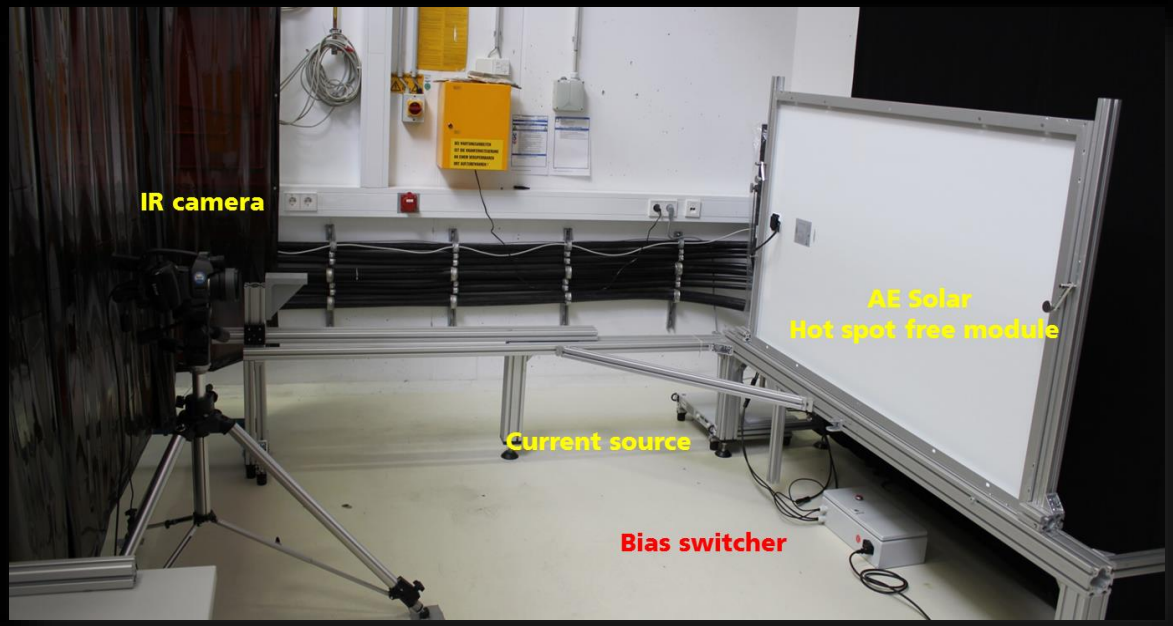
- a test to evaluate the **durability** of bypass diodes under partial shading conditions
- The device switches the bias every 60 seconds for **10,000 cycles → 25 years**



Forward bias



Reverse bias



Test setup with bias switcher and IR camera to monitor module temperature on each bias mode

Hanifi et al, Solar Energy, 2019

RELIABILITY

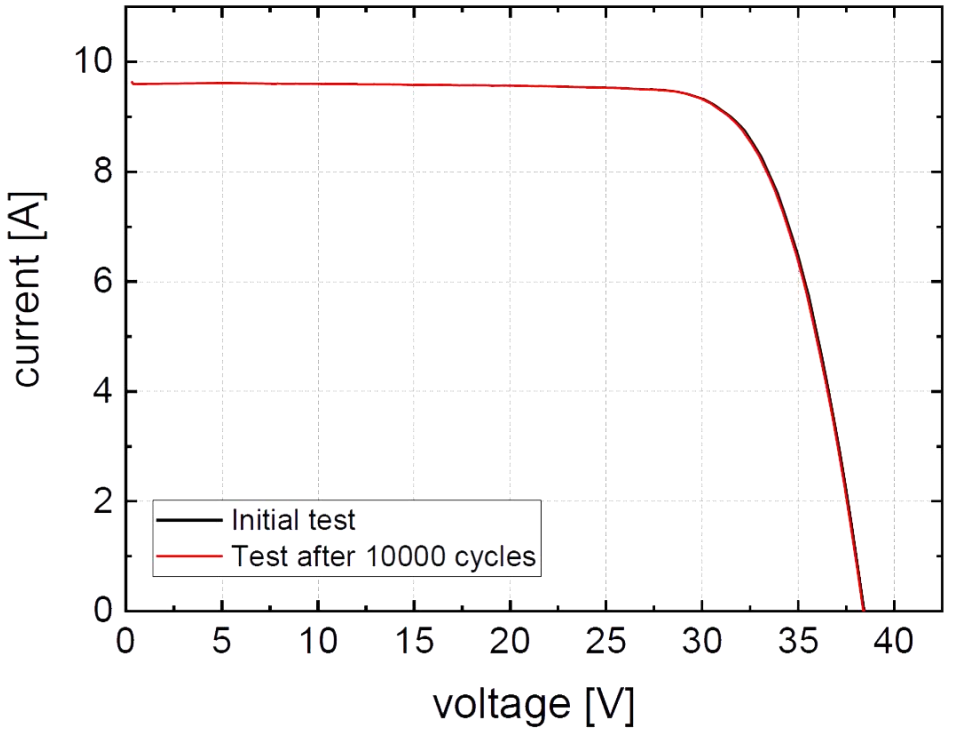
Test results – IV and EL

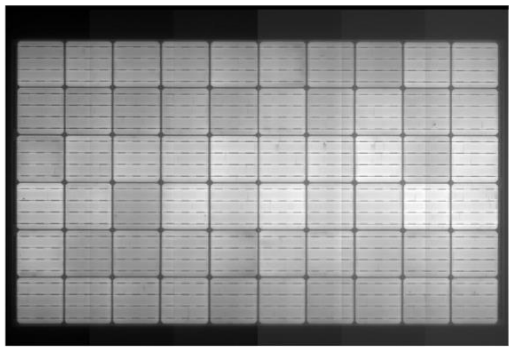
- The module is measured by flasher and electroluminescence before and after **10,000 cycles** of stress test

- I-V flash results
  - no power loss

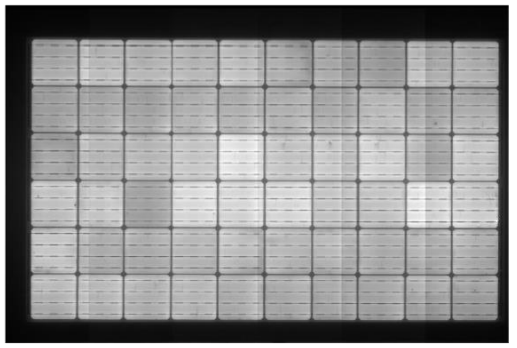
- EL results
  - No defects

The diodes are durable enough to work for 25 years





EL of module P07 before test

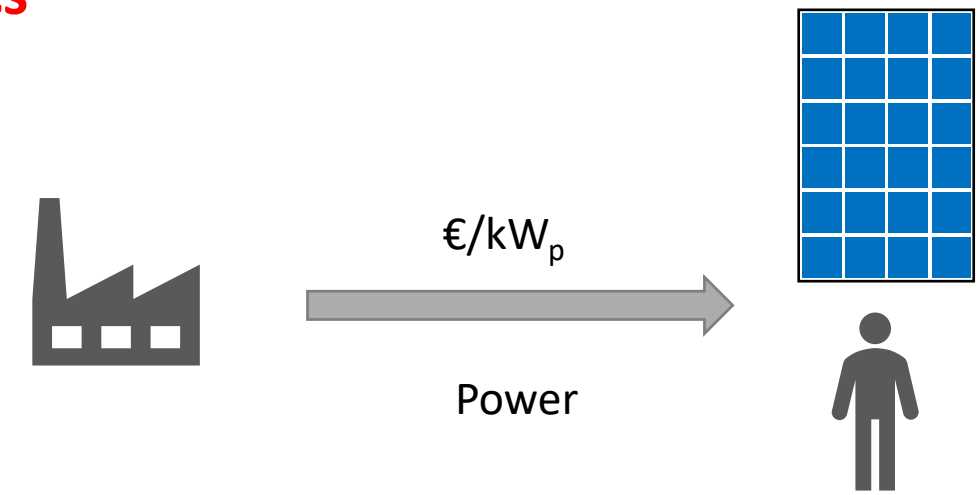


EL of module P07 after 10.000 cycles

Hanifi et al, Solar Energy, 2019

DISCUSSION

Economics



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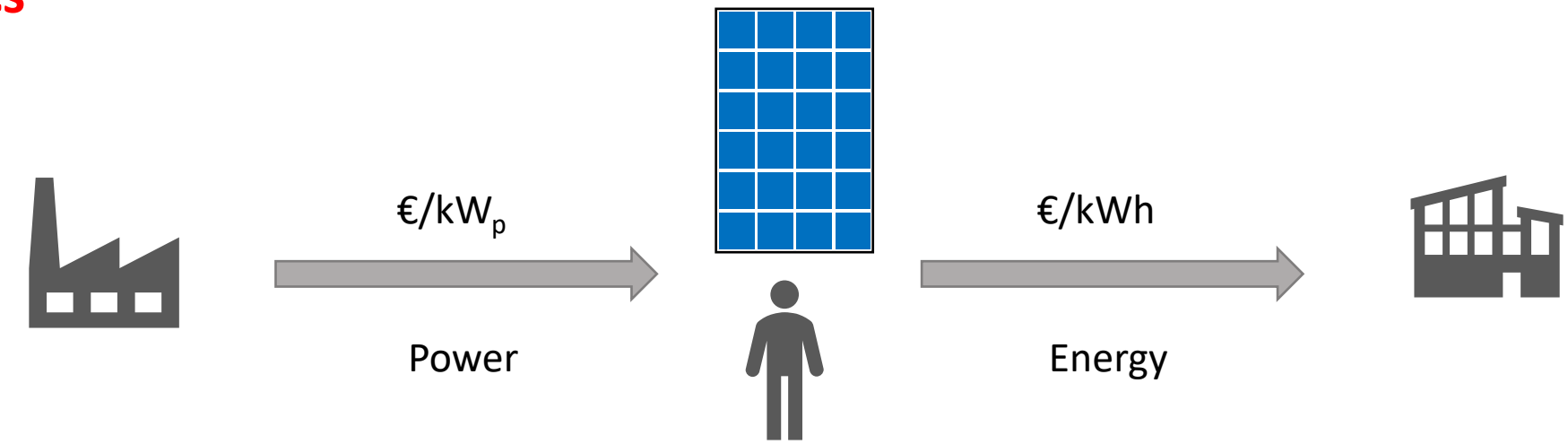

DISCUSSION

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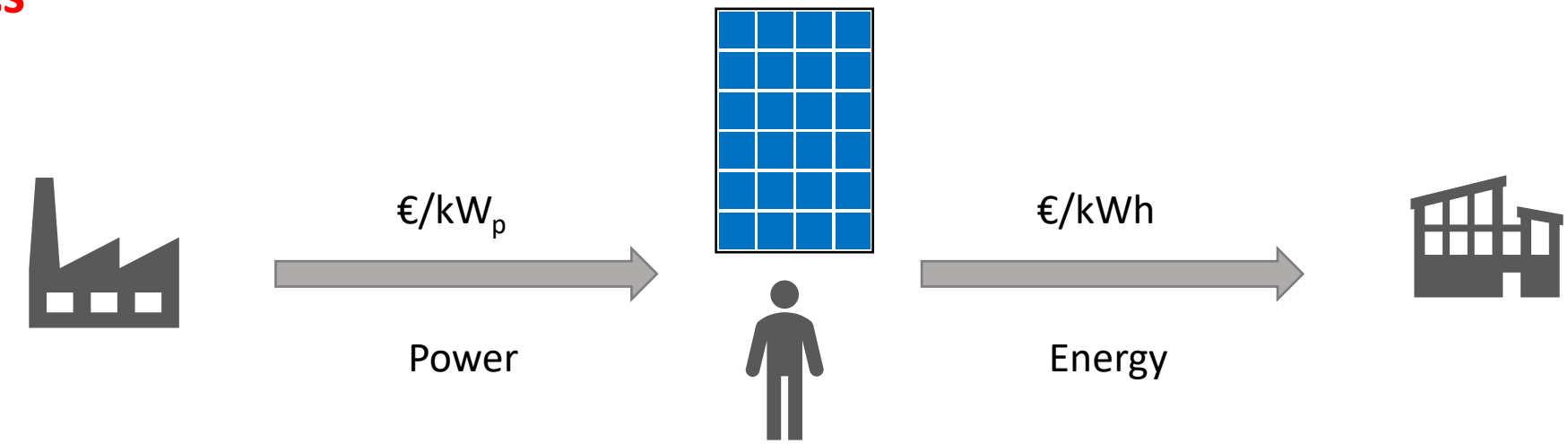
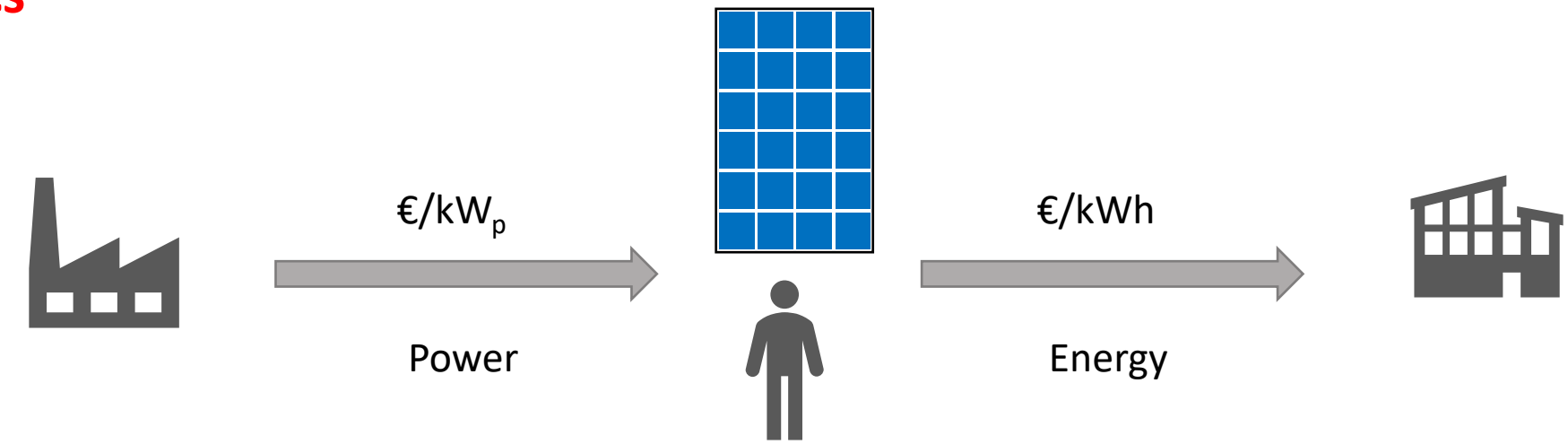


- Power
- Efficiency

- Energy
- Reliability

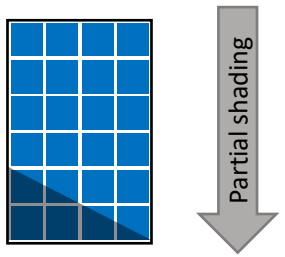
DISCUSSION

Economics



- Power
- Efficiency

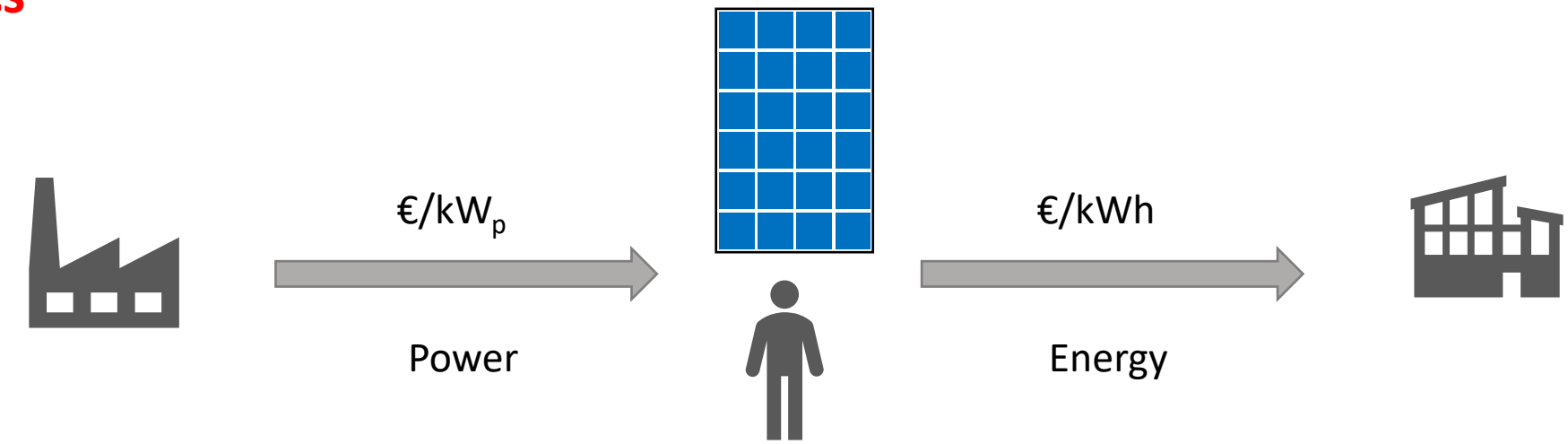
- Energy
- Reliability



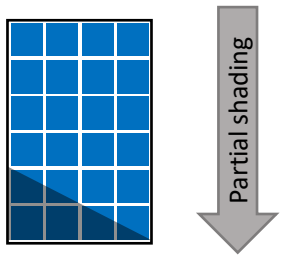
Low or no energy yield

DISCUSSION

Economics

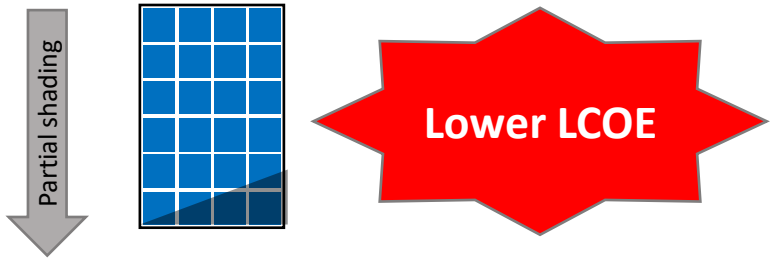


- Power
- Efficiency



Low or no energy yield

- Energy
- Reliability

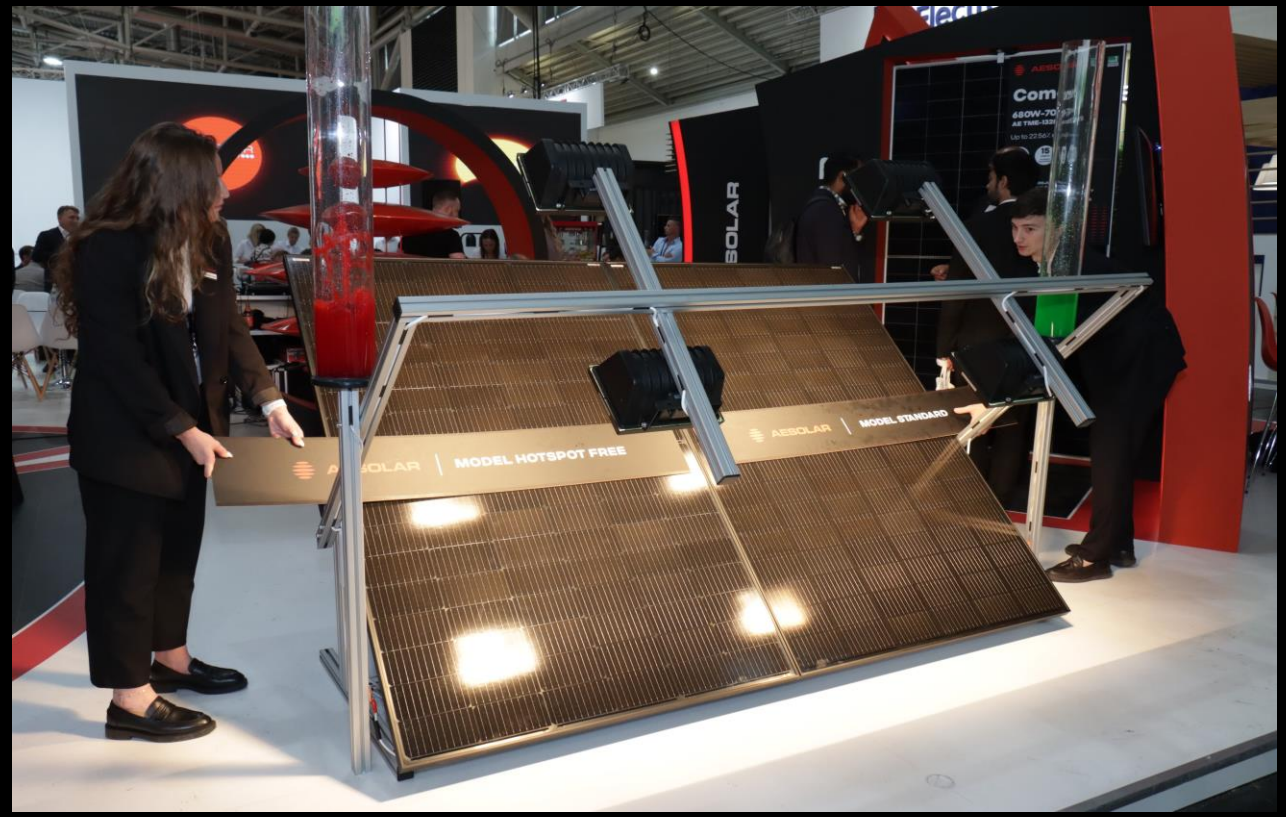


Rel. higher energy yield

OUTLOOK

Smart HSF module 2.0

- **HSF 1.0** is a successful product which is on the market since 2018
- An updated version under **HSF 2.0** is on the way
  - First prototype was presented in Intersolar 2023
  - Half-cells replaced the full-size solar cells
  - Invisible bypass diodes
  - Less bypass diodes and better functionality



Comparison of a standard half-cell and shade-resistant half-cell design of AESOLAR under partial shading conditions

TAKEAWAY MESSAGE

SHADE-RESISTANT PV MODULES

- Project owners pay for efficiency and power [€/Wp] but they need energy [€/kWh]!
- Shade-resistant modules gives you more energy per area under shading conditions

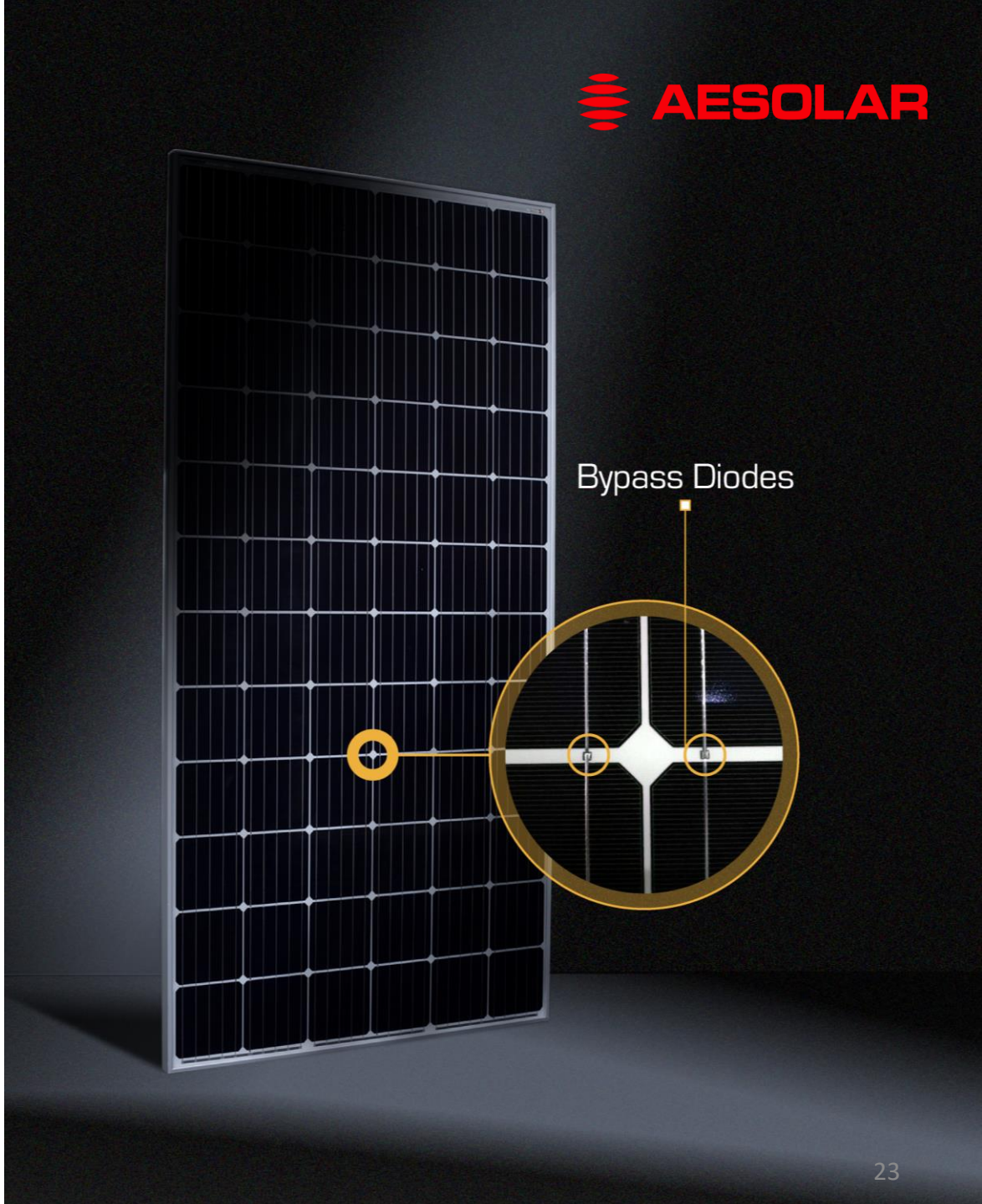
Energy

- Flexible with shading direction
- Up to 80% more power under STC
- over 30% higher yield under shading conditions in winter

Durability

- Smart HSF module has shown a good durability under stress testing and cycles equivalent to 25 years

HSF Shade-resistant module promisses a higher energy yield to achieve a lower LCOE under partial shading conditions



AESOLAR

THANK YOU VERY MUCH FOR YOUR ATTENTION!

Contact:

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Head of Product Development and Technical Marketing

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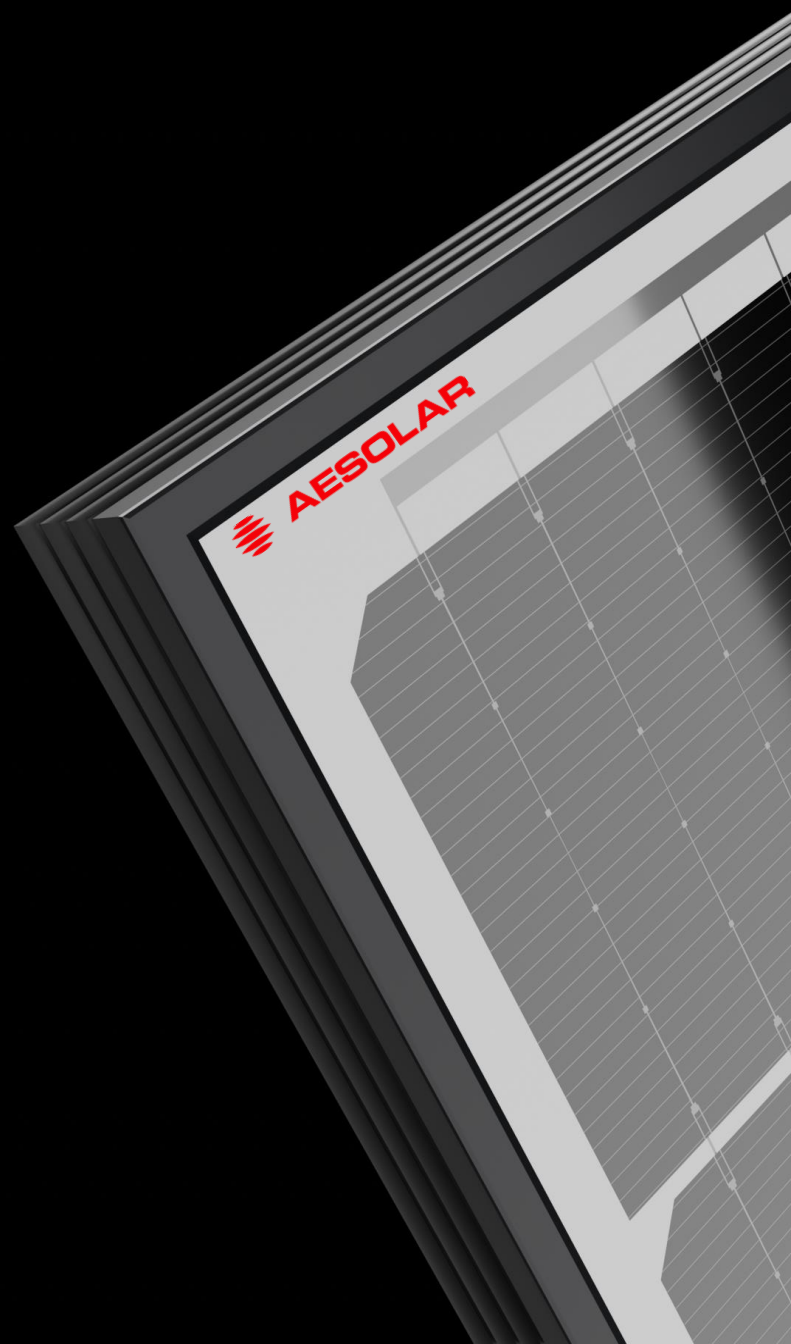
Tel: +49 8231 97 82 68-2

For sales inquieries contact: sales@ae-solar.com



The FoilMet Universe: Interconnection Using Welded Aluminum Foil

Jan Paschen
pv magazine – webinars
12th December 2023
www.ise.fraunhofer.de

Introduction

Introducing Jan Paschen

Working at Fraunhofer ISE

- The largest solar research institute in Europe

→We believe in Solar Energy

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- Laser: Cheap, Clean, Precise, Reliable

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Team for Foil Metallization (FoilMet)

- Aluminum foil: Abundant and recyclable, High conductive and affordable

→We believe in laser welded Aluminum foil

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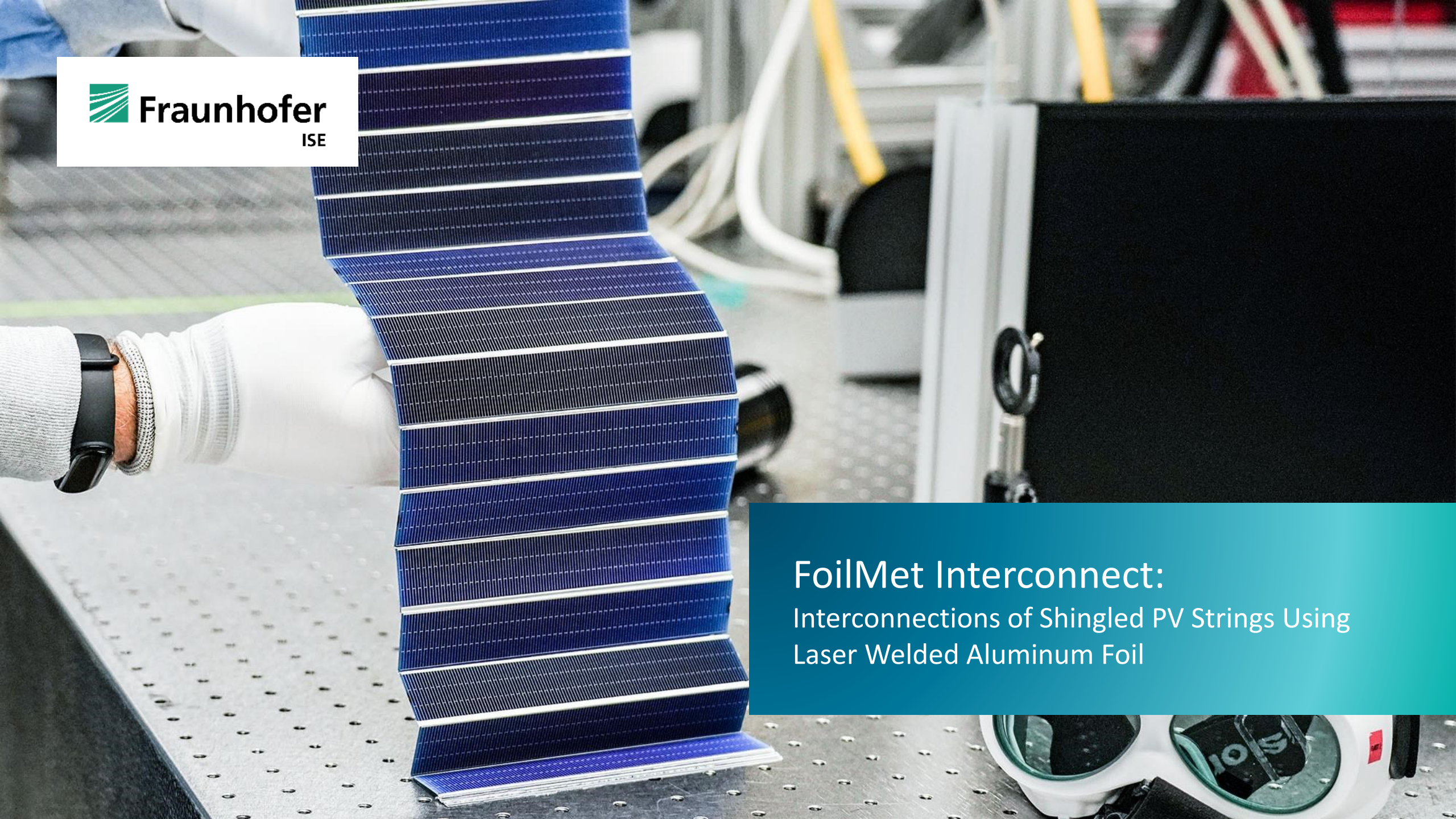
→We believe in laser welded Aluminum foil

We develop solutions in PV via laser welded Aluminum foil



Fraunhofer ISE

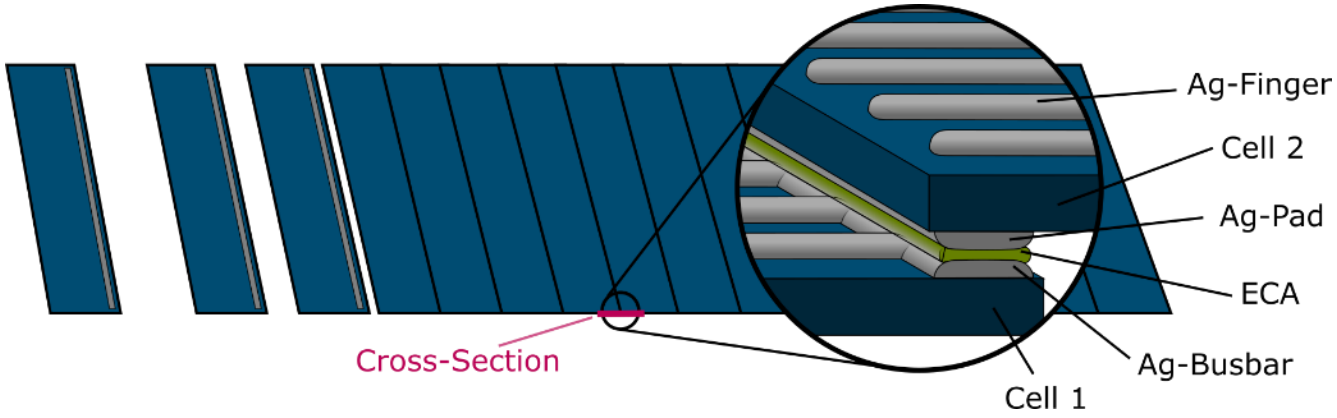
FoilMet Interconnect:

Interconnections of Shingled PV Strings Using Laser Welded Aluminum Foil

FoilMet Interconnect Shingling

Shingling of solar cells is …

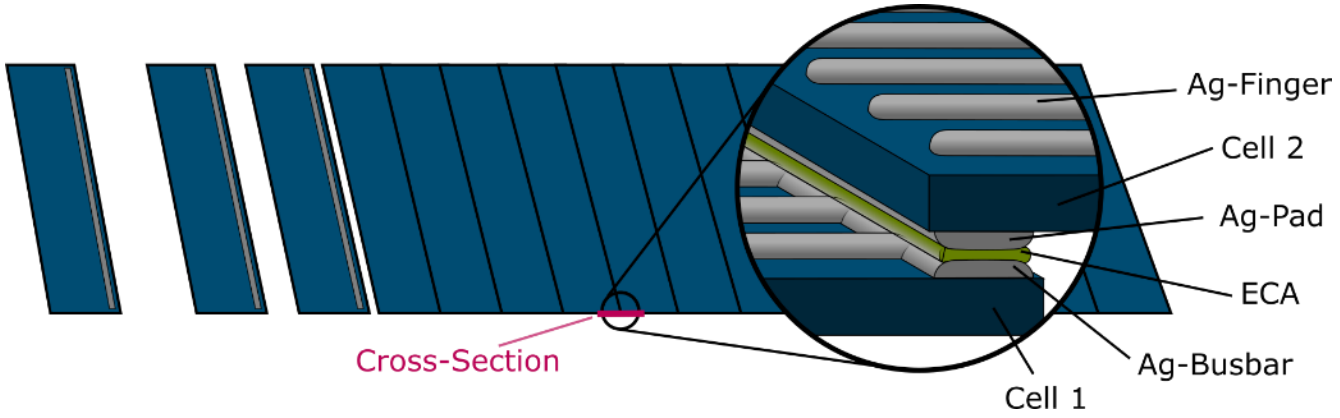
- an edge interconnection of separated solar cells…
- by overlapping adjacent cells…
- and joining them with a conductive material, e.g. solder or ECA



FoilMet Interconnect Shingling

Shingling of solar cells is …

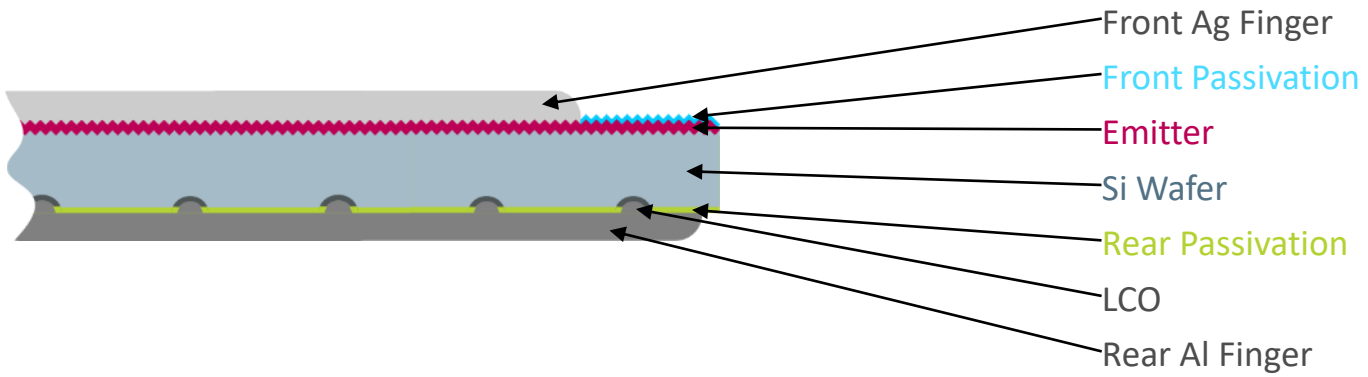
- an edge interconnection of separated solar cells…
- by overlapping adjacent cells…
- and joining them with a conductive material, e.g. solder or ECA
- … or Aluminum foil



FoilMet Interconnect Shingling

Structure of Shingled Strings

Step 1: Place 1st cell.

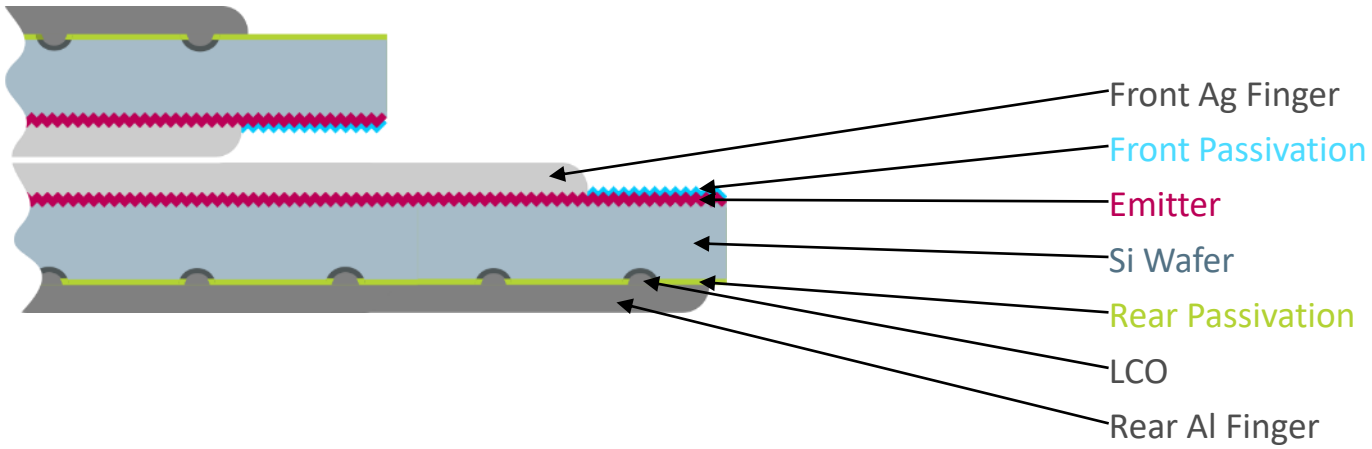


FoilMet Interconnect Shingling

Structure of Shingled Strings

Step 1: Place 1st cell.

Step 2: Place 2nd cell.



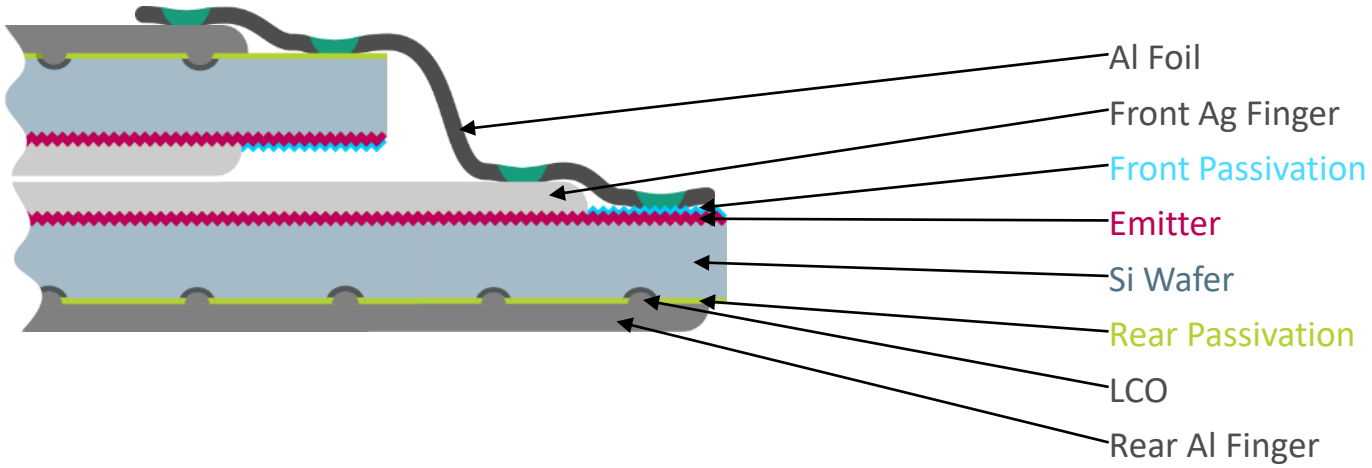
FoilMet Interconnect Shingling

Structure of Shingled Strings

Step 1: Place 1st cell.

Step 2: Place 2nd cell.

Step 3: Place Al-foil



Fraunhofer ISE

FoilMet Interconnect Shingling

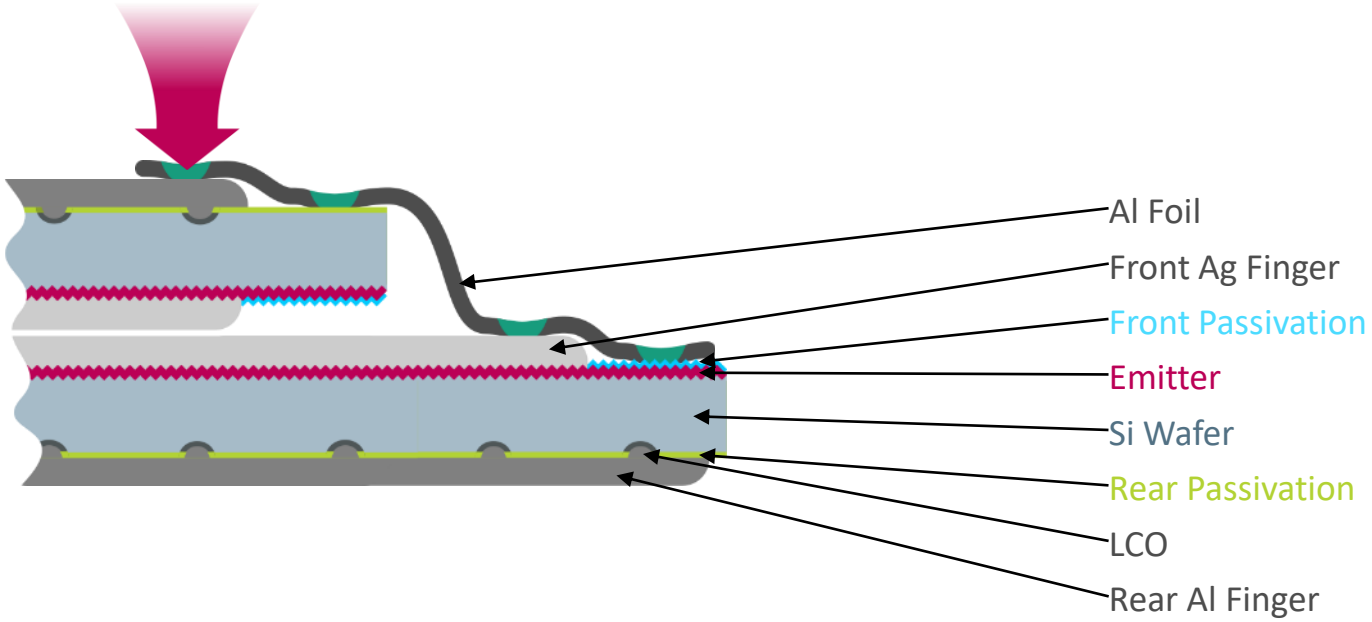
Structure of Shingled Strings

Step 1: Place 1st cell.

Step 2: Place 2nd cell.

Step 3: Place Al-foil

- Laser-weld Foil
  - Al-Al



FoilMet Interconnect Shingling

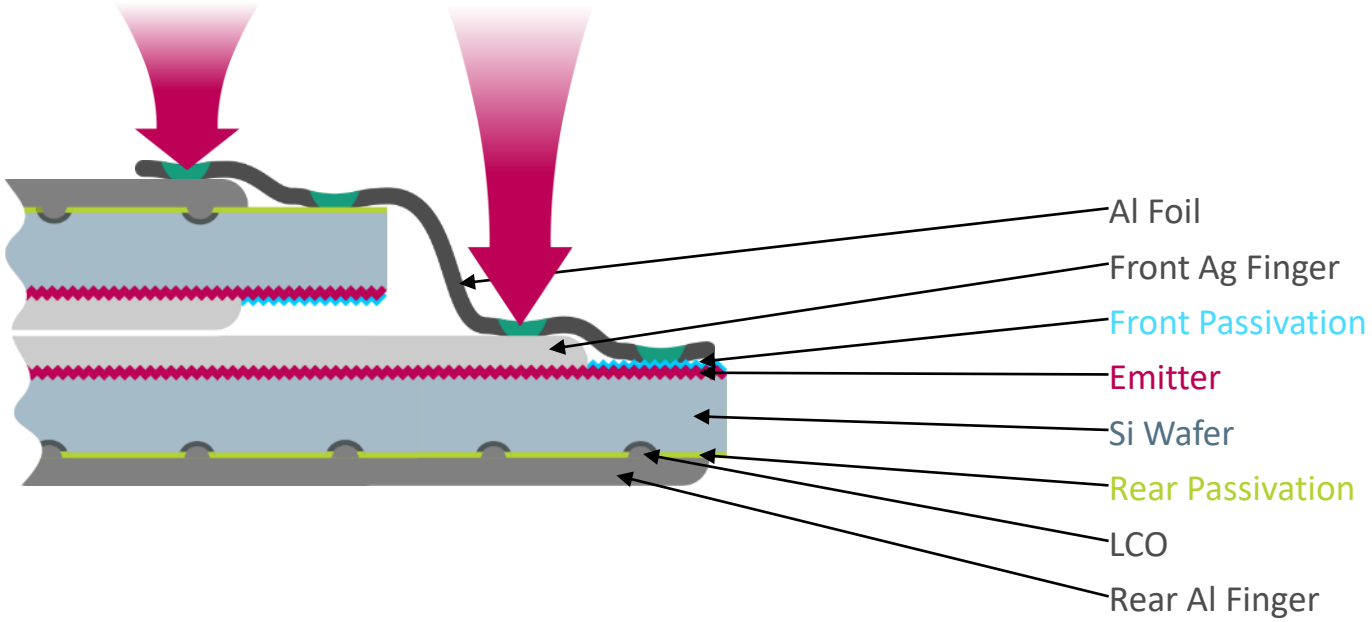
Structure of Shingled Strings

Step 1: Place 1st cell.

Step 2: Place 2nd cell.

Step 3: Place Al-foil

- Laser-weld Foil
  - Al-Al
  - Al-Ag



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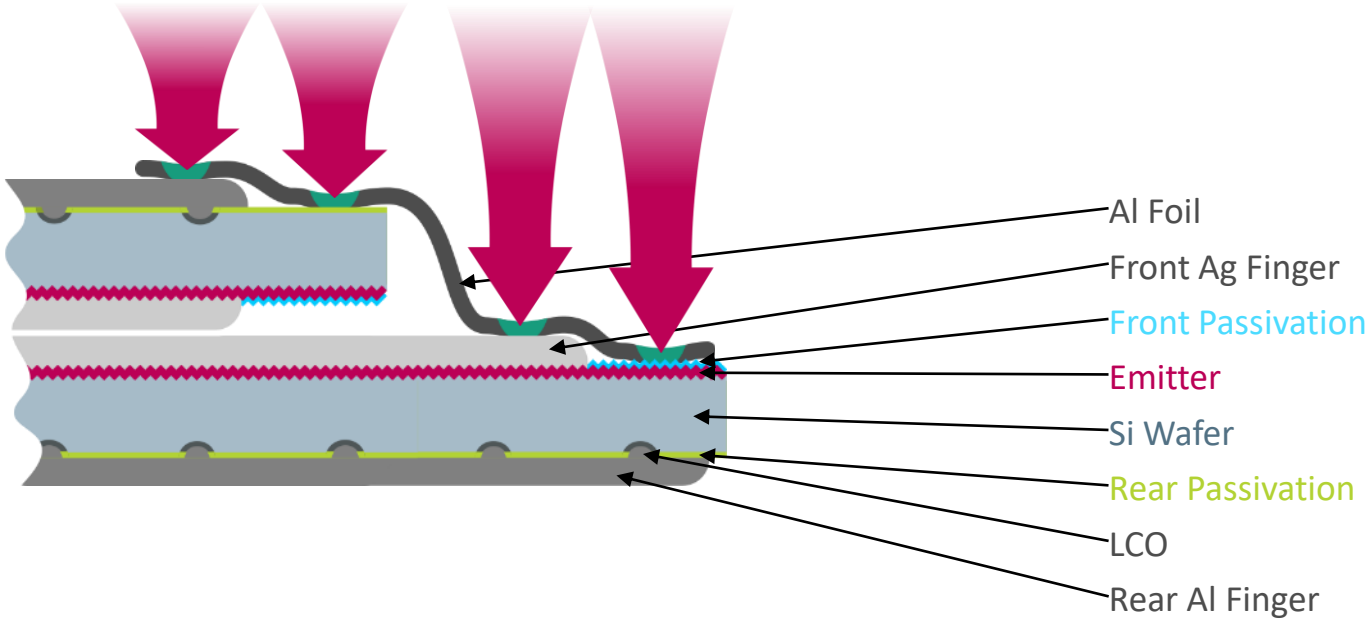

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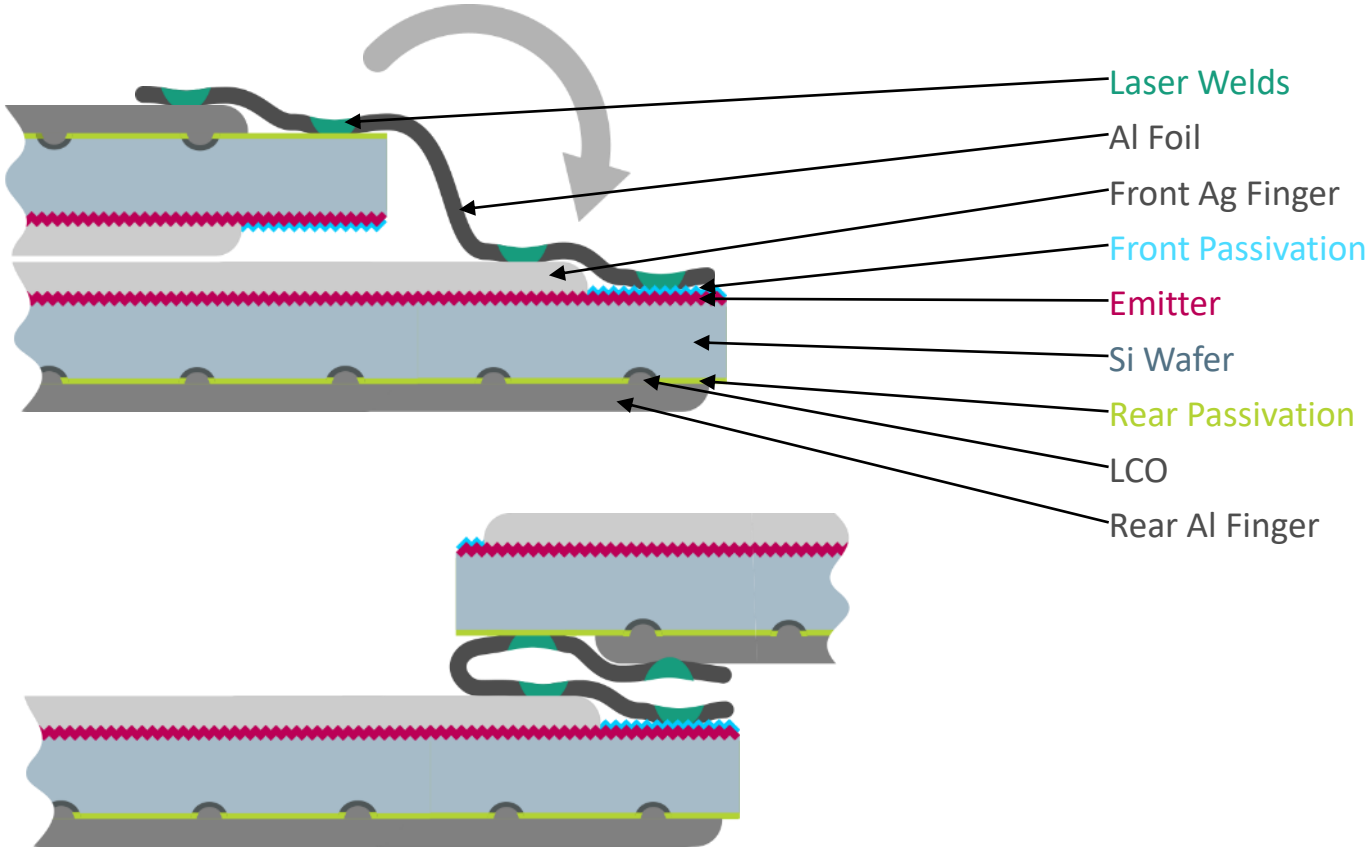
  - Al-SiN_X

Step 4: Flip top cell



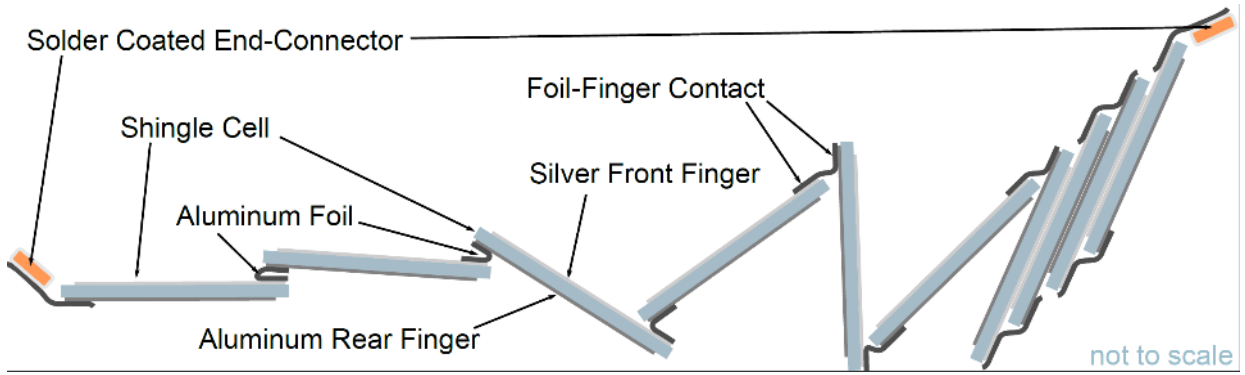
Fraunhofer ISE

FoilMet Interconnect Shingling

Structure of Shingled Strings

Process of string sized stacks at once

- Potential for an acceleration of processing
- and reduction of cost



Fraunhofer ISE

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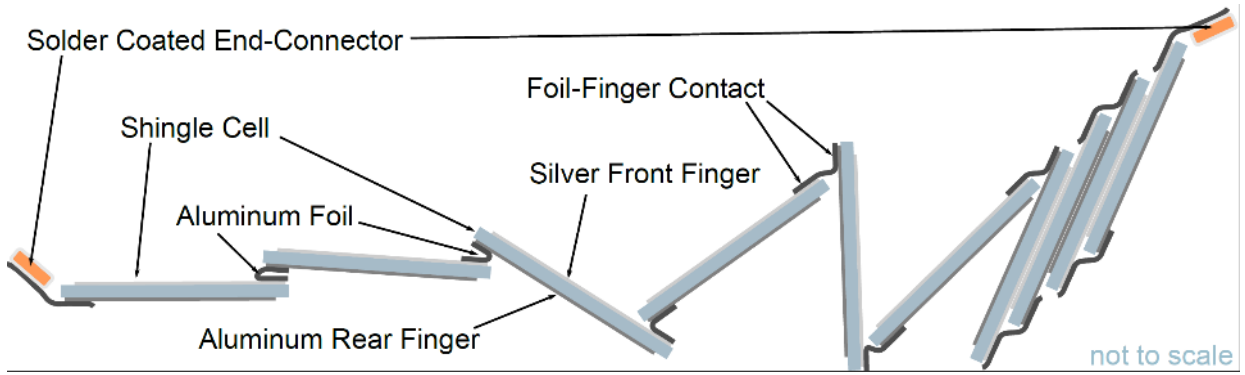
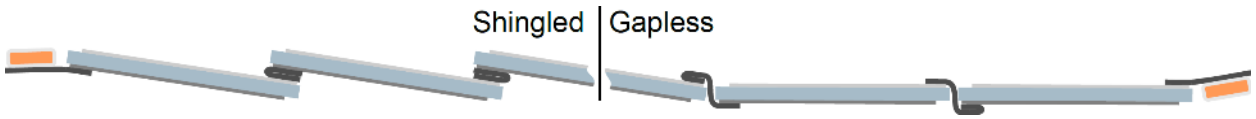
Shingled and Gapless





Fraunhofer ISE

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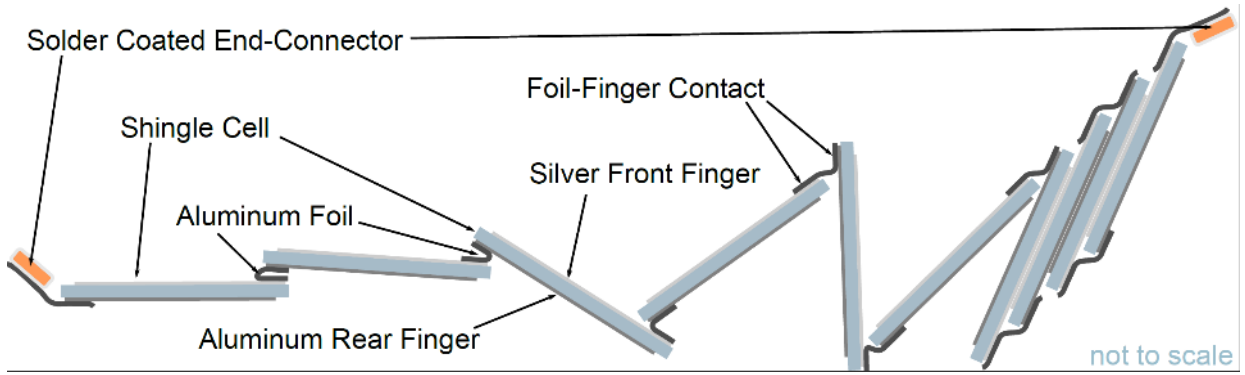
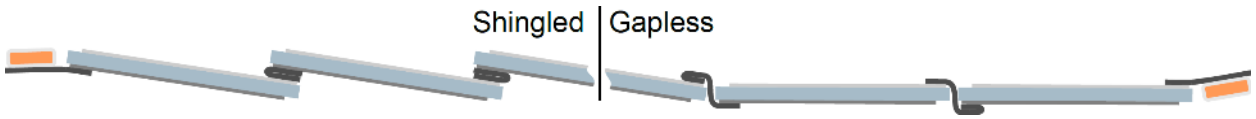
Project with the target of a pilot stringer





Fraunhofer ISE

FoilMet Interconnect Shingling

Structure of Shingled Strings

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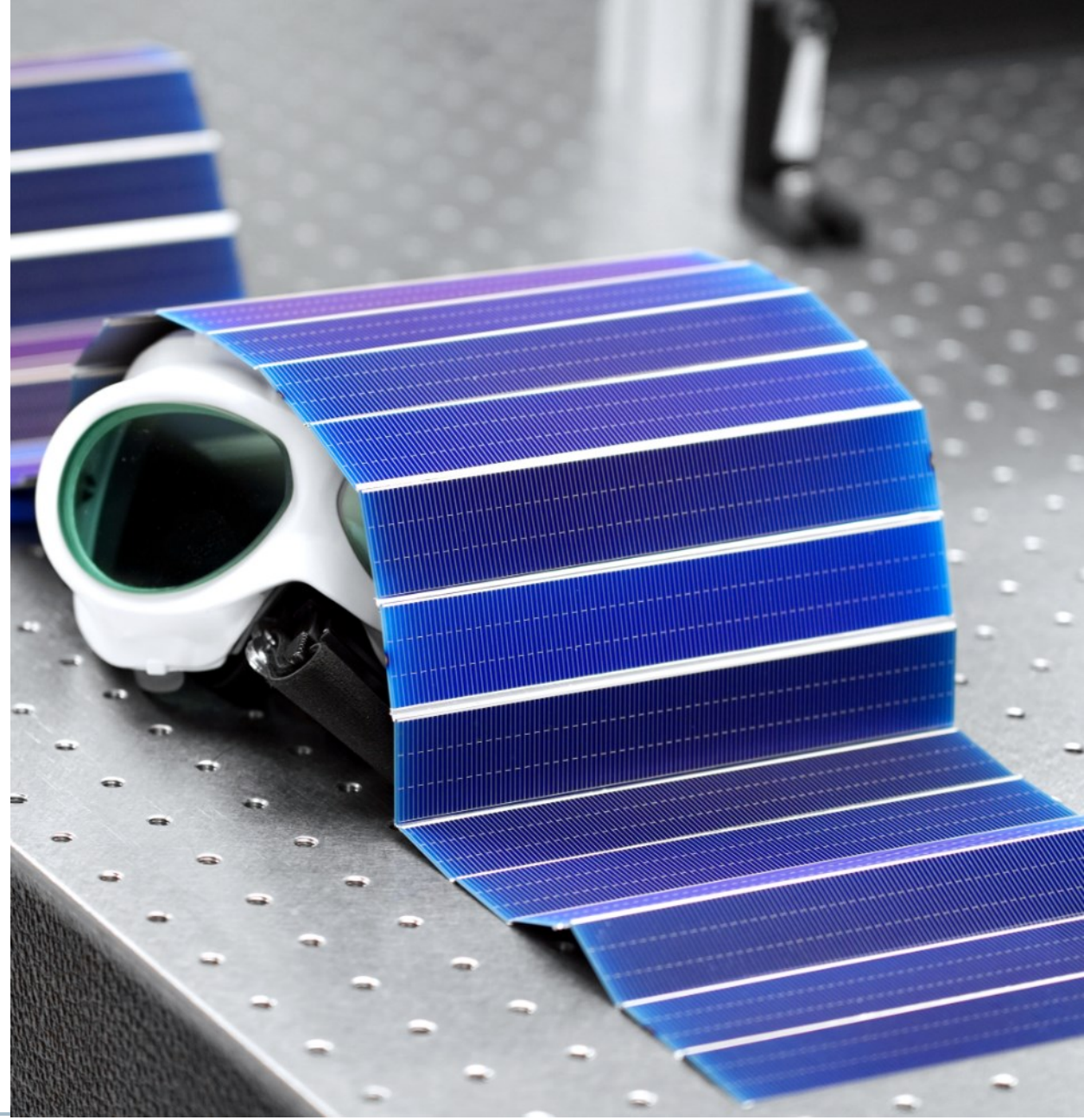
Shingled and Gapless

Project with the target of a pilot stringer

Shading resilience

- Good cross conductivity
- Matrix shingling might be possible
- Aluminum foil accessible in string for bypass diodes
- … but we will see



Fraunhofer ISE

FoilMet High Voltage:

Eliminating the Need for Handling Individual Sub-Cells for Small Appliance PV Modules

Photovoltaic Modules for Small Appliances

What are small appliance PV modules for:

- Everything with a low current demand in the sun.

Photovoltaic Modules for Small Appliances

What are small appliance PV modules for:

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How are they designed:

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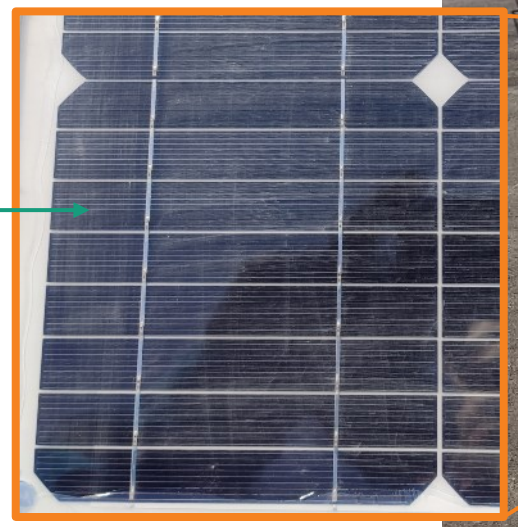
How are they designed:

- **Small subcells**
  - Poor edge to surface ratio



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How are they designed:

- **Small subcells**
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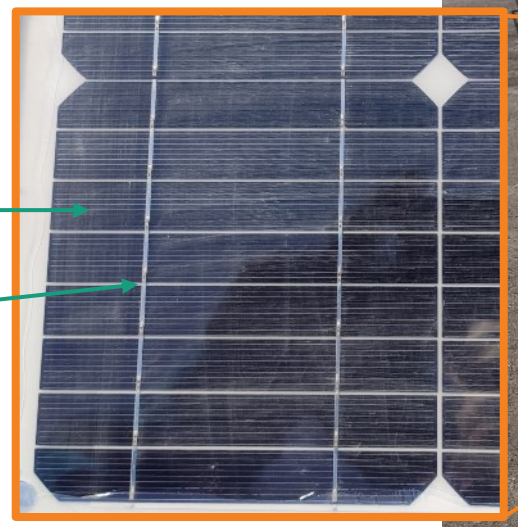
- **"Threading through" cell connectors**
  - High handling effort
  - Only two busbar



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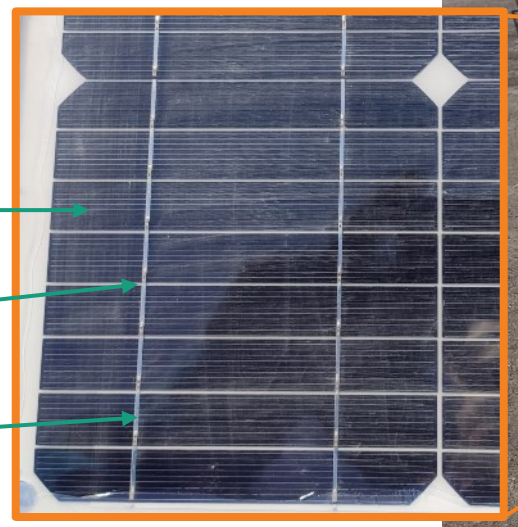
  - Only two busbar
- **Soldering**
  - Lead loaded
  - Silver pads/busbar necessary



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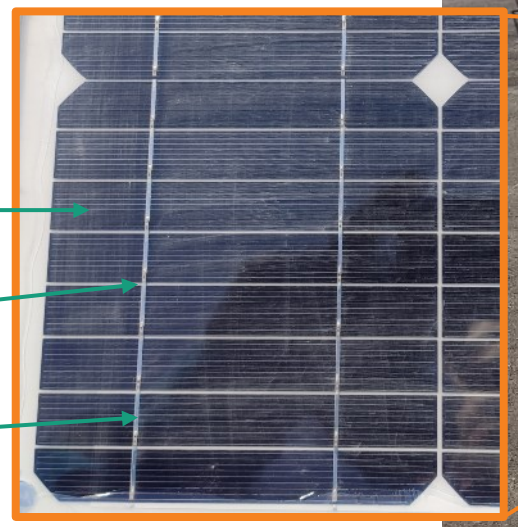

FoilMet HV provides a solution for these problems

What is FoilMet HV

FoilMet HV:

- **No handling of small sub cells**
  - Interconnect first, then separate → Handling only at host cell level

Fraunhofer ISE

What is FoilMet HV

FoilMet HV:

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- **No “threading through" cell connectors**
  - Interconnection of back contact solar cells

What is FoilMet HV

FoilMet HV:

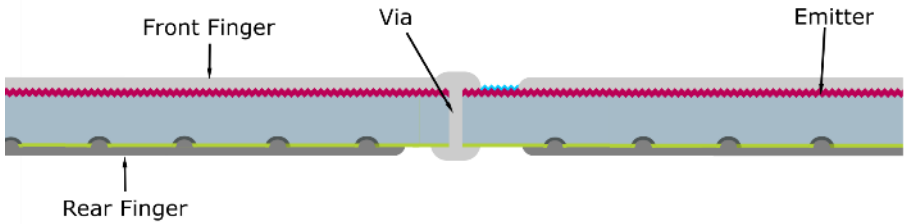
- **No handling of small sub cells**
  - Interconnect first, then separate → Handling only at host cell level
- **No “threading through" cell connectors**
  - Interconnection of back contact solar cells
- **No soldering**
  - Laser welded aluminum foil
  - Directly to fingers → no pad/busbar
  - No lead, no soldering fluxes, no adhesives, no inert gas
    → only light and aluminum

Fraunhofer ISE

FoilMet High Voltage

Back Contact Solar Cell

- Metal Wrap Through (MWT)
- → TopCon IBC



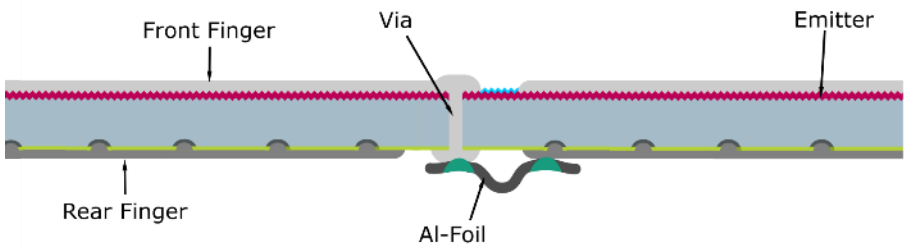
FoilMet High Voltage

Back Contact Solar Cell

- Metal Wrap Through (MWT)
- → TopCon IBC

Process

- Place Aluminum foil



FoilMet High Voltage

Back Contact Solar Cell

- Metal Wrap Through (MWT)
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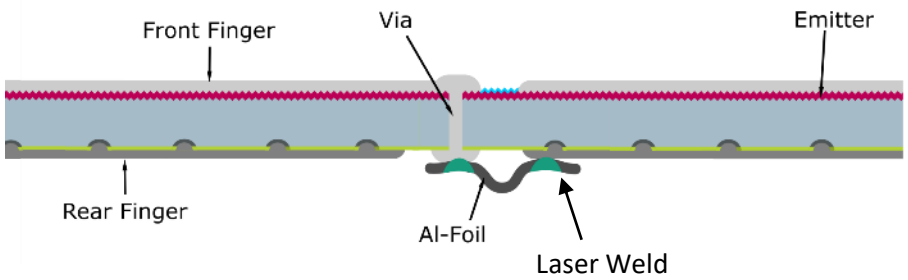
Process

- Place Aluminum foil
- Laser weld to both electrodes



FoilMet High Voltage

Back Contact Solar Cell

- Metal Wrap Through (MWT)
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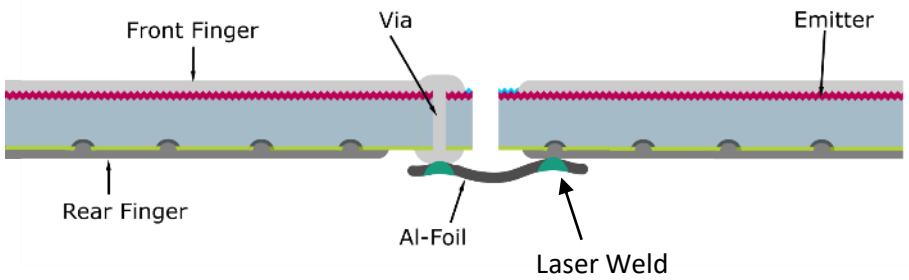
Process

- Place Aluminum foil
- Laser weld to both electrodes
- Separate sub-cells via TLS



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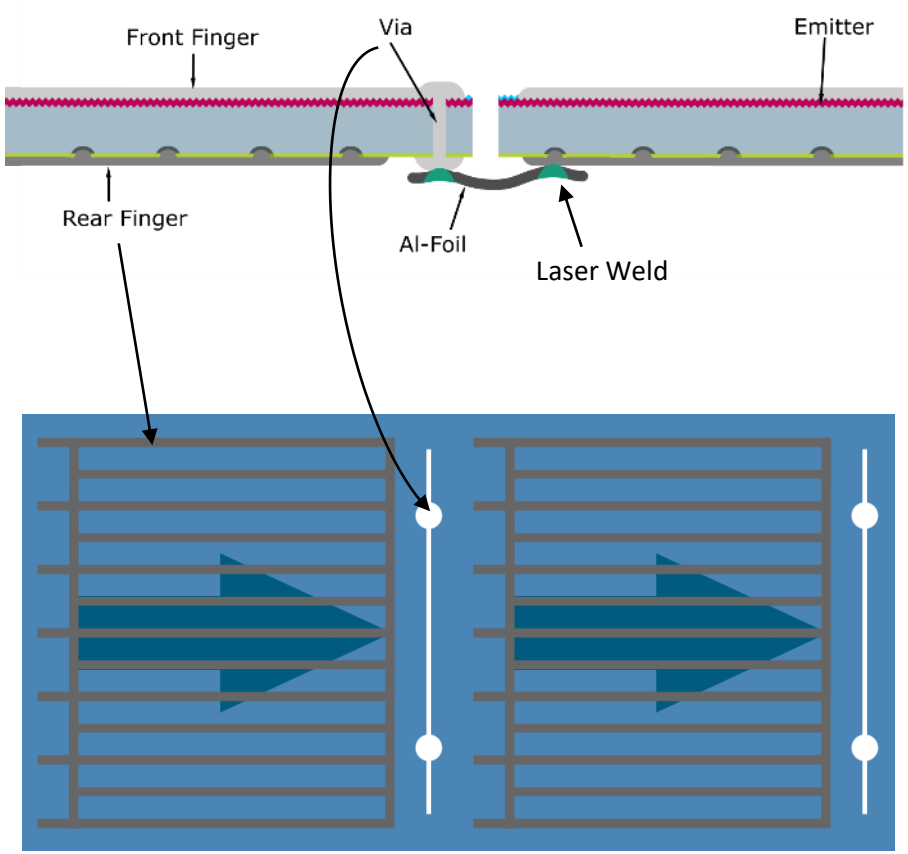

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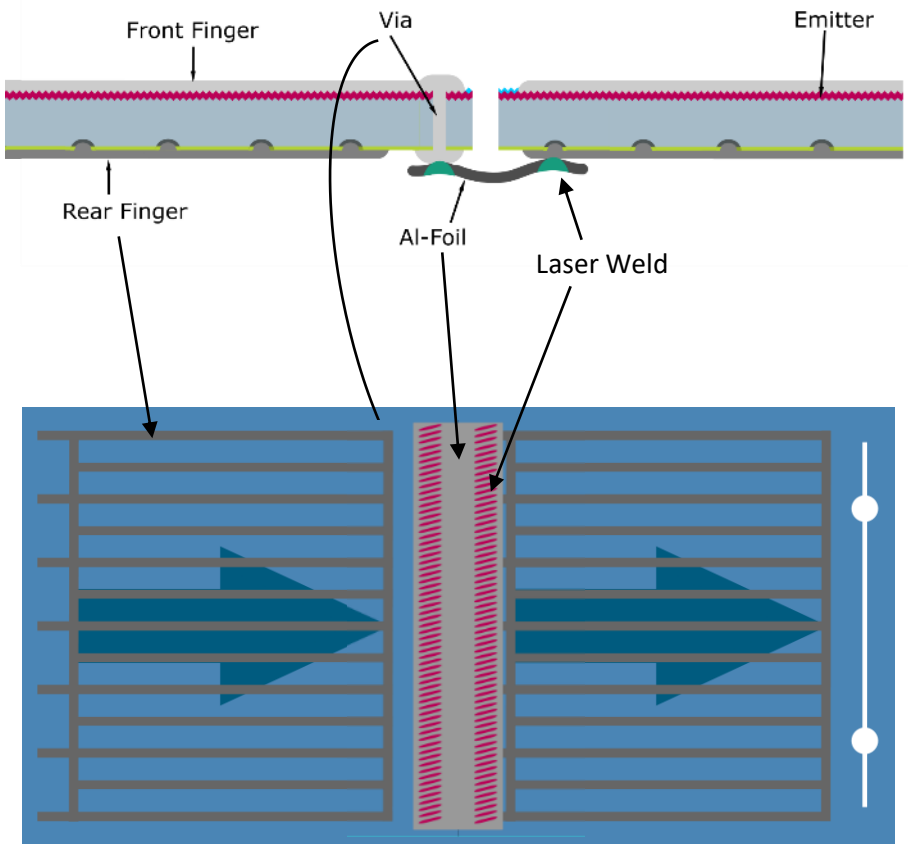


Fraunhofer ISE

FoilMet High Volate

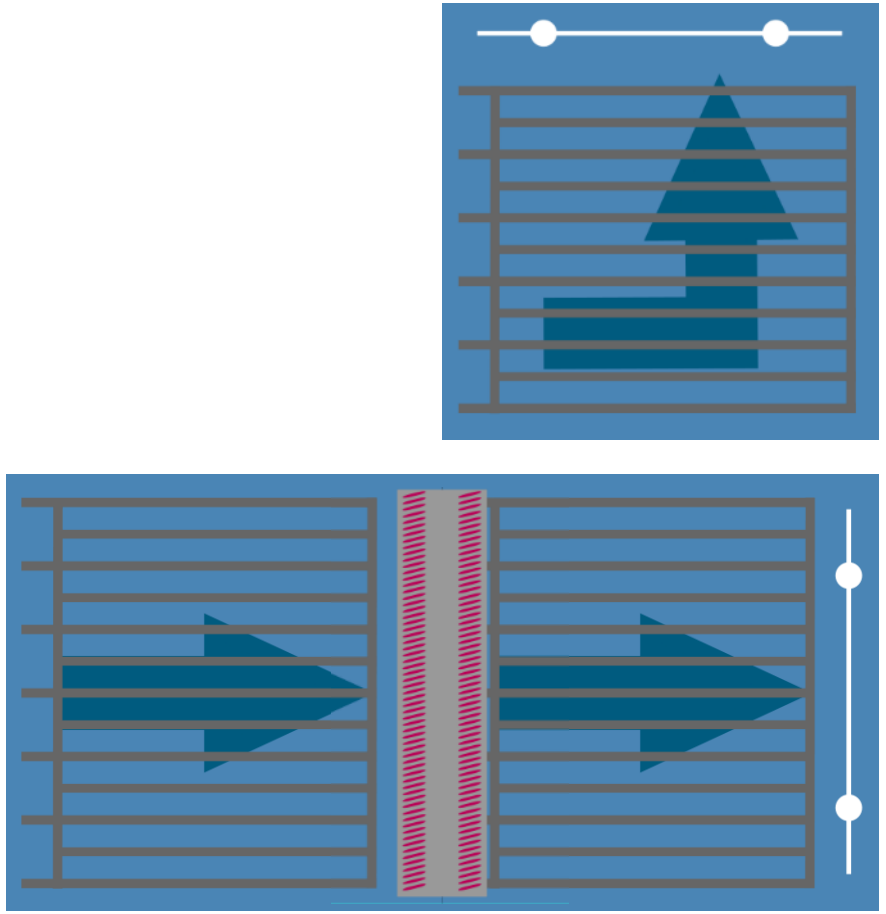
Back Contact Solar Cell

- Metal Wrap Through (MWT)
- → TopCon IBC

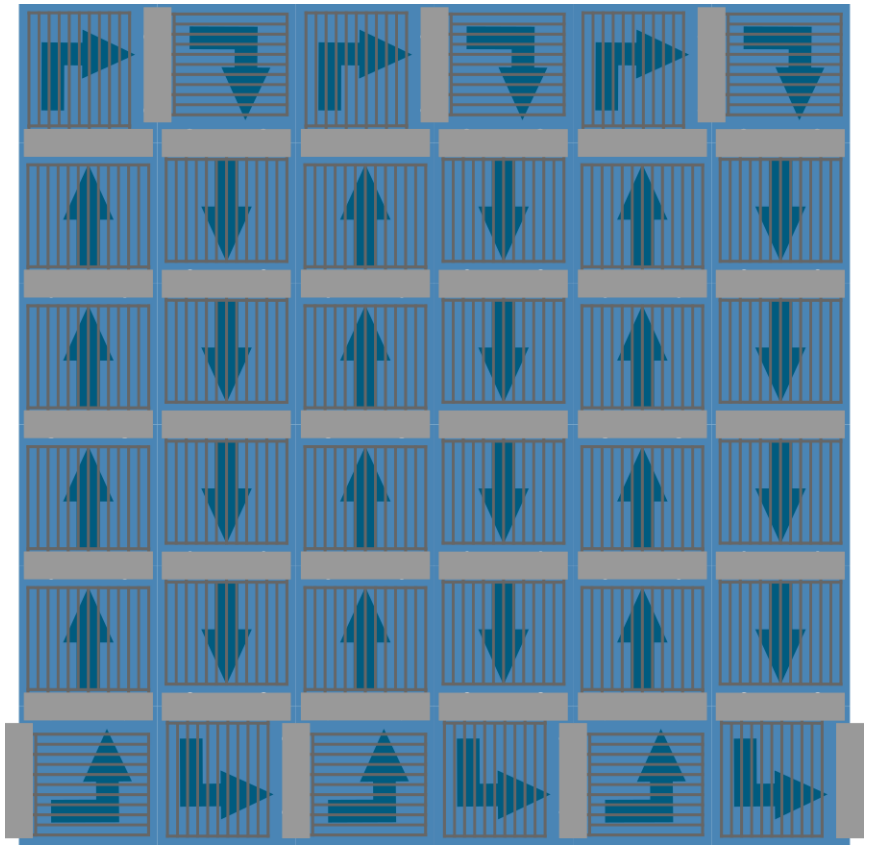
Process

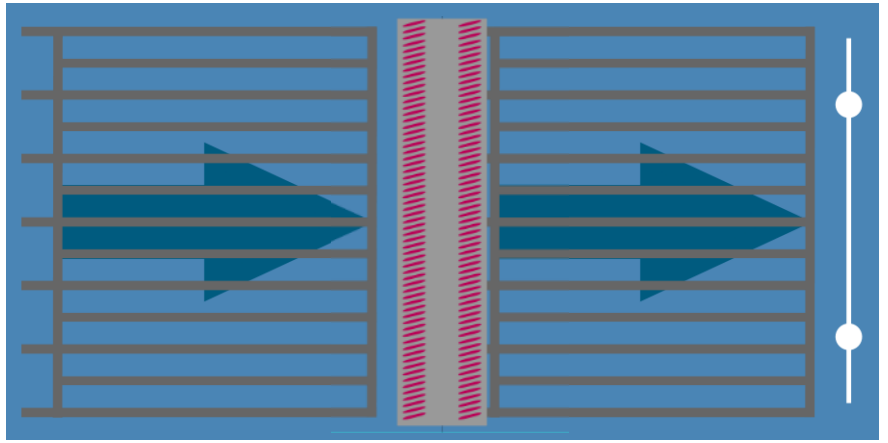
- Place Aluminum foil
- Laser weld to both electrodes
- Separate sub-cells via TLS

- Change of direction



FoilMet High Voltage





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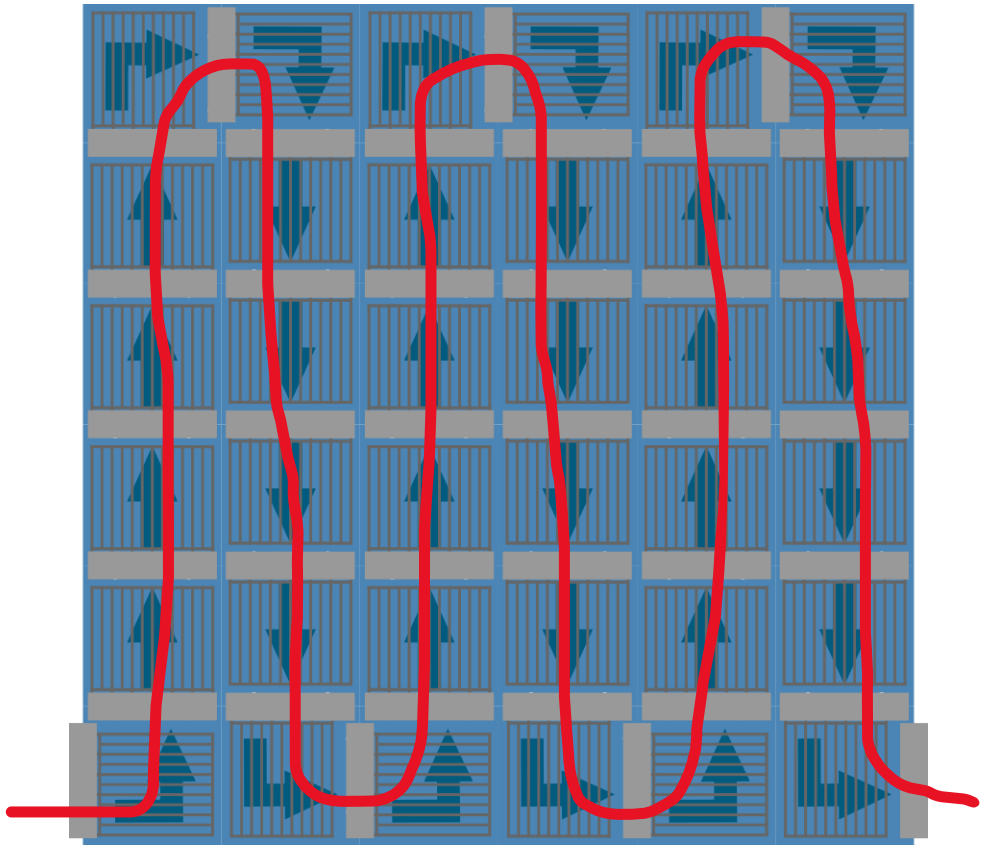
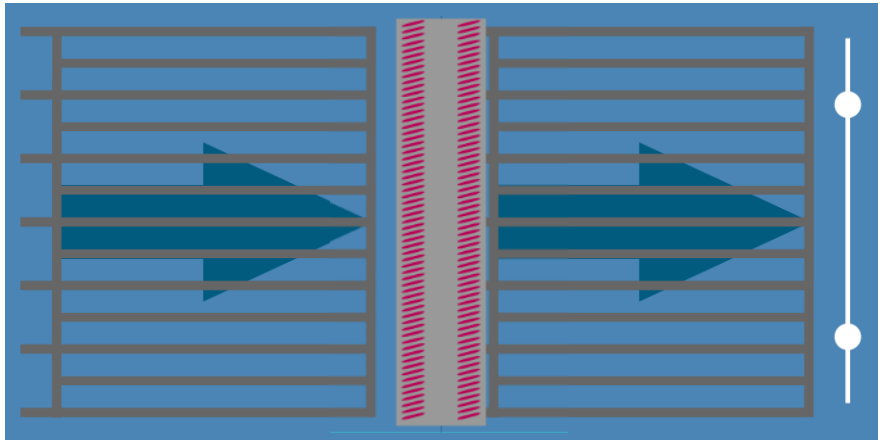
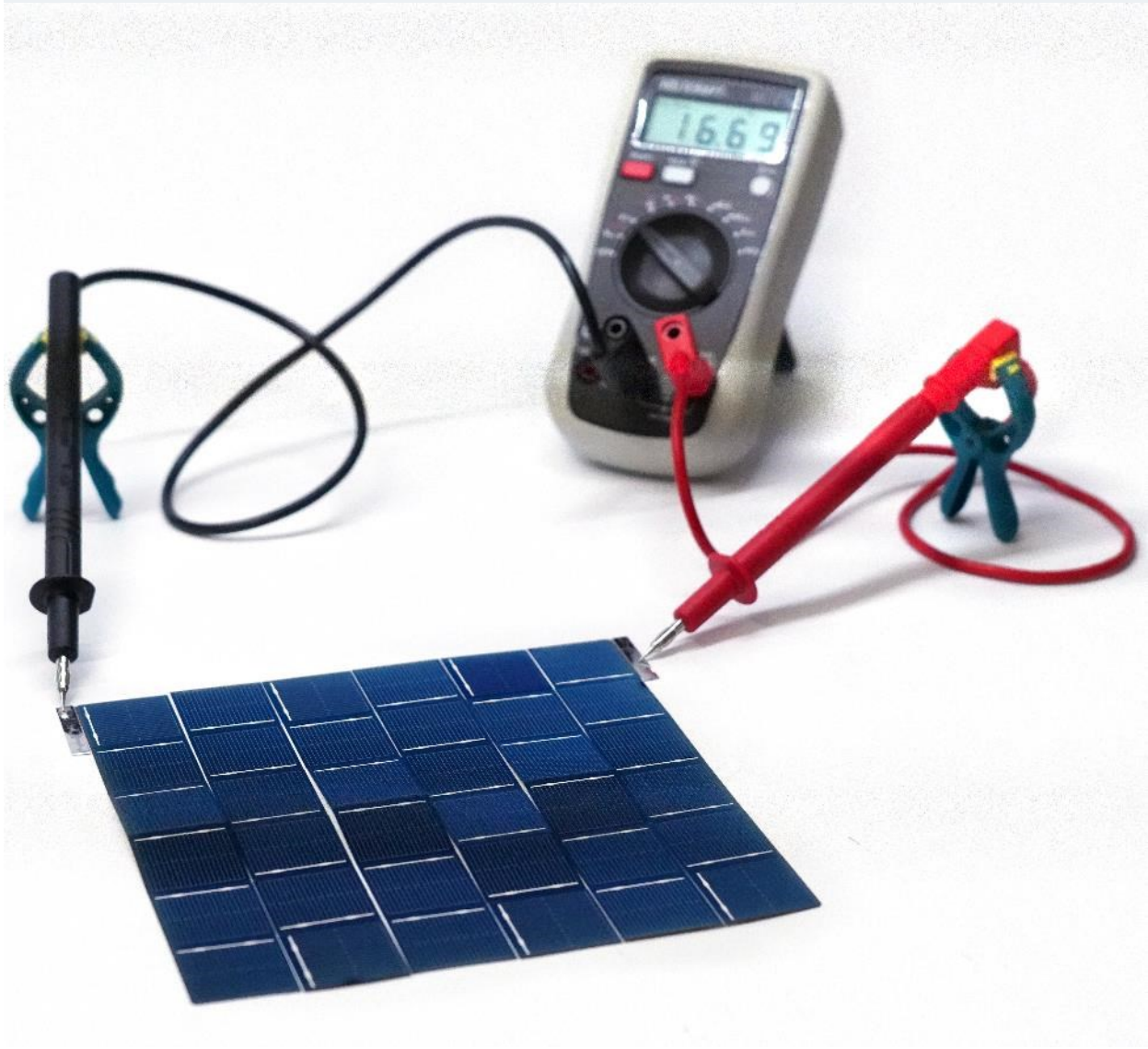




FoilMet HV Prototype

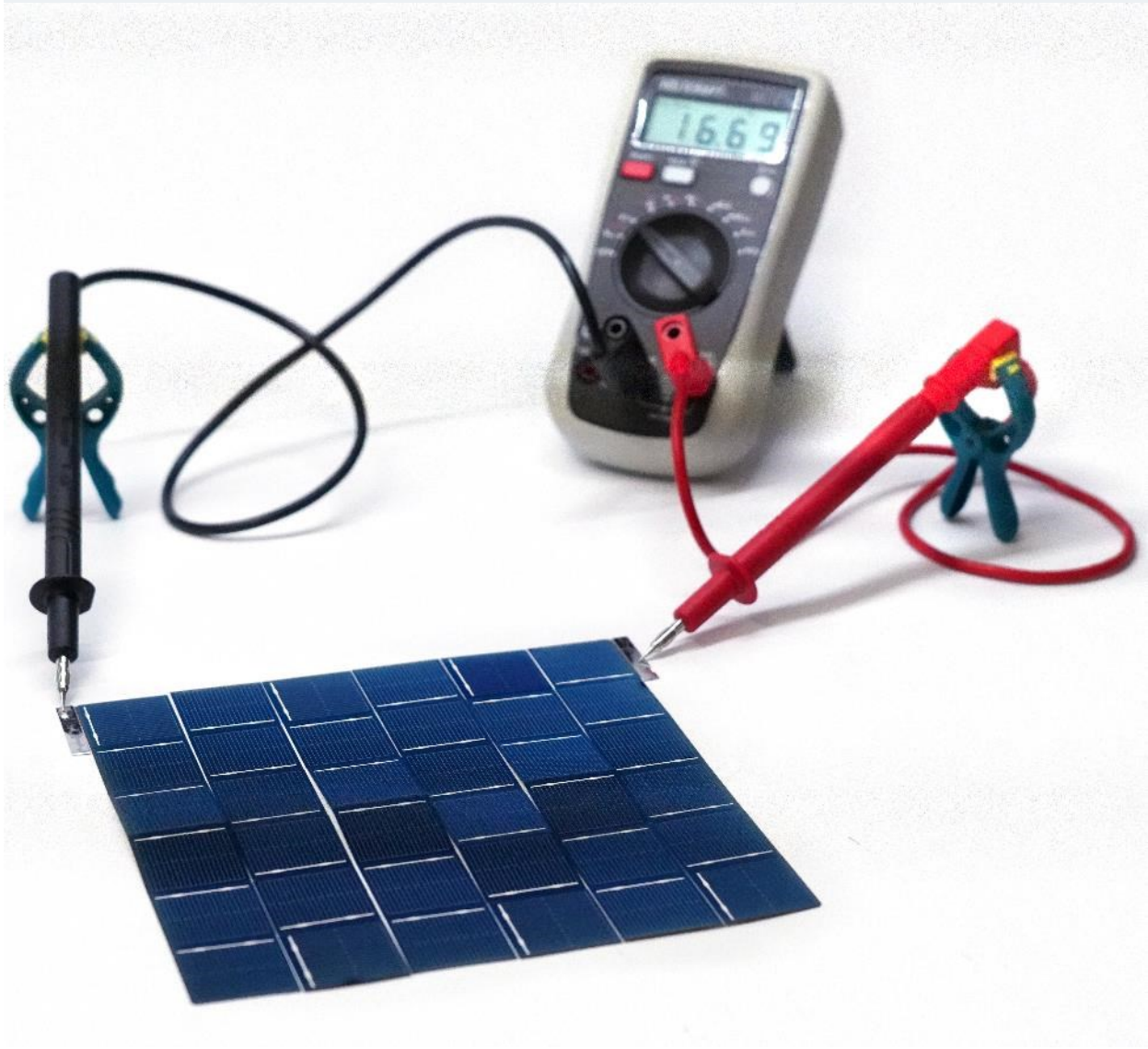


Fraunhofer ISE

FoilMet HV Prototype

IV-Measurement

Id	I_{SC}/mA	V_{OC}/V	I_{MPP}/mA	V_{MPP}/V	FF/%	P_{MPP}/W	η/%
1	273.7	24.41	233.0	19.69	68.7	4.59	17.90
2	274.4	24.37	235.2	19.72	69.4	4.64	18.02



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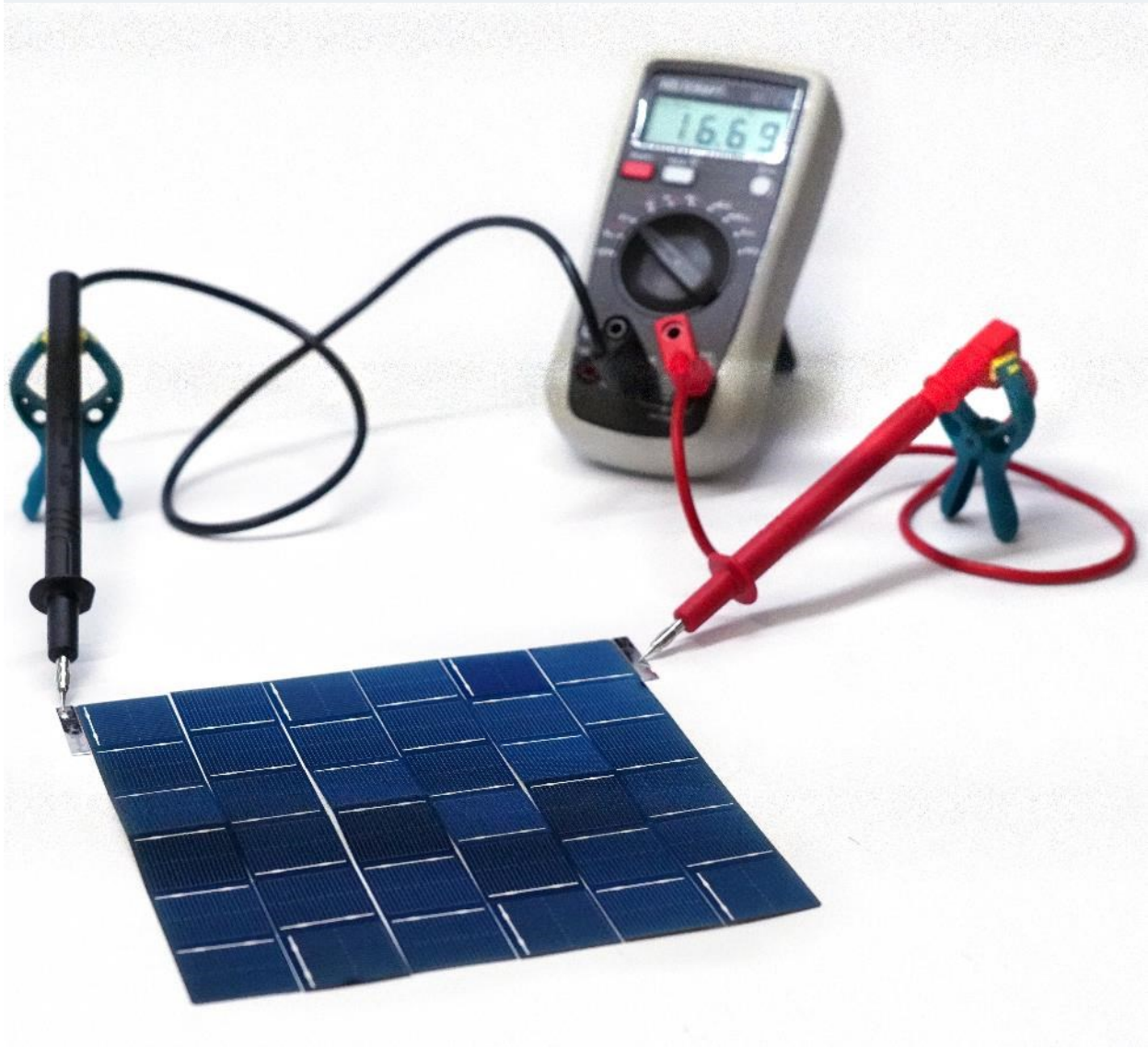
  - Interconnect first, then separate → Handling only at host cell level
  - Square sub cells



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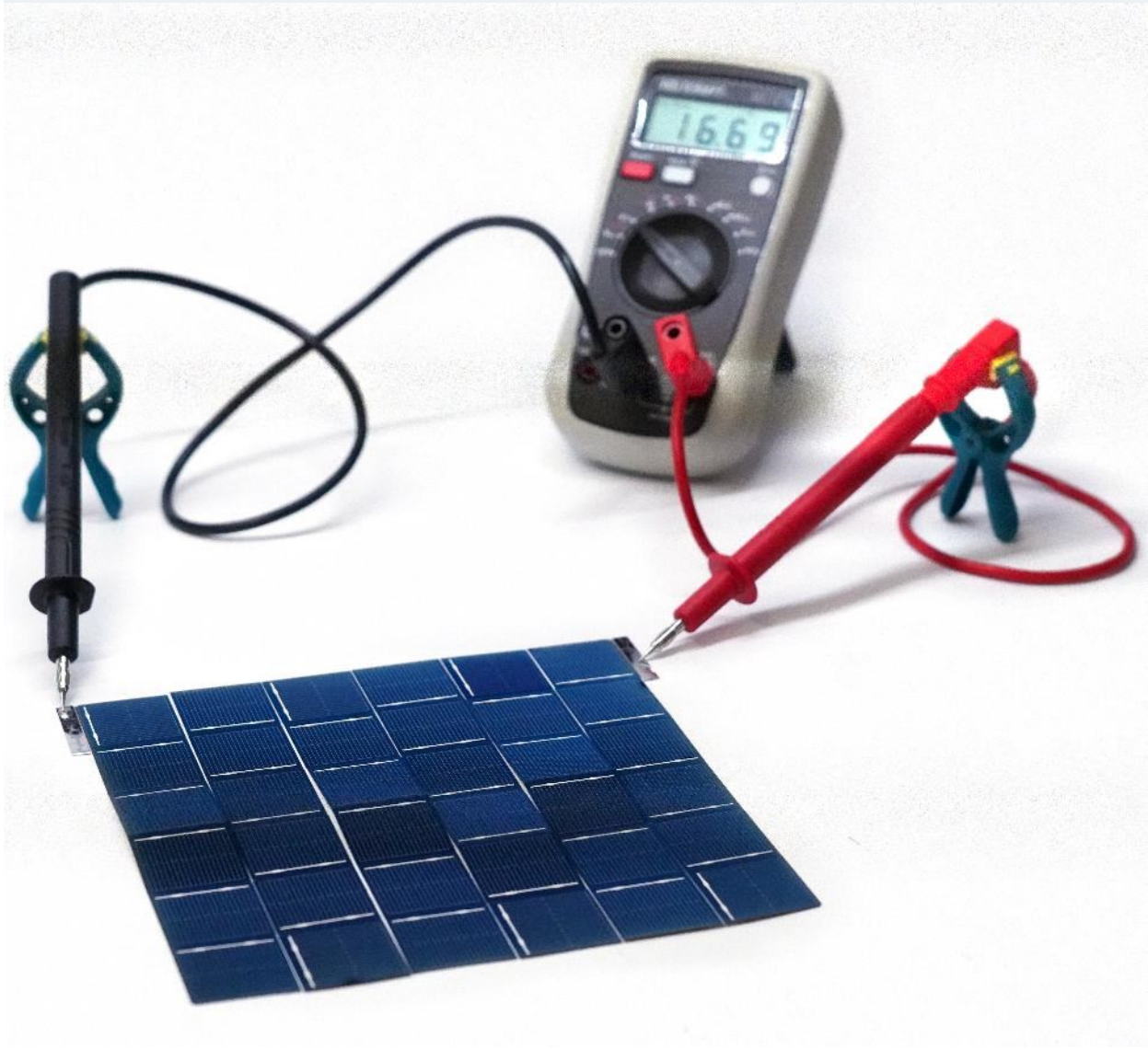

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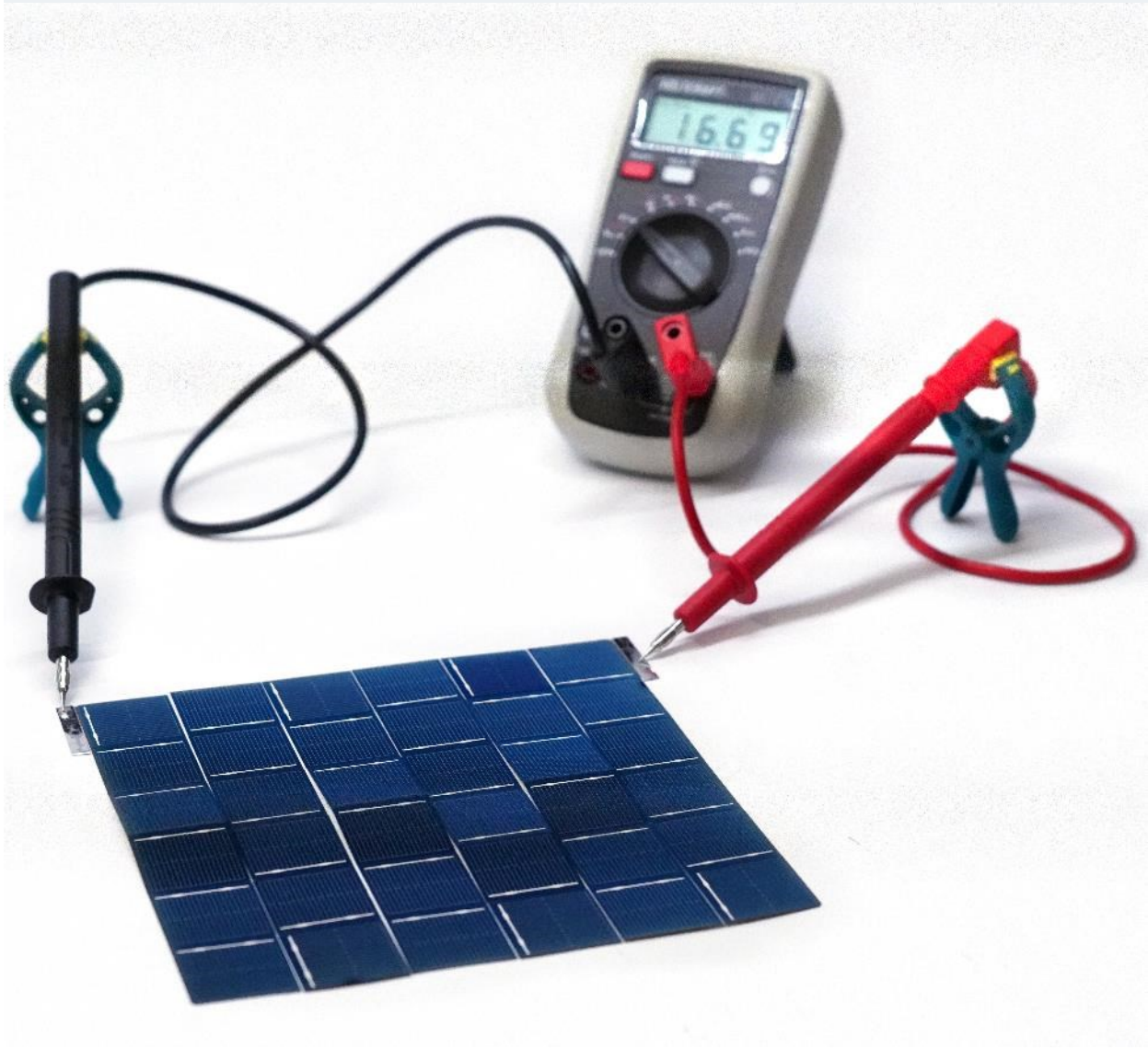
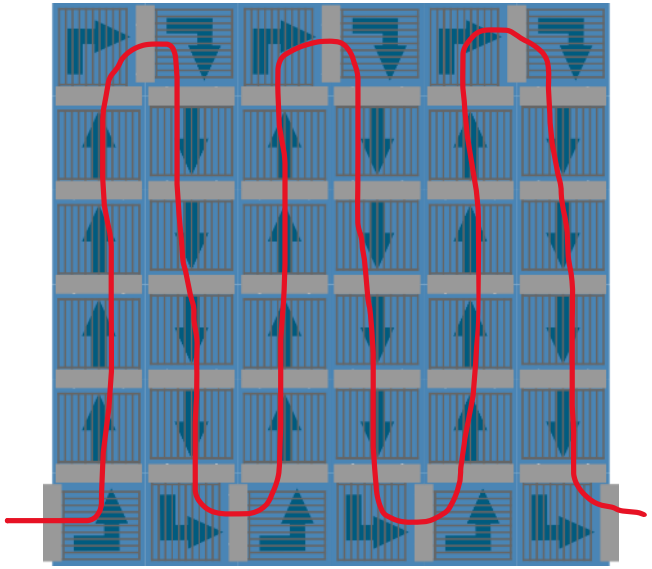


Fraunhofer ISE

FoilMet High Voltage

Shading

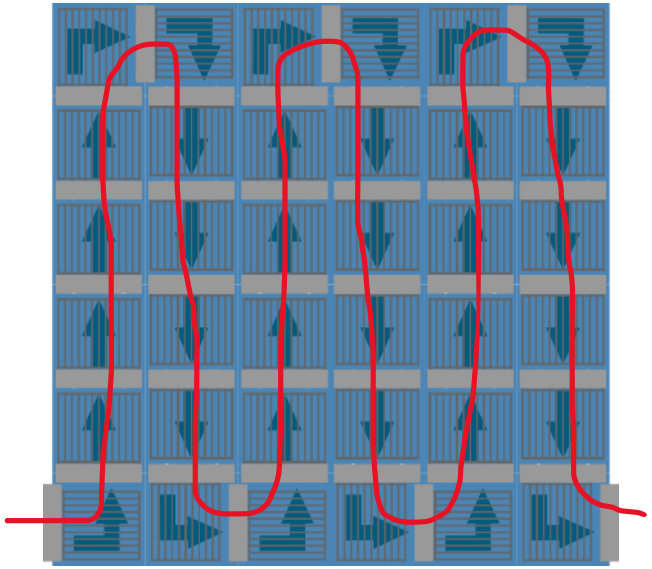


All Cells in series

1x36 sub-cells

FoilMet High Voltage

Shading



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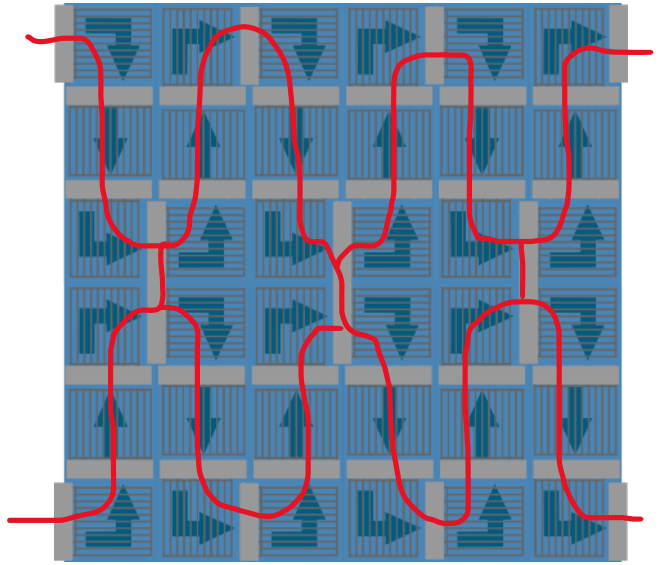
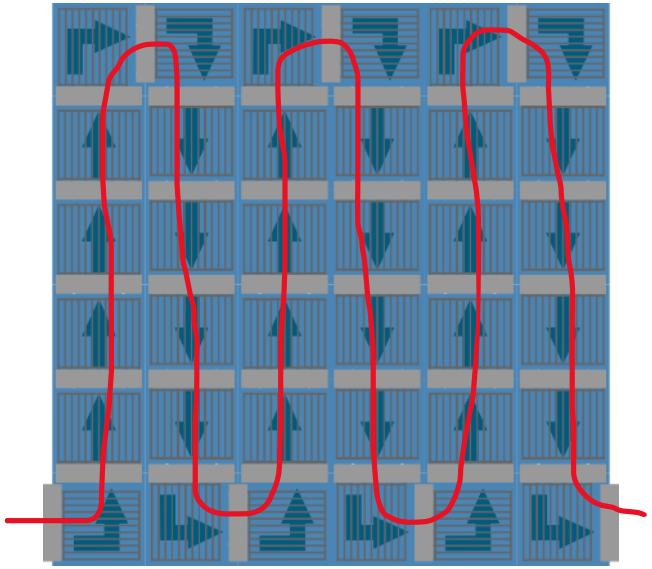


2 parallel strings

2x18 sub-cells

FoilMet High Voltage

Shading



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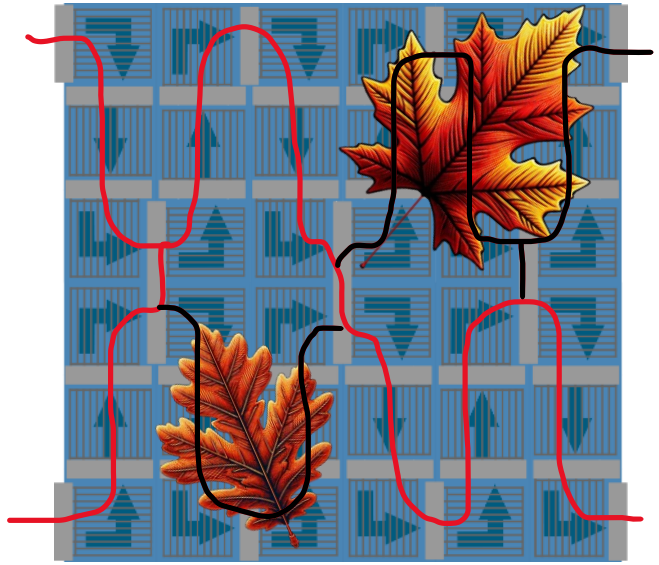

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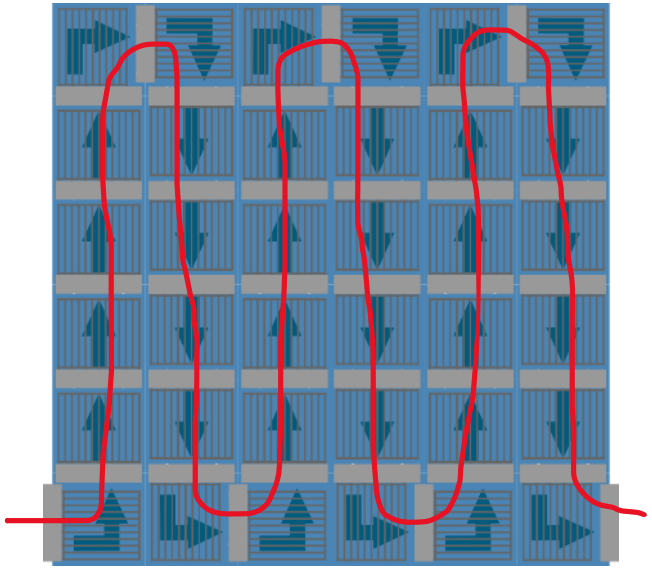

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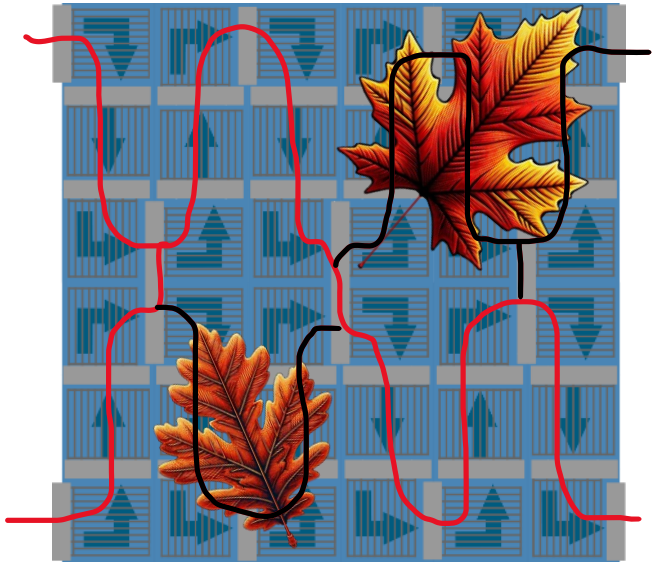

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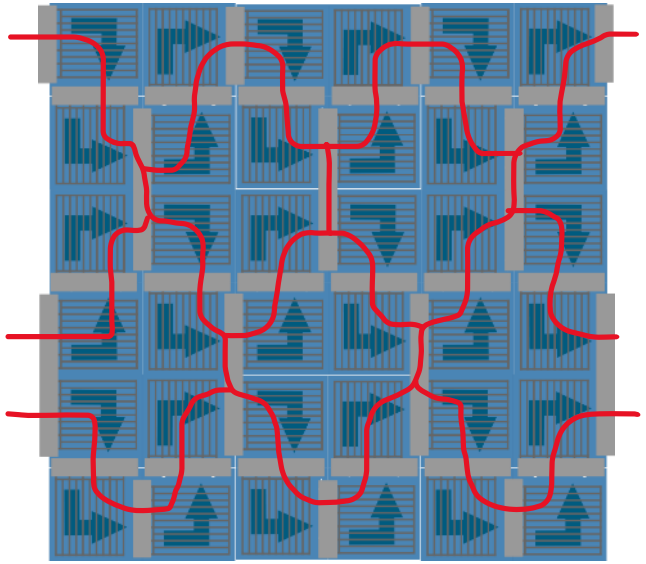
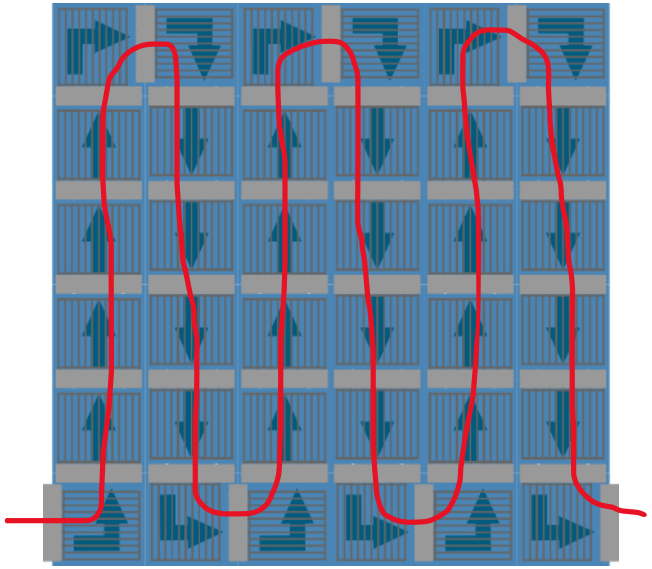


3 parallel strings

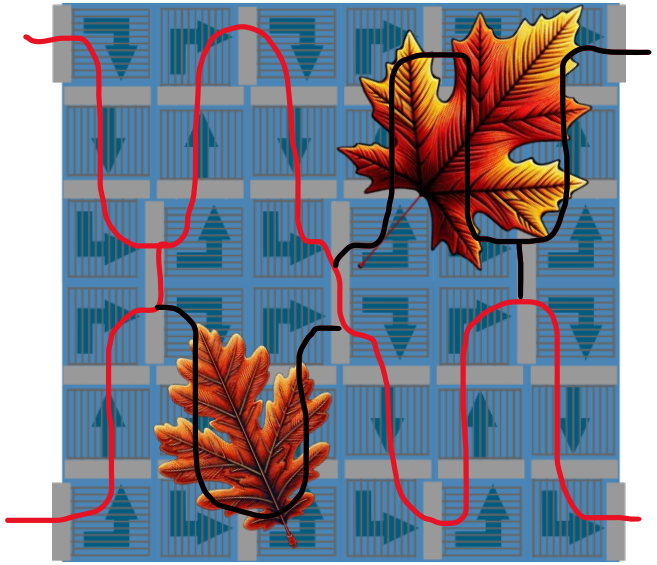
FoilMet High Voltage

Shading



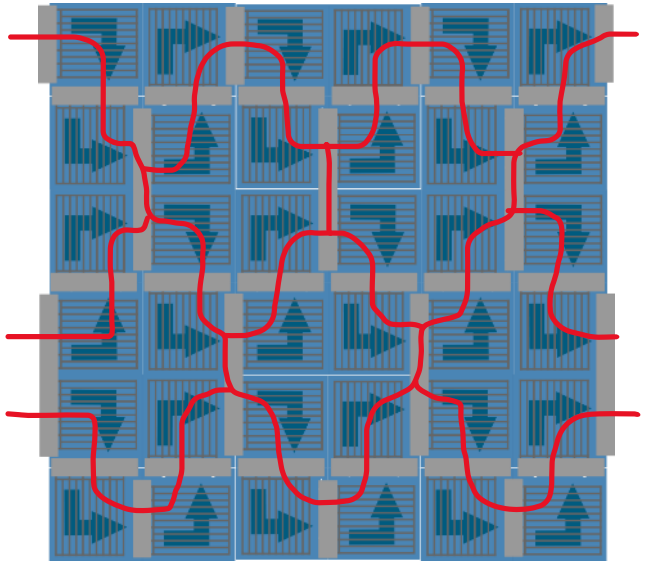
All Cells in series

1x36 sub-cells



2 parallel strings

2x18 sub-cells

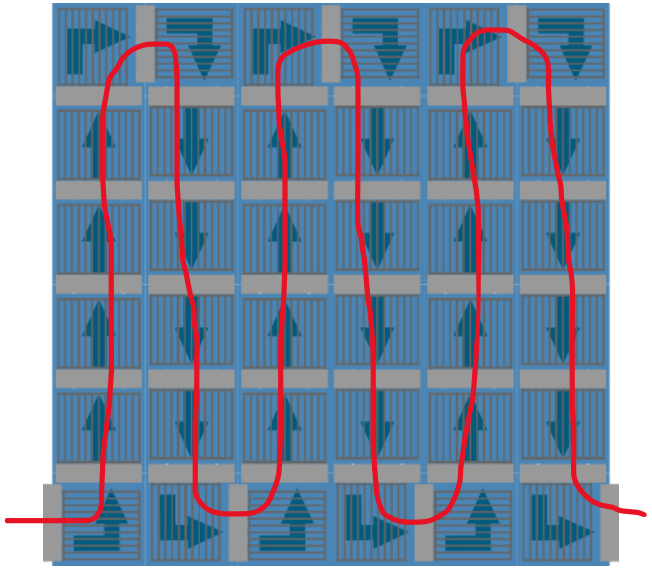


3 parallel strings

3x12 sub-cells

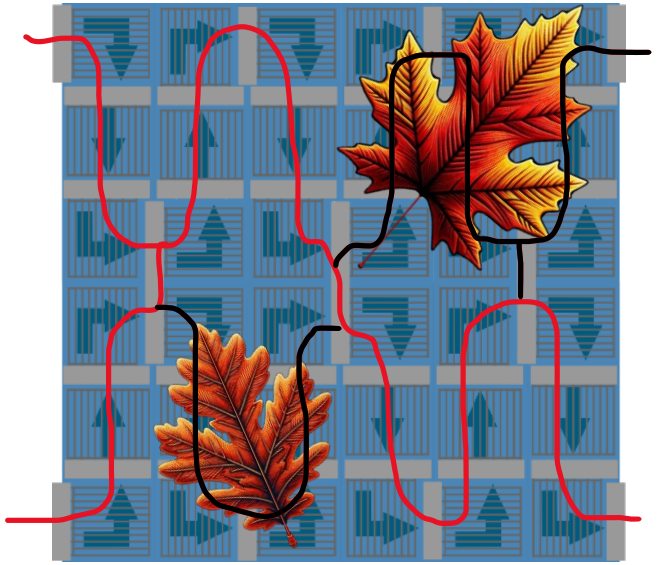
FoilMet High Voltage

Shading



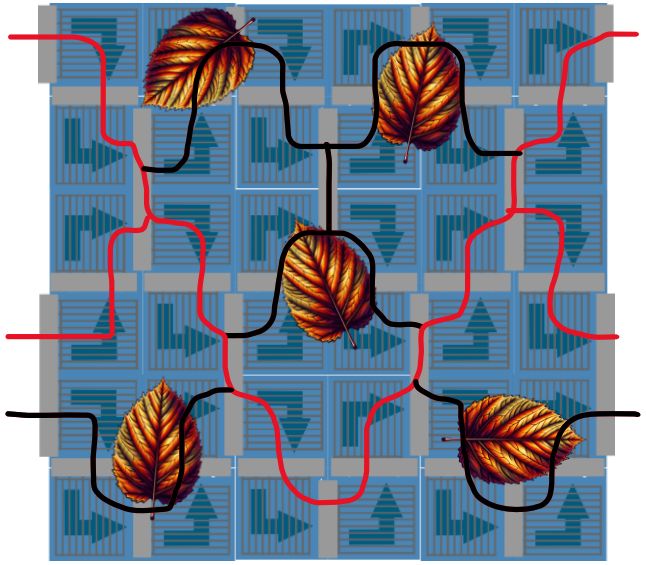
All Cells in series

1x36 sub-cells



2 parallel strings

2x18 sub-cells

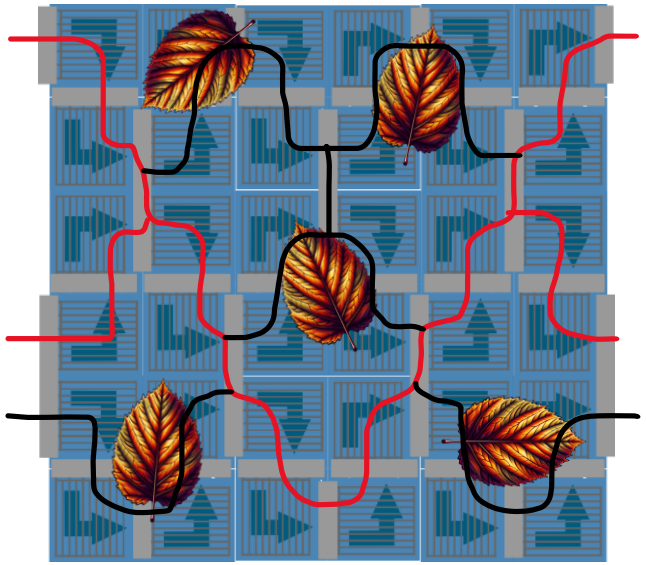


3 parallel strings

3x12 sub-cells

FoilMet High Voltage

Shading



Thank you for your attention

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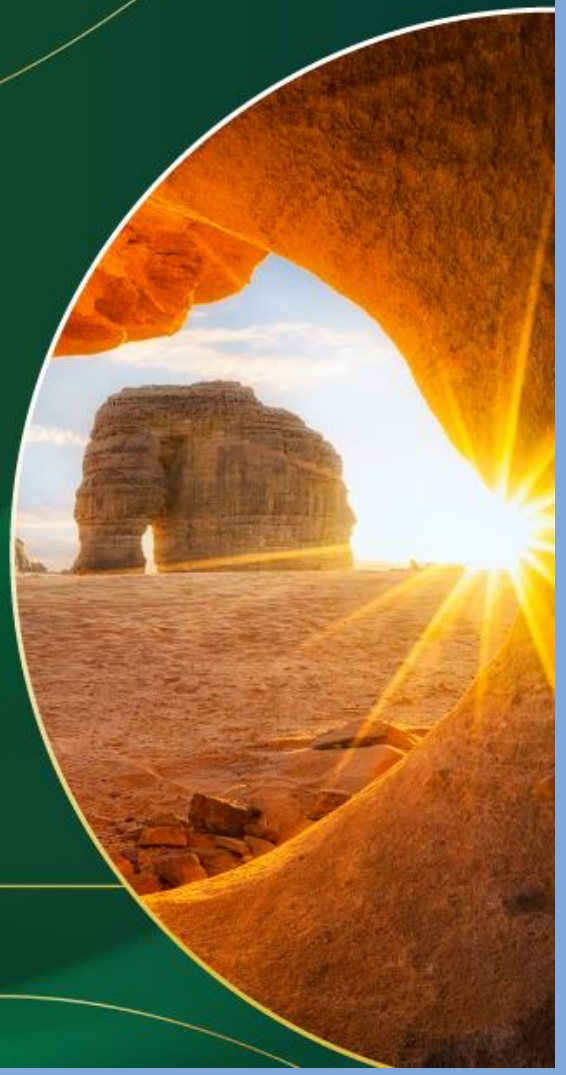

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