Shingled Cell Interconnection: Aiming for a New Generation of Bifacial PV-Modules

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Fraunhofer Institute for Solar Energy Systems ISE

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www.ise.fraunhofer.de

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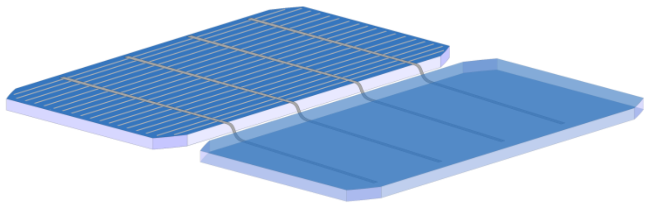
Interconnection Technologies

- Conventional: ribbon
  - 6" solar cells
  - Solder coated Cu-interconnectors
  - Up to 6 ribbons / cell



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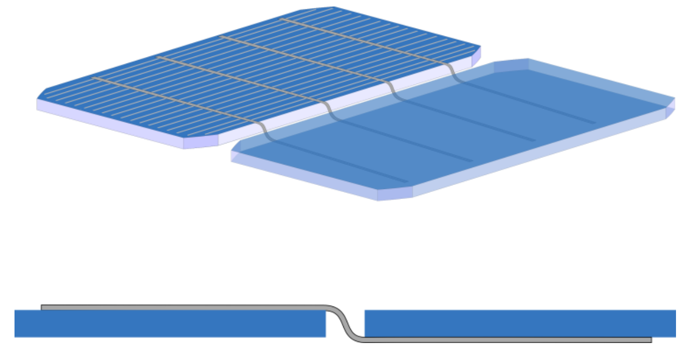
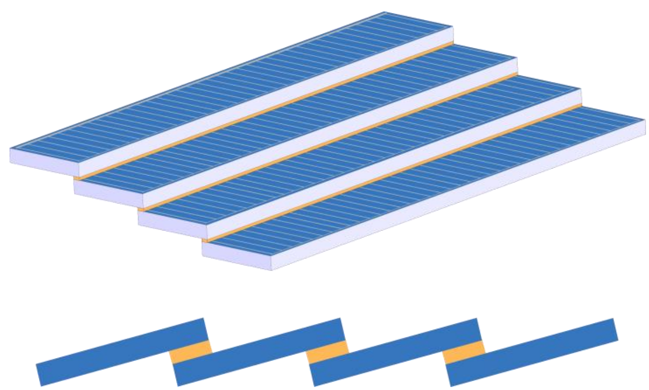


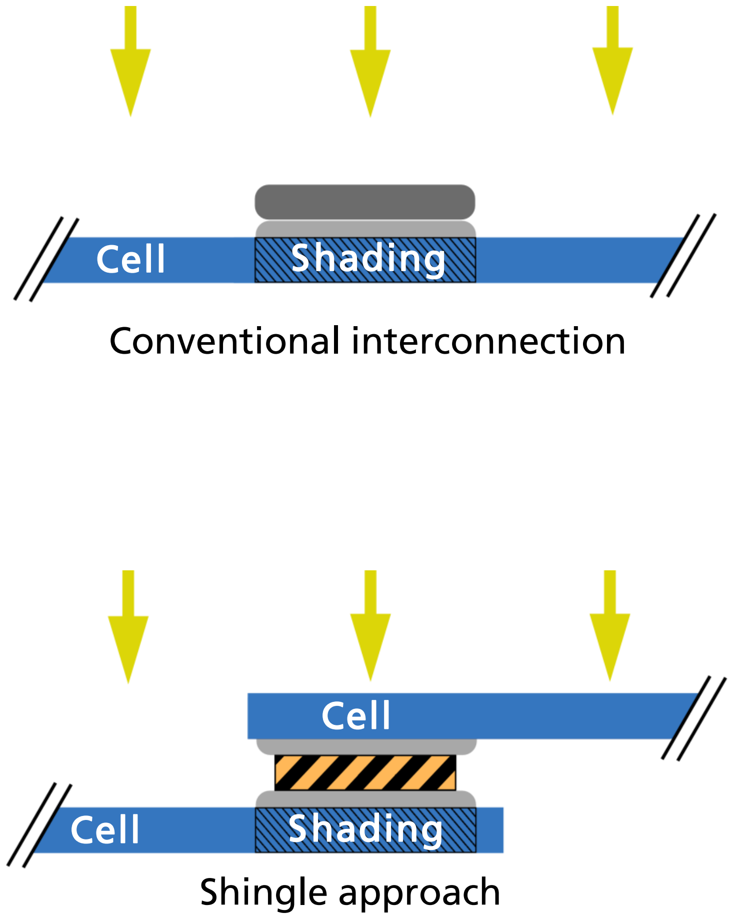
- Shingle interconnection [1]
  - Overlapping solar cell „stripes“
  - ~ 1/6 of 6“ wafer
  - Joint material (ECA / solder)



[1] Donald C. Jr., Dickson (1960): Photovoltaic semiconductor apparartus or the like. Registered by Hoffmann Electronics Corp. Patentnr.: US 2938938 A.

Shingle Interconnection Advantages

- Shingle interconnection advantages
  - No ribbon shading
  - Reduced cell spacing
  - No interconnector losses
  - Reduced string current



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Shingle Interconnection Advantages

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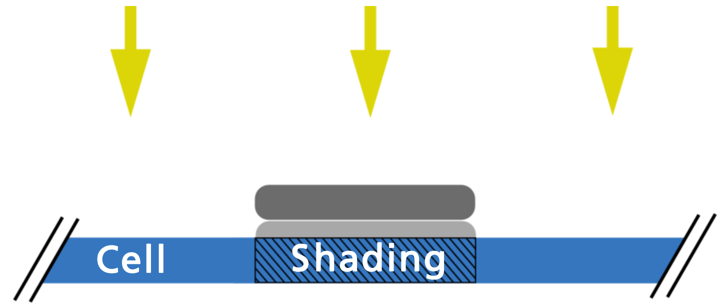
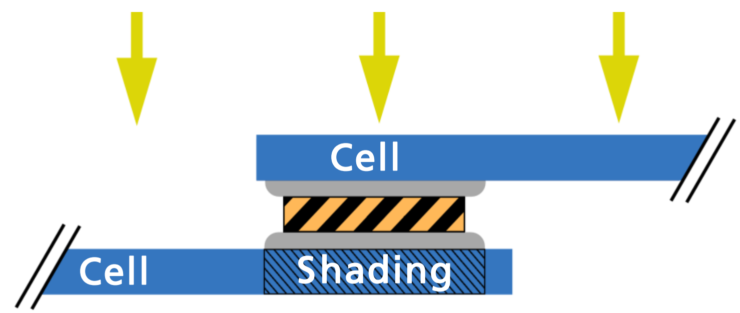
- Decreasing current significantly reduces ohmic losses
  - $I_{ph} \propto A$
  - $P_{loss} \propto I_{ph}^2$



Conventional interconnection



Shingle approach

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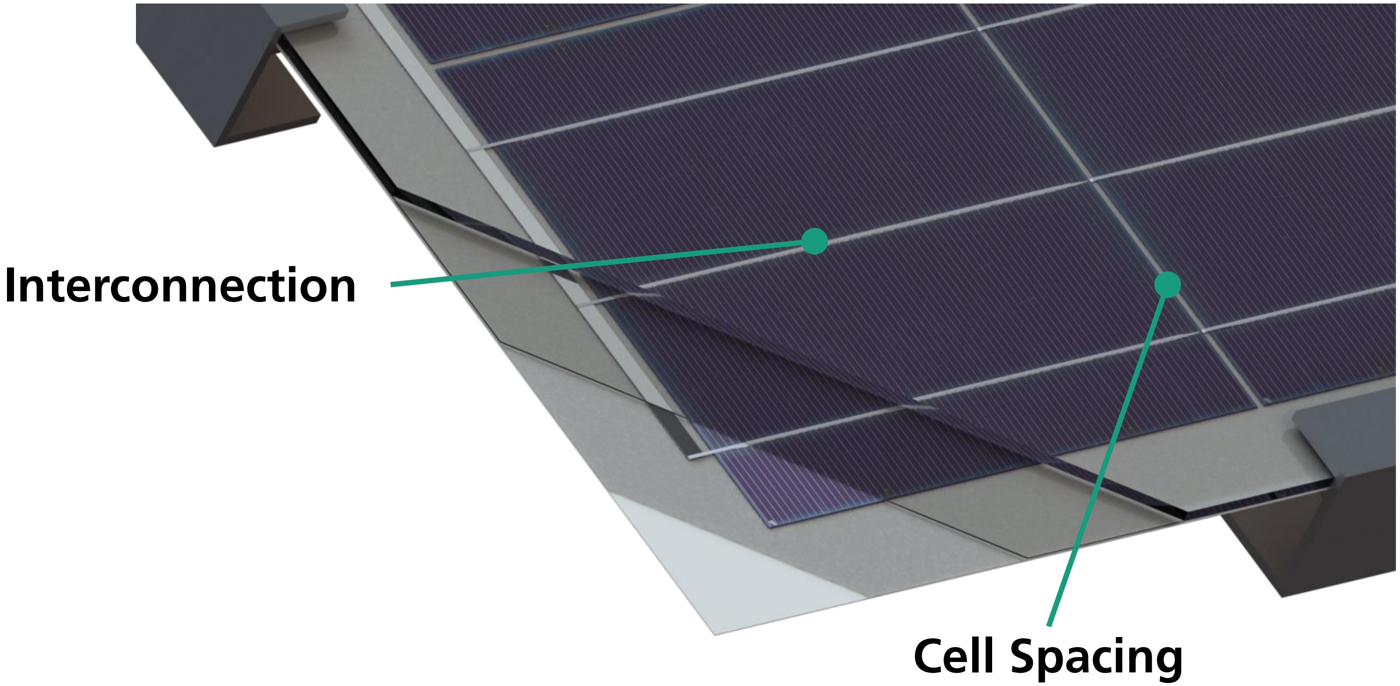
Conventional PV Module

SmartCalc.CTM

www.cell-to-module.com

- Loss simulation via Cell-to-Module (CTM) analysis [2]
- Focus on two major features



[2] Haedrich, Ingrid et al (2014): Unified methodology for determining CTM ratios. Systematic prediction of module power. In: *Solar Energy Materials and Solar Cells* 131

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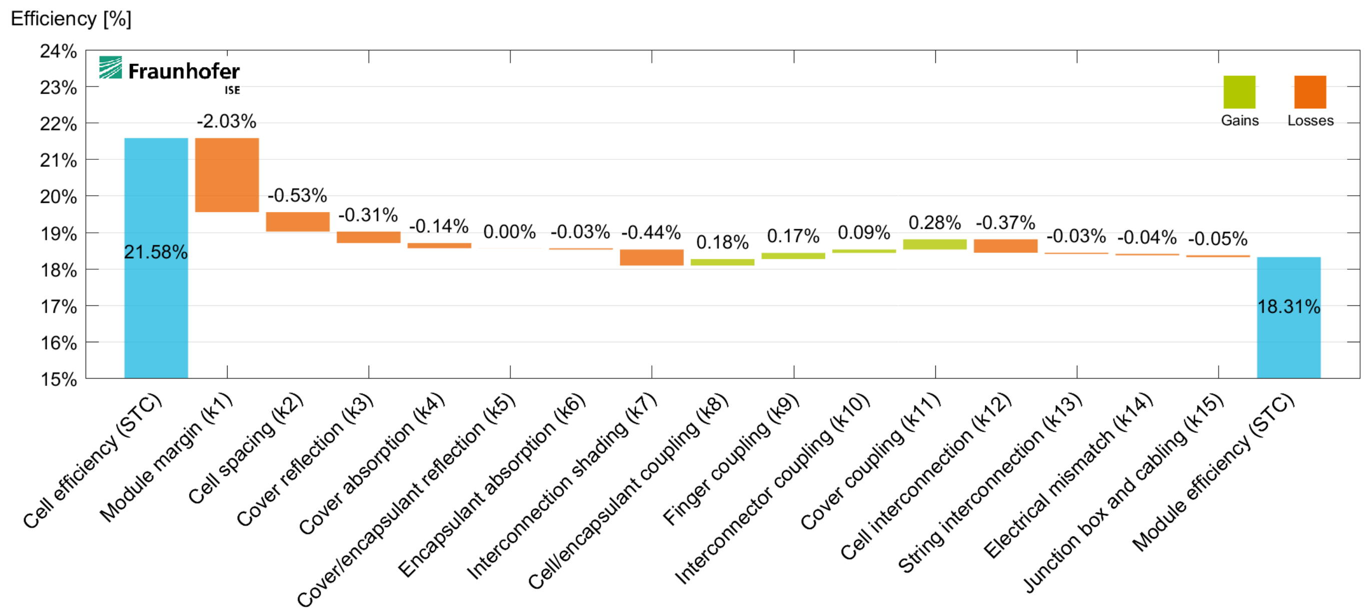
CTM Efficiency Analysis [3]

SmartCalc.CTM

www.cell-to-module.com



[3] Mittag, Max et al (2017): Cell-to-Module (CTM) analysis for photovoltaic modules with shingled solar cells. presented at the 44th IEEE PVSC, Washington, D.C.

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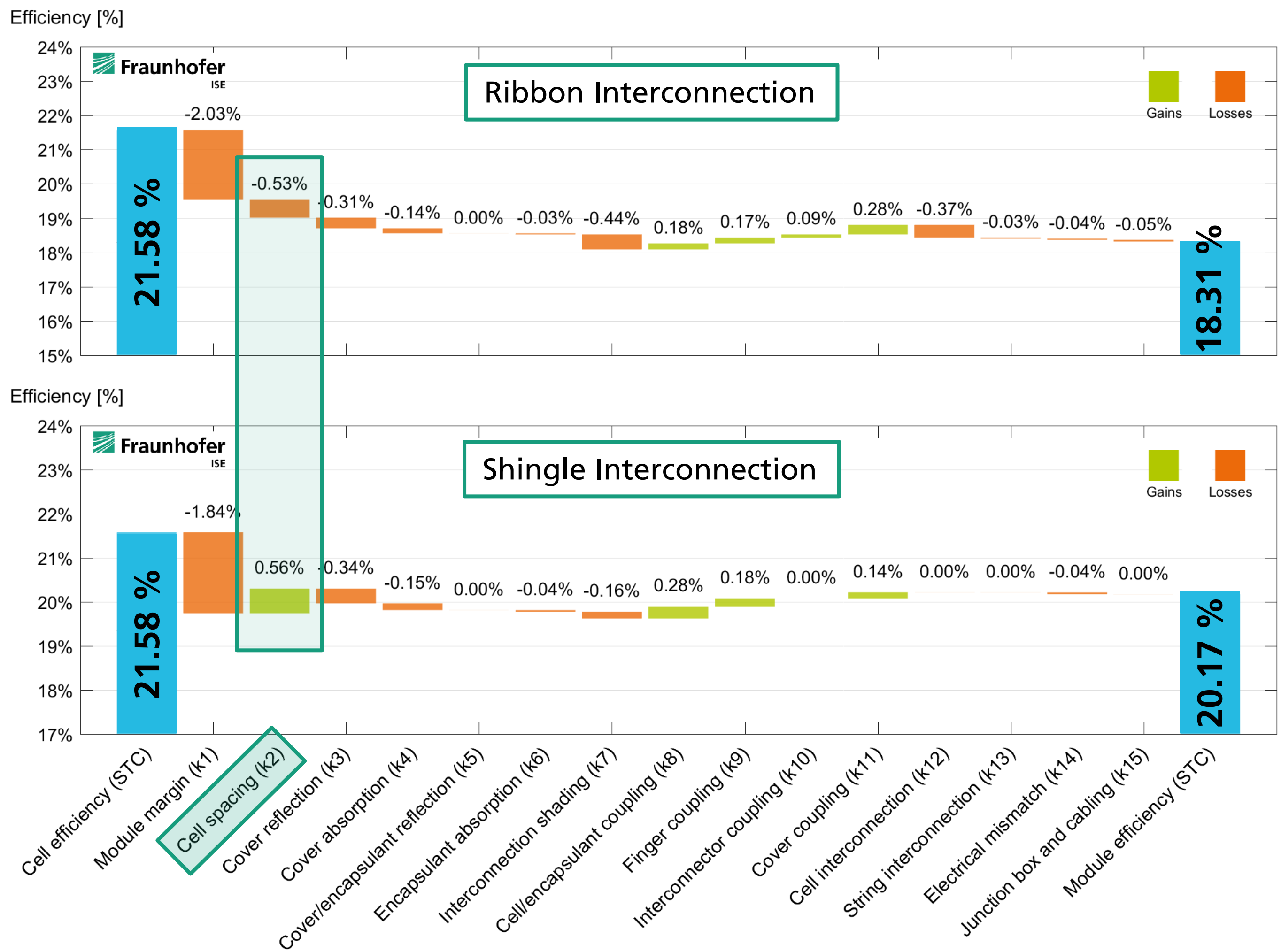

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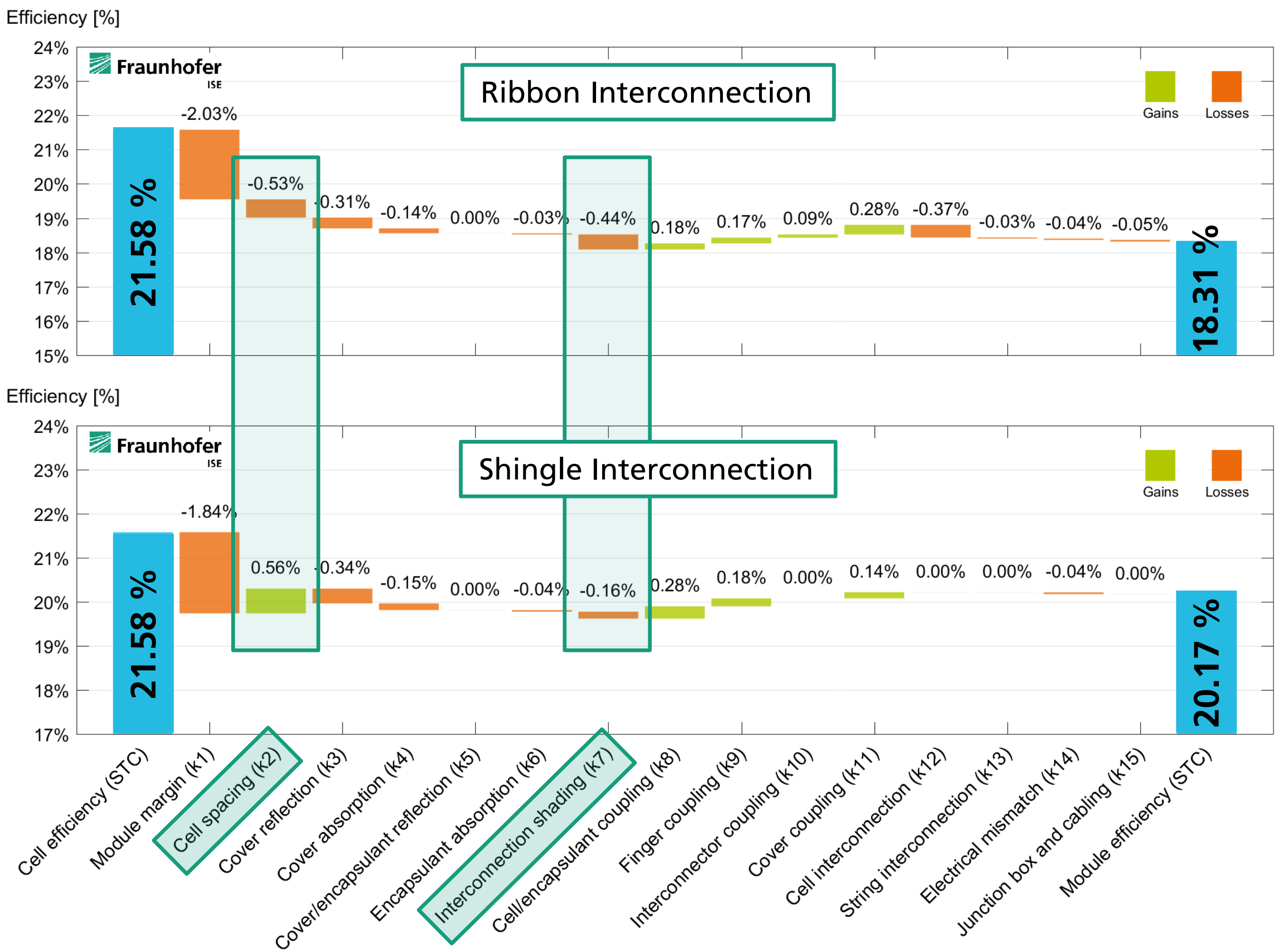

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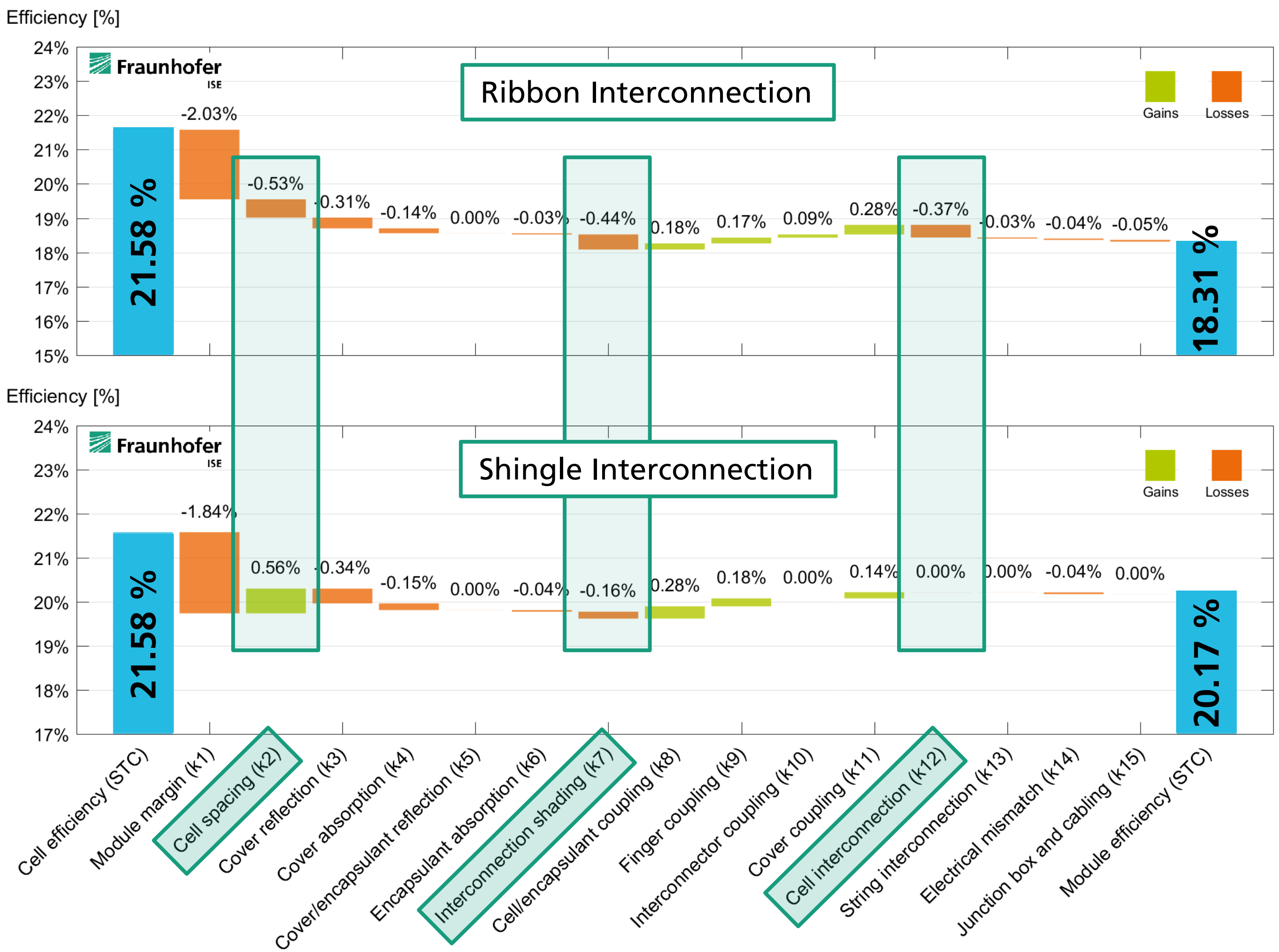

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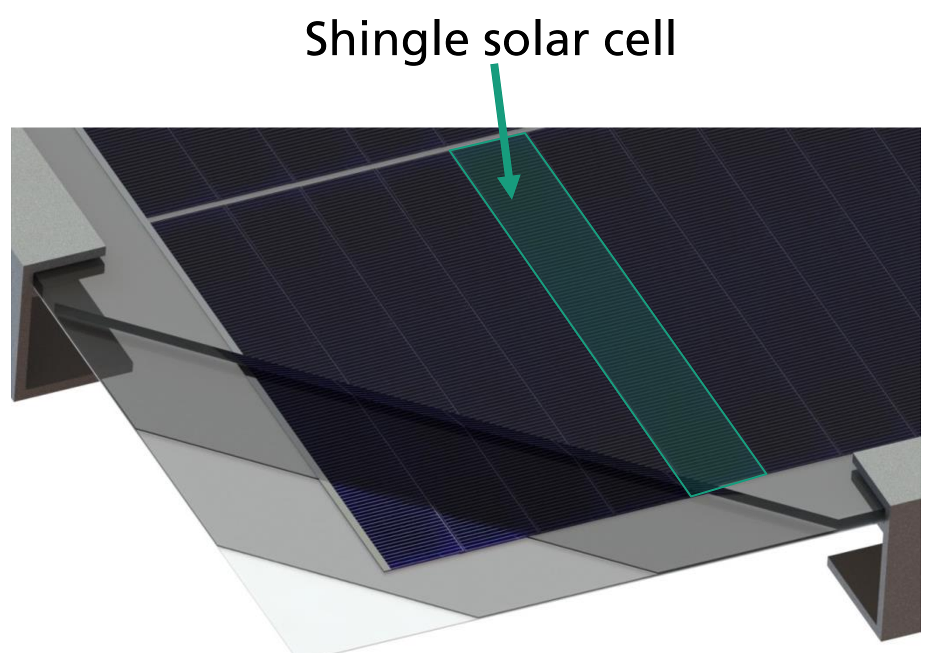
Features Shingle Module

SmartCalc.CTM

www.cell-to-module.com

- High aesthetics for building integration
- Transparent backsheet for bifacial solar cell integration
- Lead-free solders or ECAs as joint material

- Very high module power densities aiming for:
  - 400 W @ 1,6 m² or
  - 240 W/m²
- Combined cell & module development at Fraunhofer ISE



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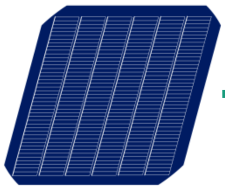
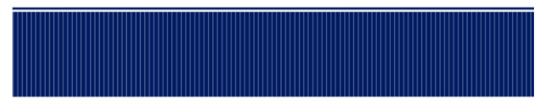
Process from Cell to Module

Bifacial p-**SPEER [4]** solar cell. 148x23 mm²



Bifacial p-type PERC

Singulation & edge passivation



Aim
$\eta = 22.1\ \%$

Shingled **P**assivated **E**dge **E**mitter and **R**ear Solar Cell

Cell development

[4] Baliozant et al. (submitted). Bifacial p-type silicon shingle solar cells - the "pSPEER" concept.

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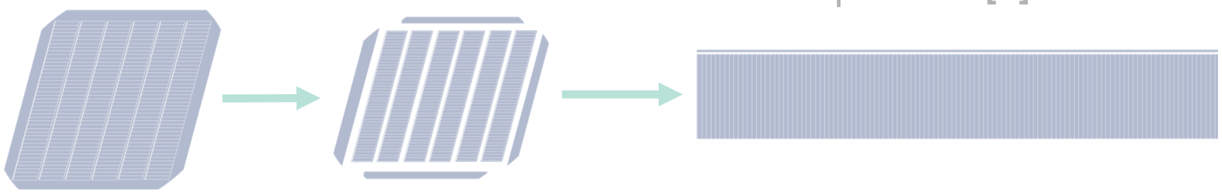

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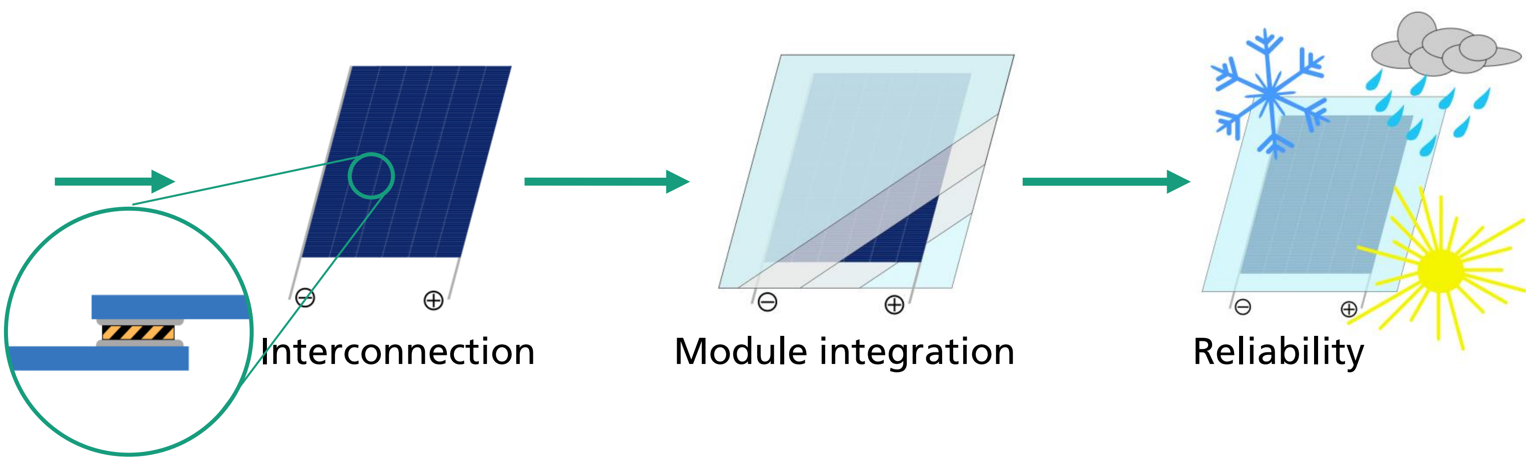

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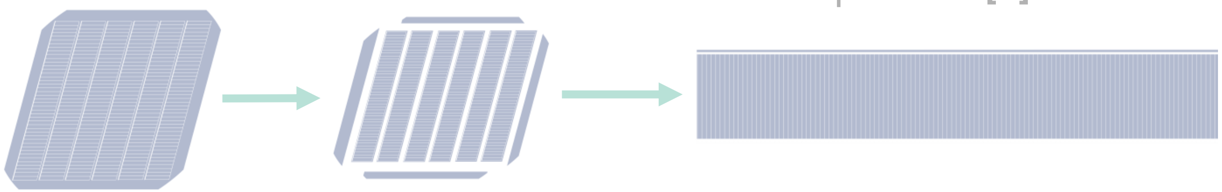

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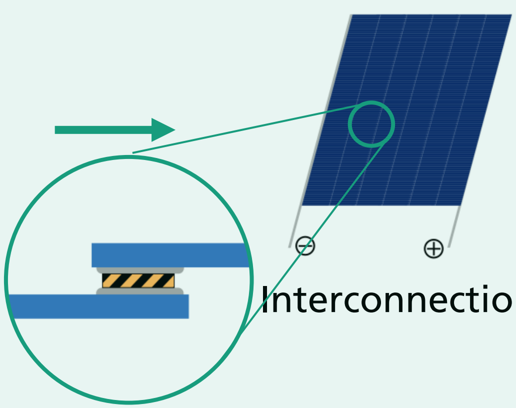
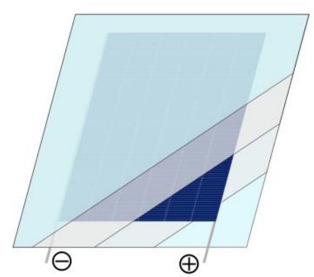
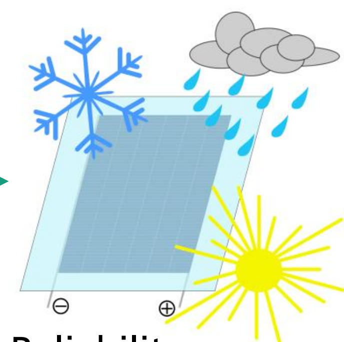


Interconnection



Module integration



Reliability

Aim

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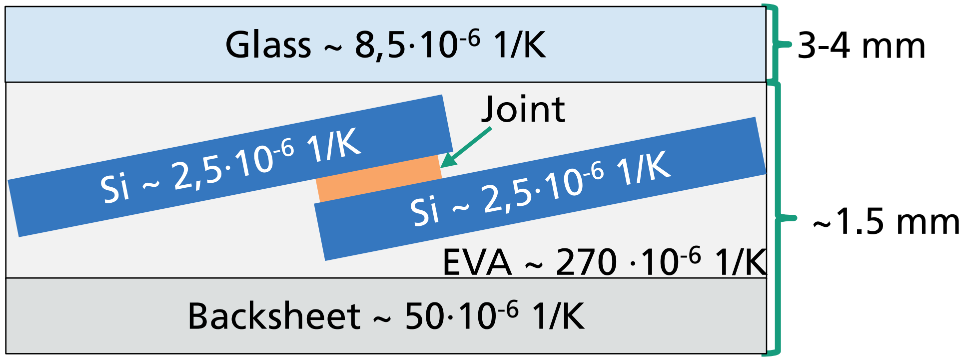
Challenge: Shingle Joint

- Different Coefficients of Thermal Expansion (CTE)
- Joint has to compensate relative cell movement



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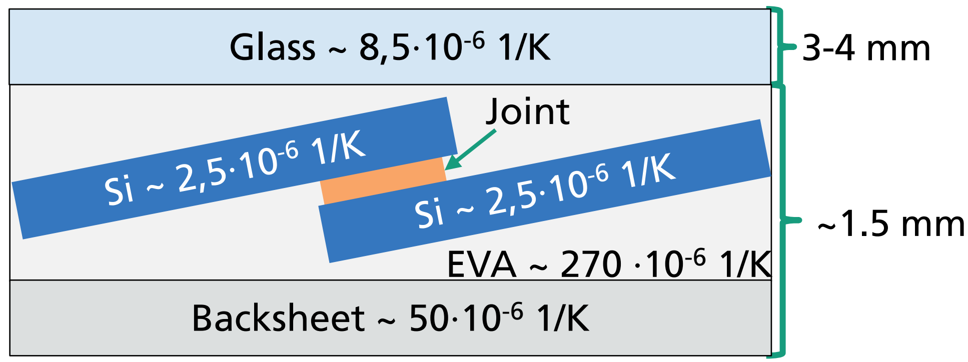

- Recent Investigation suggest:
  - Solder is too stiff
  - ECAs currently in use

	Soldering (SnPb)[8]	Soldering (SnBi)[6,7]	Glueing (Epoxy)[8]
$T_{process}$ [°C]	> 200	160	150-180
G [MPa]	11,000 – 14,000	36,000 – 38,000	200 – 2,000
τ_{str} [MPa]	23 – 48	28	5 – 10
G / τ_{str} [-]	230 – 600	1280 – 1350	20 – 400

[6] Shen et al. (2013): Nanoindentation study on the creep resistance of SnBi solder alloy with reactive nano-metallic fillers. In: *Materials Science and Engineering: A* 561.
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[8] Beaucarne, Guy (2016): Materials Challenge for Shingled Cells Interconnection. In: *Energy Procedia* 98

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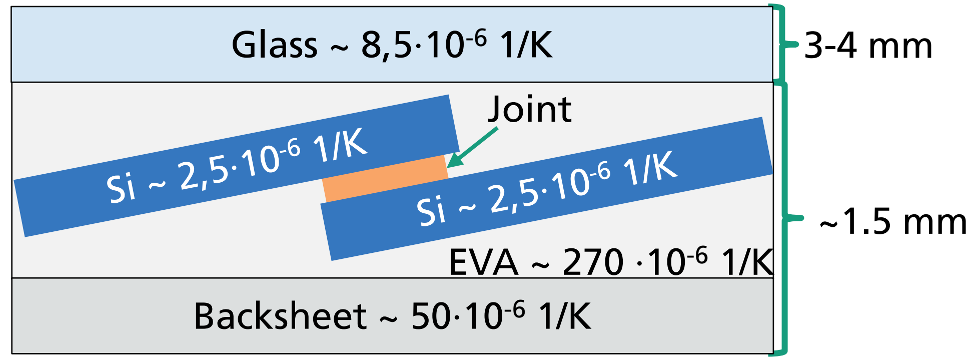

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Module Integration Process

Joint material application | *ECA or solder*

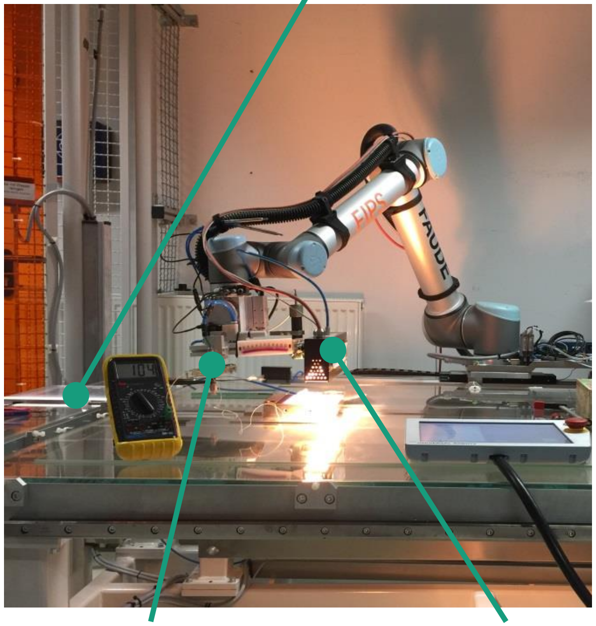
Pick and place routine | *UR5 robot manipulator*

Epoxy - ECA	**Sn42Bi58**

Layup | *Glass, EVA, ETFE Backsheet*

Slimline process |
Combined lamination / interconnection

Camera-based correction of cell position



Vacuum picker

Infrared radiator

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I-V Characterization & EL-Imaging

a-TC200 | 8 K/min, - 45 to 85 °C,15 min dwell

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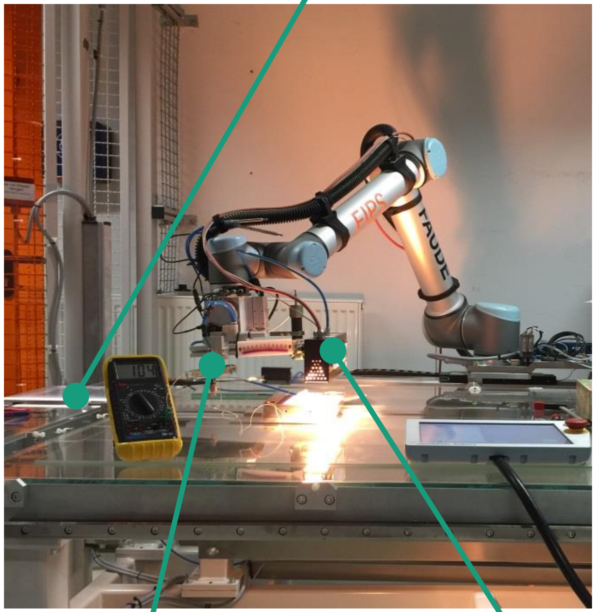

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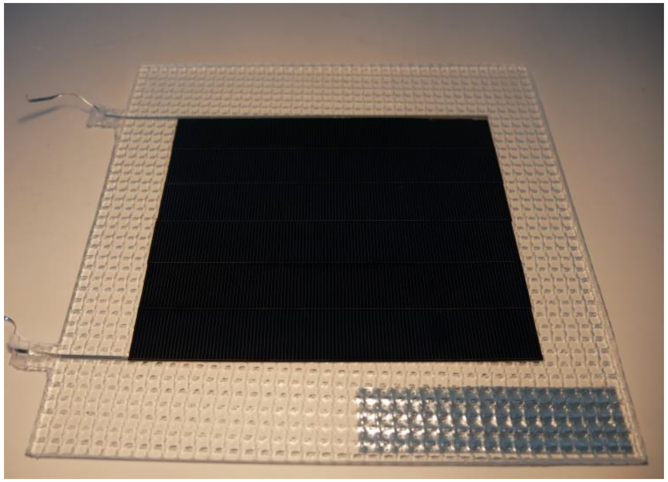

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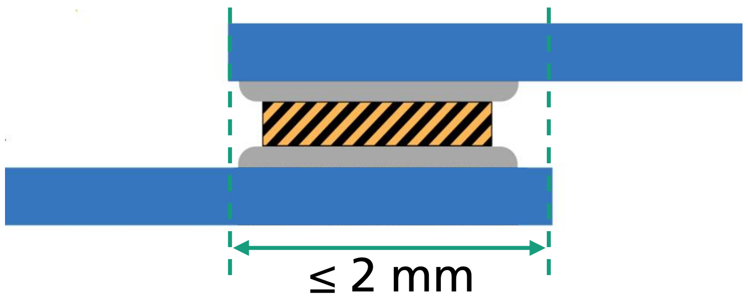
Interconnecting the Rear Side

- Little space for metallization in the overlap
- Aim for overlap ≤ 2 mm



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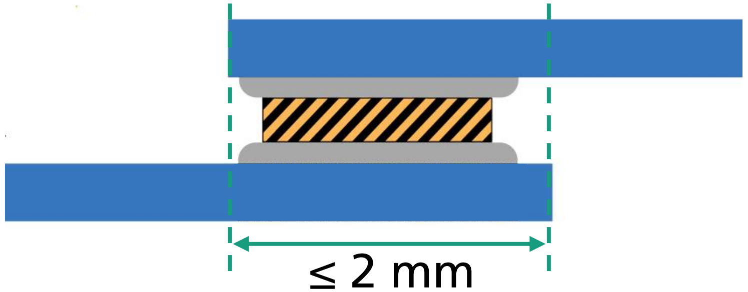
- Al / Ag rear-metallization
  - Contact passivation (**Al**)
  - Interconnection (**Ag**)



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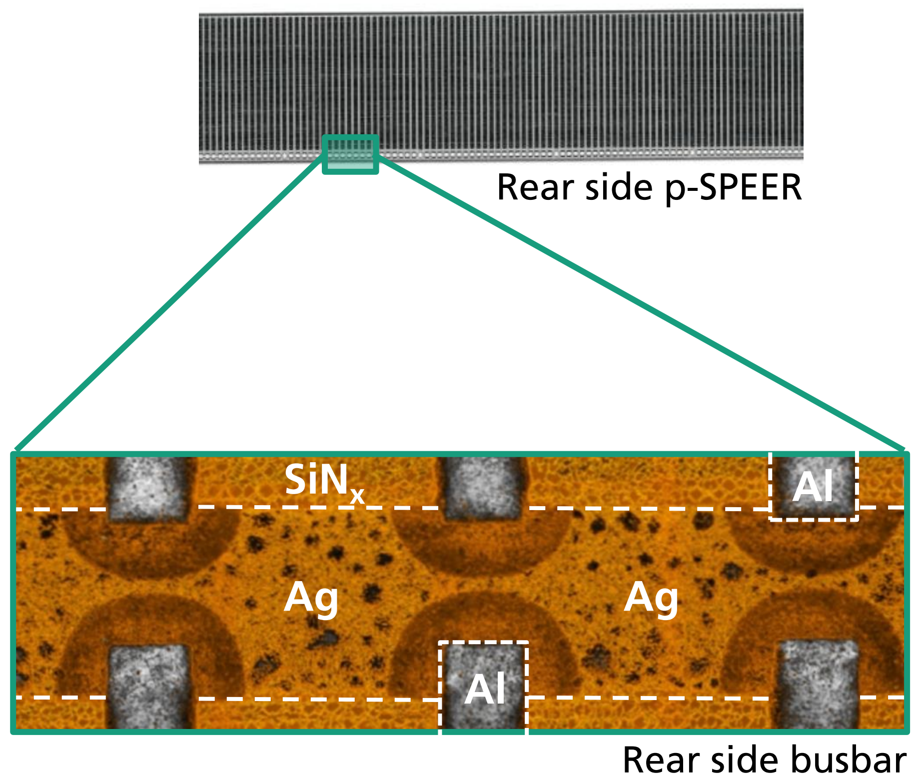
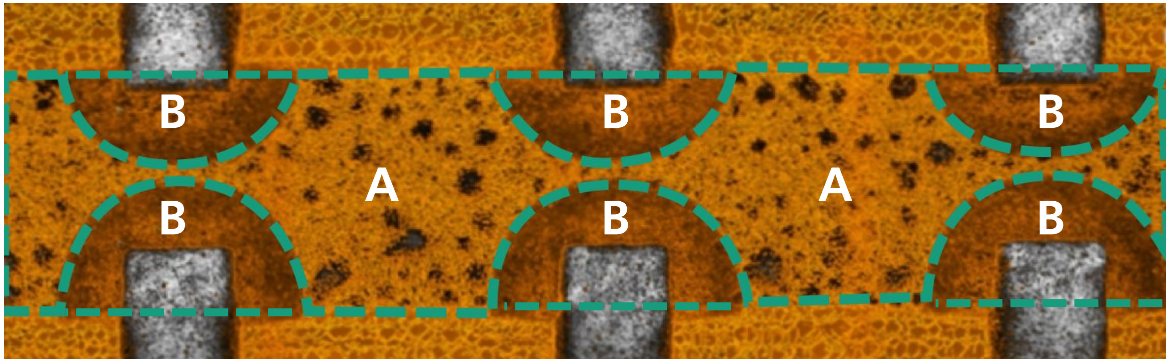
- Aluminum challenging for soldering



Interconnecting the Rear Side

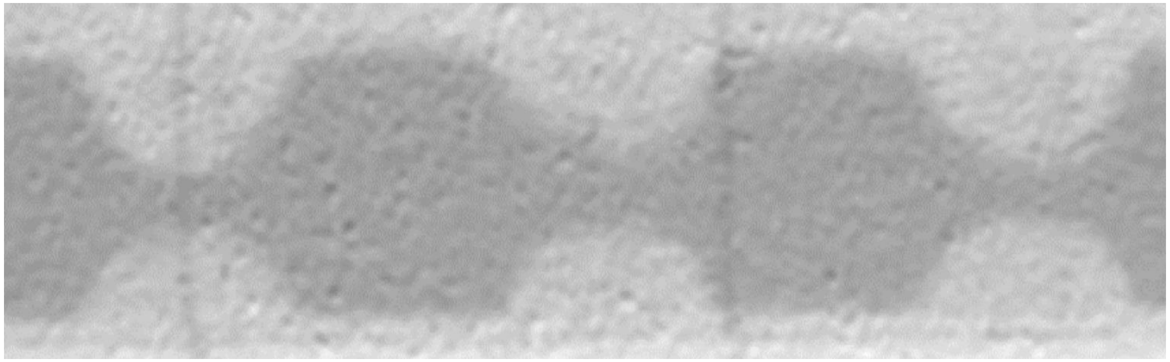
- Convocal microscopy indicates two different regions



Rear side busbar of a p-SPEER cell

Interconnecting the Rear Side

- X-Ray transmission images
- Solder experiments show similar structures



Overlap of two soldered p-SPEER Cells

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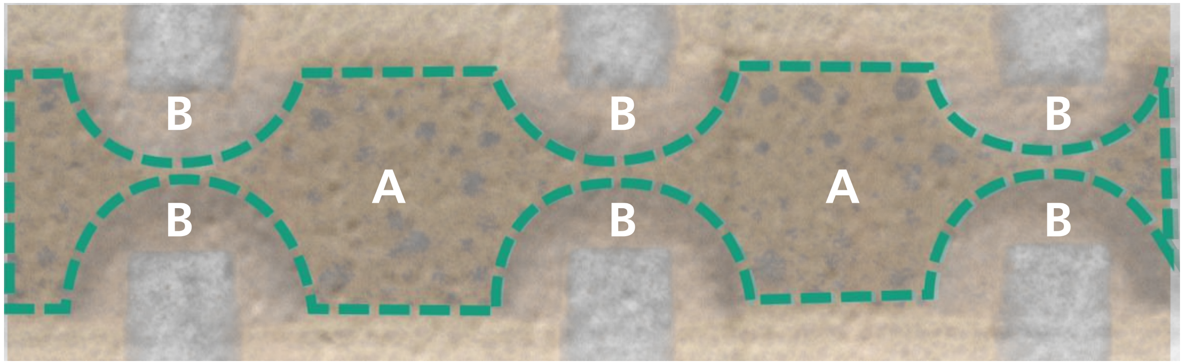

Overlap of two soldered p-SPEER Cells

- Dewetting of solder indicates Al

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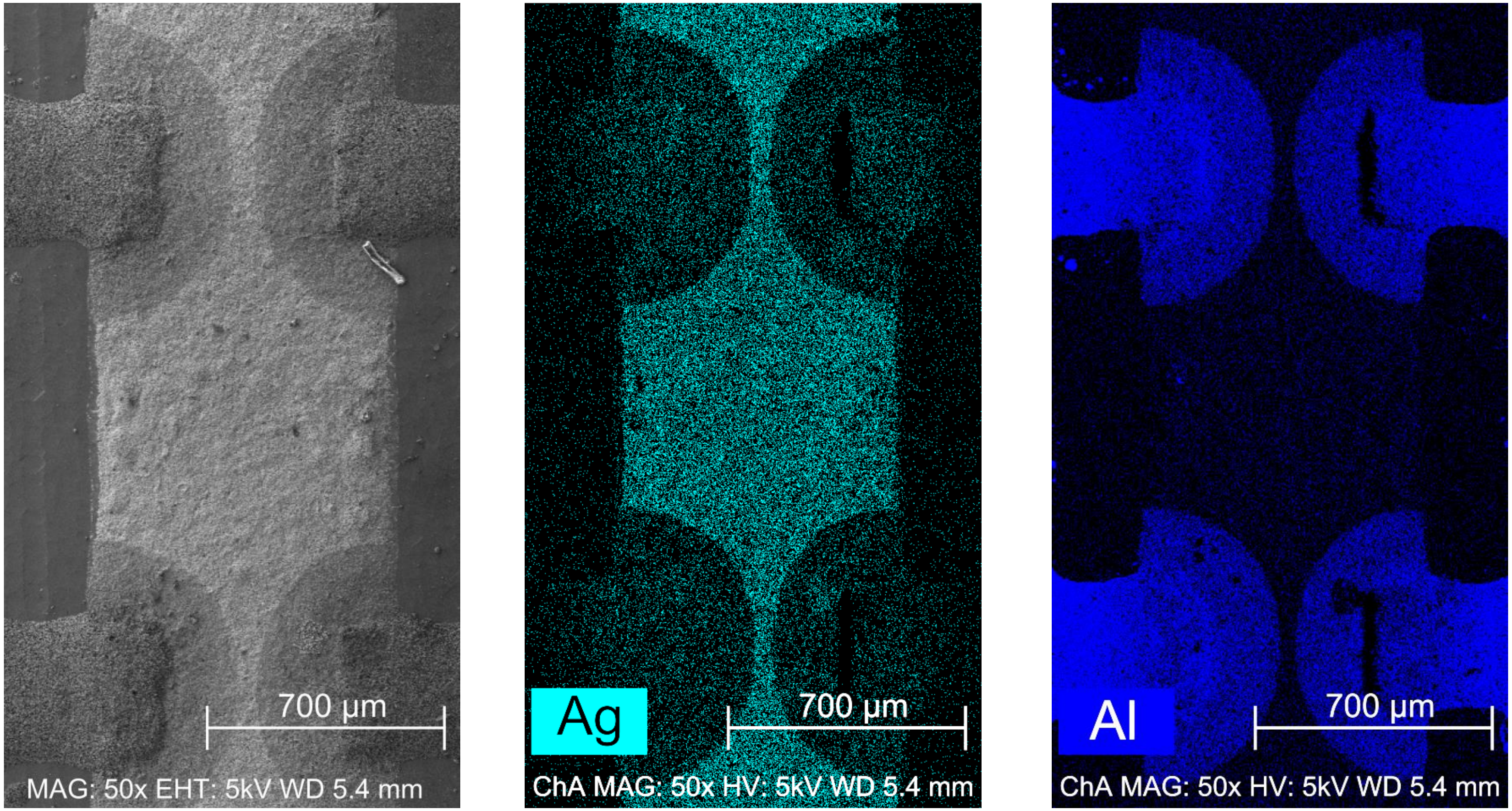
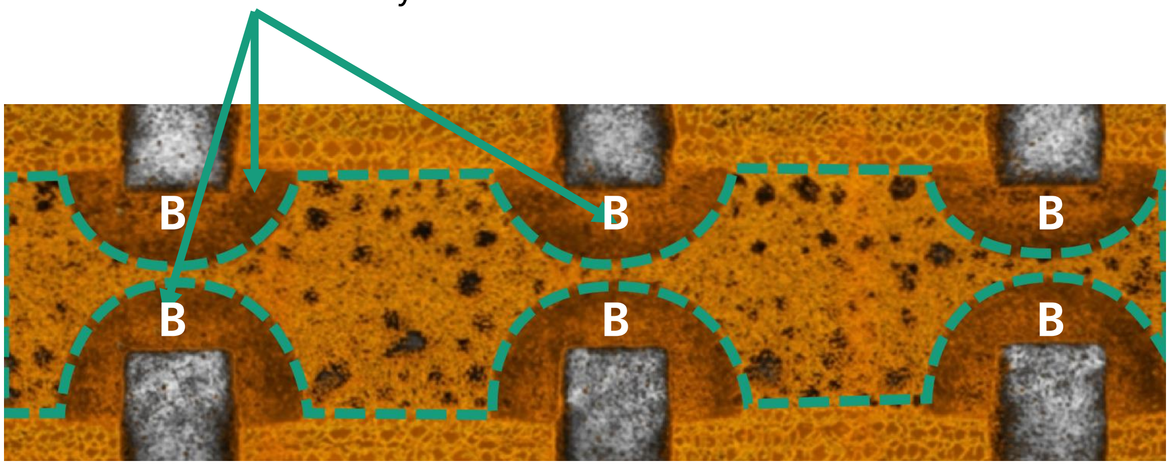


- EDX-Mapping Ag/Al
- Depth: ~ 160 nm

Interconnecting the Rear Side

- Al → Ag Diffusion during Co-Firing
- Formation of stable Al_xAg_y- Phase (B) [9]

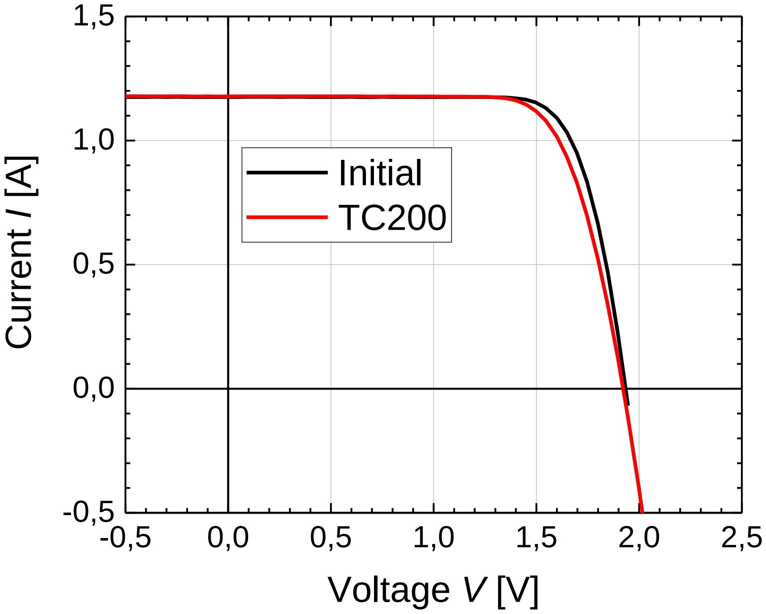


- Further development of rear side metallization needed
- Reduction of area covered by phase B

[9] Baker, Hugh (2016): Alloy Phase Diagrams. ASM Handbook. 3. Aufl.: ASM International.

Module Results – I-V Characterization

- Slight decrease in FF
- SnBi solder passes a-TC200 in shingle interconnection



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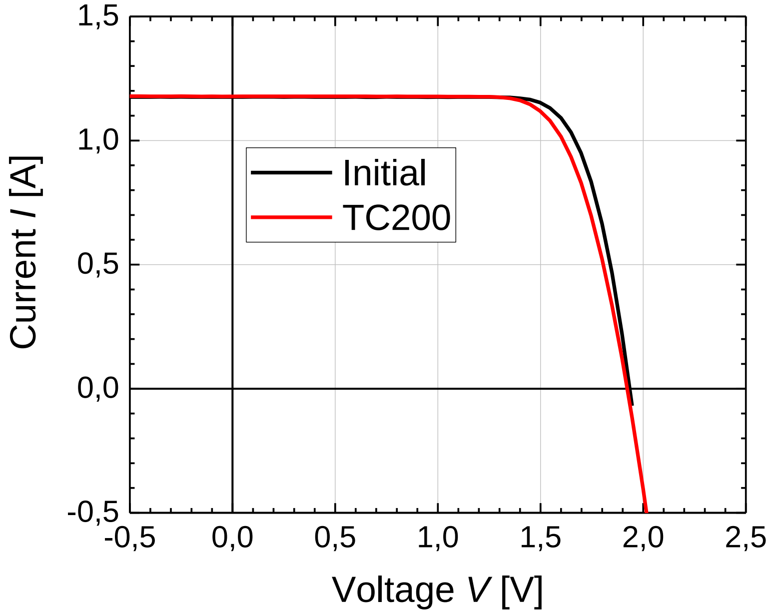
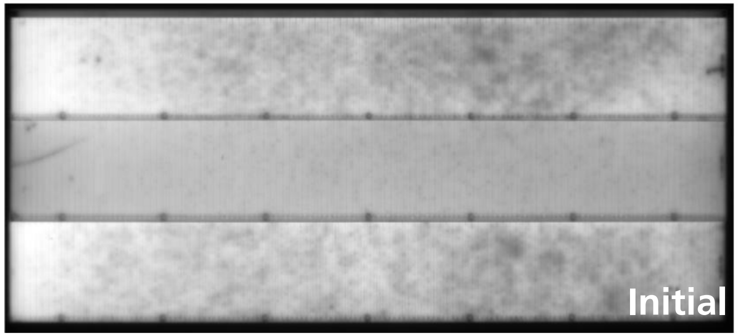


- < 5% power decay after 200 cycles

		Initial	a-TC200	
I_{SC}	[mA]	1175	1178	100.2 %
V_{OC}	[mV]	1934	1922	99.4 %
FF	[%]	77.0	74.1	96.2 %
P_{MPP}	[mW]	1750	1677	95.8 %

Module Results – EL Imaging

- Homogeneous current distribution indicates good interconnection



[10] Schmid, Cordula V. (2010): Schadensmechanismen bei Silizium-Solarzellen und Maßnahmen zur Festigkeitserhöhung. Fakultät für Maschinenbau, Karlsruher Institut für Technologie (KIT), Karlsruhe

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Module Results – EL Imaging

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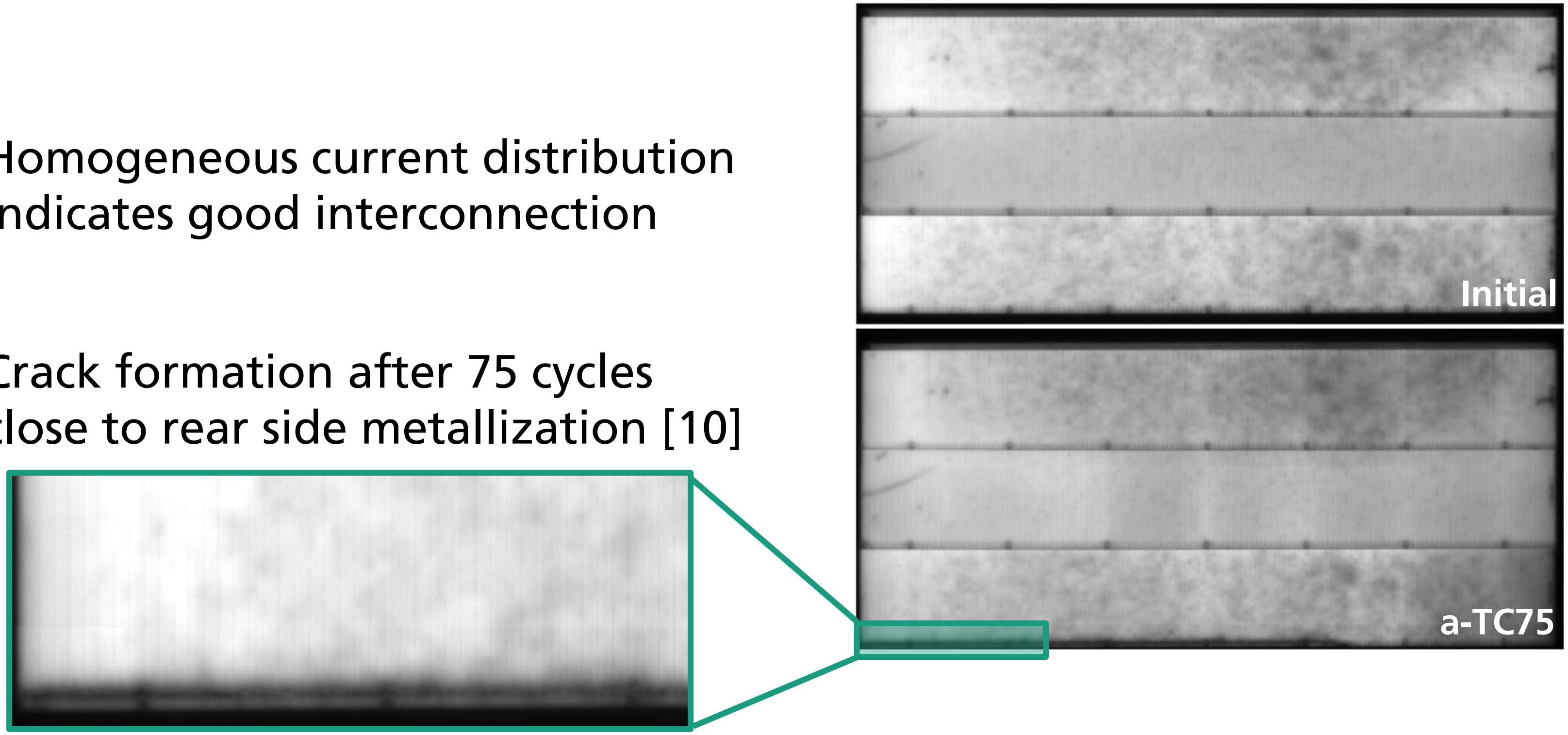
- Crack formation after 75 cycles close to rear side metallization [10]



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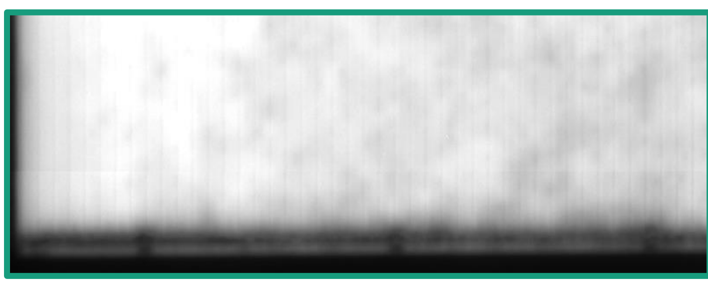
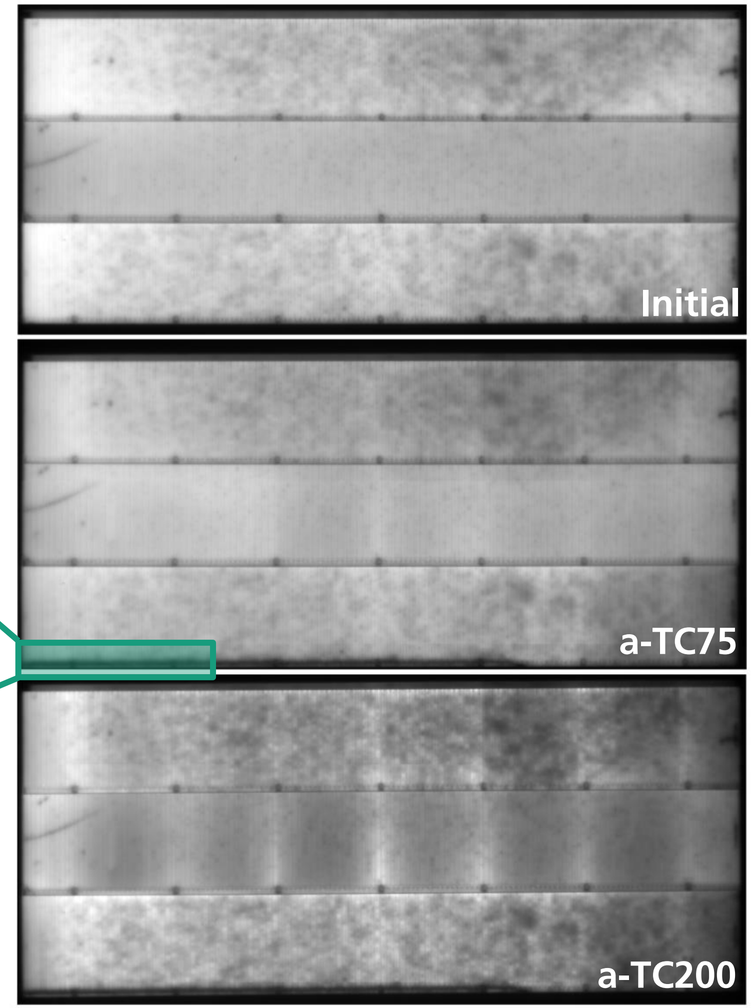


- Slight decrease in interconnection quality after a-TC200



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Summary & Outlook

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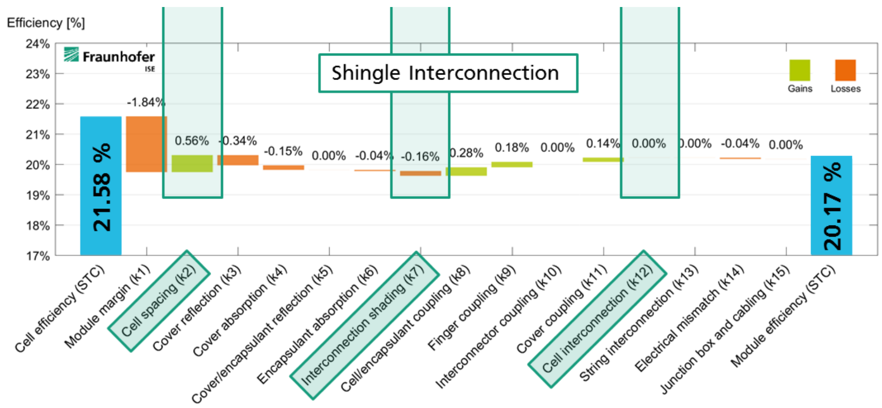
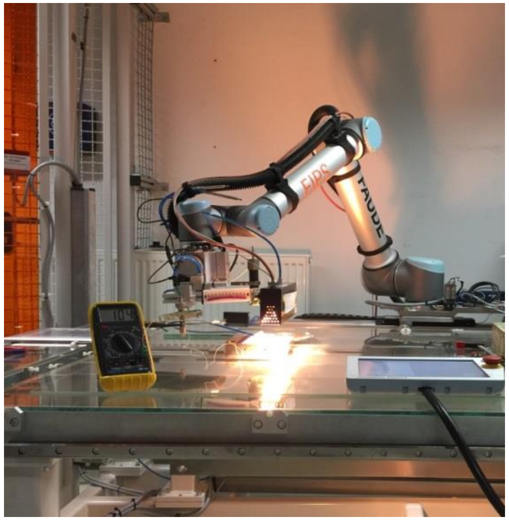
- Combined lamination & interconnection process
- < 5 % power loss after a-TC200 for shingled bifacial SPEER cells soldered with SnBi





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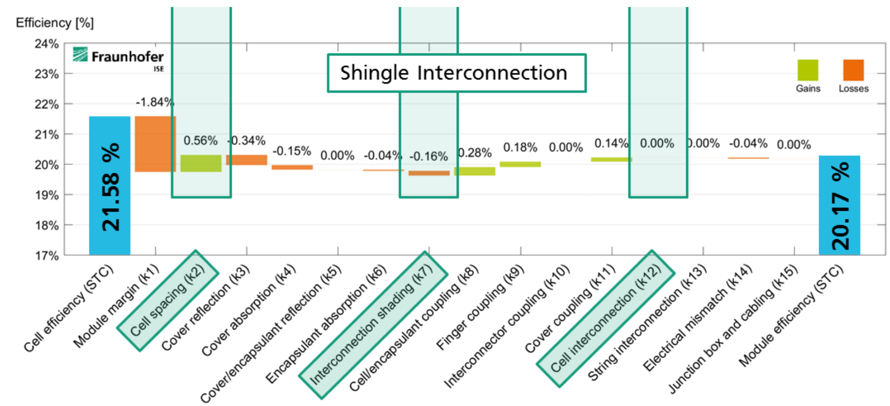
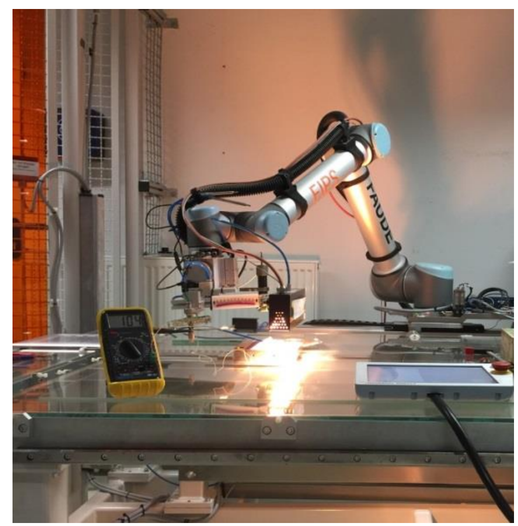
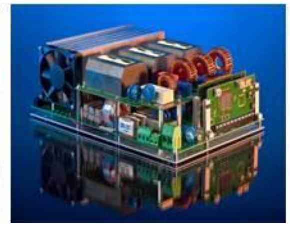
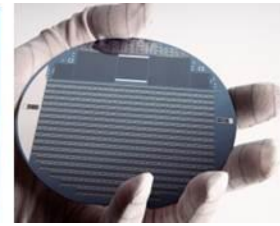
- Detailed research on solder and ECA joint materials
- Further reliability testing and FEM simulations on shingle interconnection





Thank you for your attention

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