J. D. Huyeng, G. Emanuel, O. John, J. Paschen, R. Efinger, R. Keding,
A. A. Brand, S. Kluska, F. Clement, J. Nekarda

12th BCworkshop
Delft, the Netherlands, 4th – 5th December 2024

Flexible Cell Interconnection Using Al-Foils and Laser Processing

Image: © Fraunhofer ISE

Our Services for the Industry

Technology Evaluation from Processing to Testing and Certification

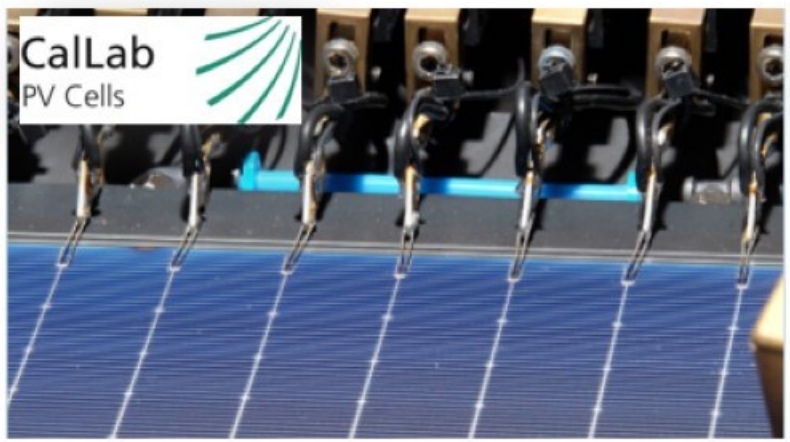
Technological Evaluation Centers

PV-TEC Front-End

PV-TEC Back-End

Module-TEC

Accredited Laboratories



CalLab
PV Cells

CalLab
PV Modules

TestLab
PV Modules

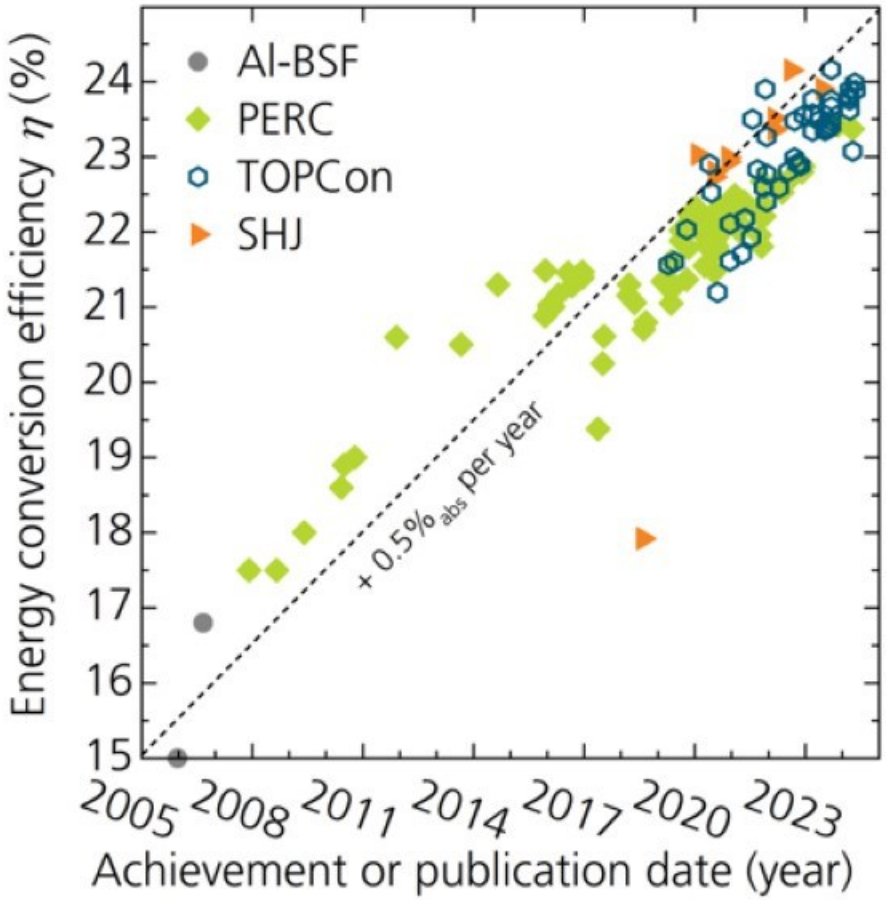
Fraunhofer
ISE

Fraunhofer ISE - Photovoltaic Technology Evaluation Center (PV-TEC)

Pilot-line Production of Mainstream Industrial Solar Cells

PV-TEC Front-End

PV-TEC Back-End

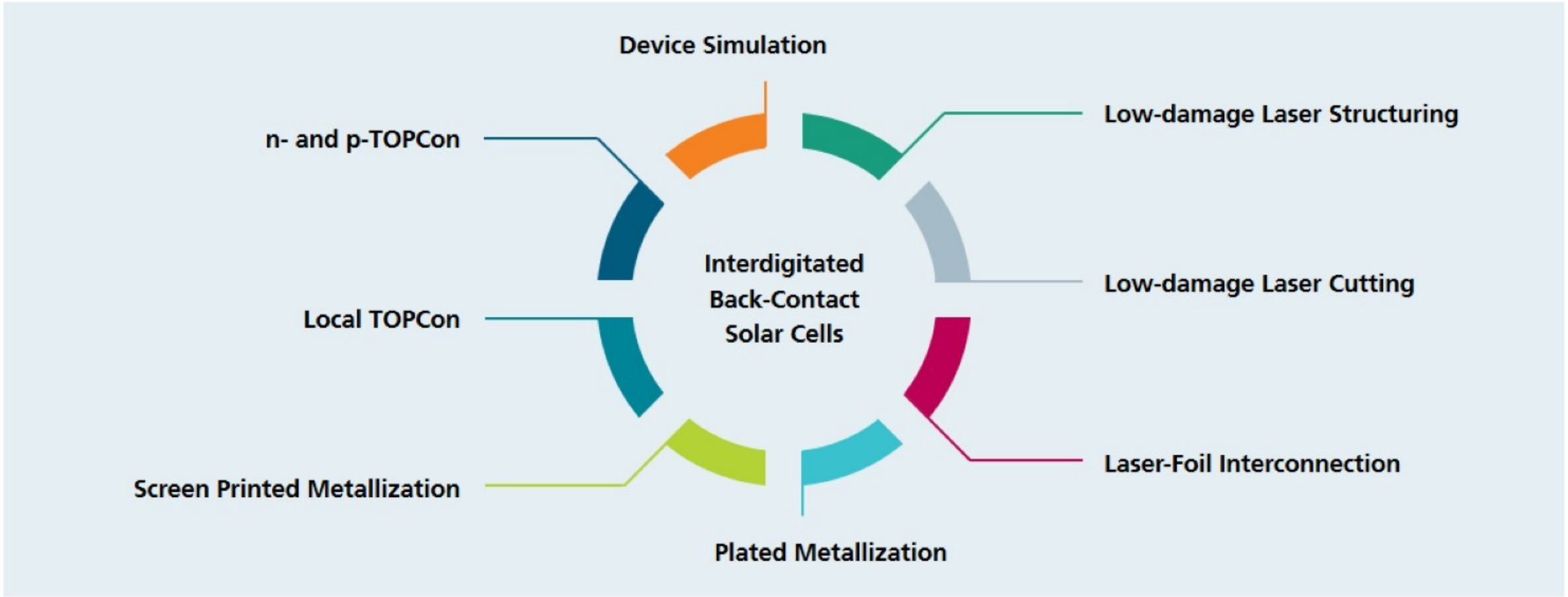


Source: Updated from R. Preu, 8th WCPEC, Milano, 2022

Fraunhofer ISE

Processes Relevant for Back-Contact Cells at Fraunhofer ISE

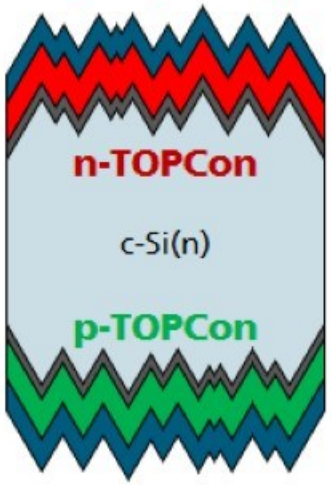
Passivation, Structuring, Metallization and Interconnection



Processes Relevant for Back-Contact Cells at Fraunhofer ISE

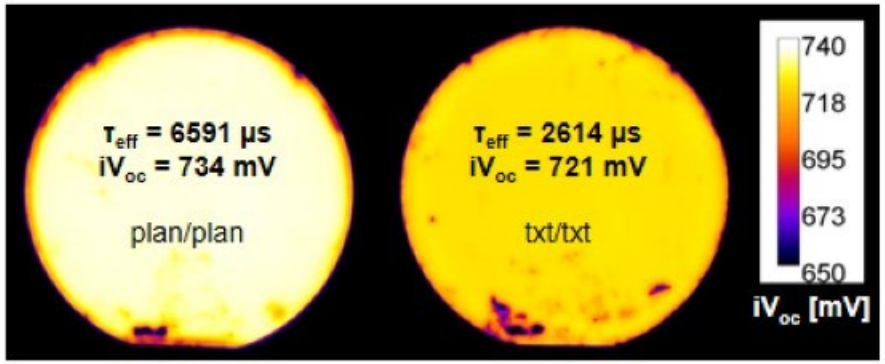
TOPCon Passivation and Local TOPCon

High-quality Passivation by PECVD p-TOPCon [1, 2]



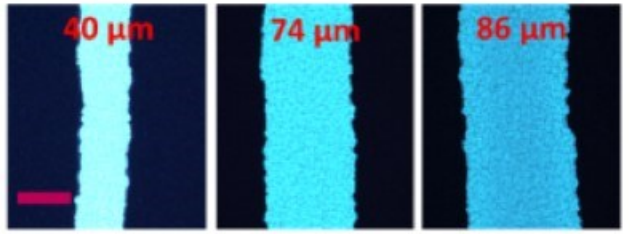
n-TOPCon on txt:
5.0 fA/cm²

p-TOPCon on txt:
9.8 fA/cm²

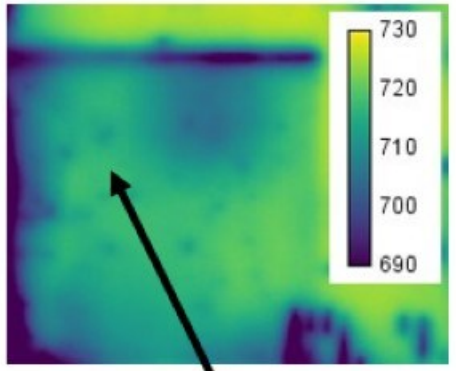


Local p-TOPCon by Dopant Ink Printing [3, 4]

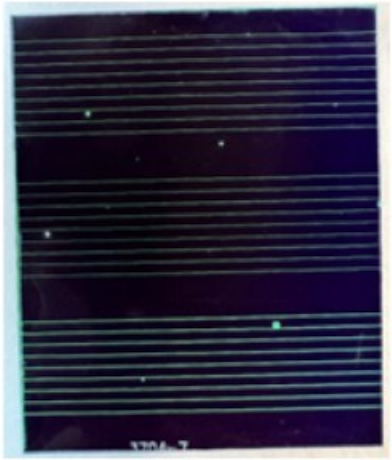
Printed dopant ink lines



PL of Local TOPCon



Local p-TOPCon
~716 mV



Local p-TOPCon lines after etching

[1] A. Damm *et al.*, SiliconPV 2024.
[2] M. Bories *et al.*, SiliconPV 2024.
[3] H. Nasser *et al.*, SiliconPV 2024.
[4] B. Uygun *et al.*, EUPVSEC 2024.

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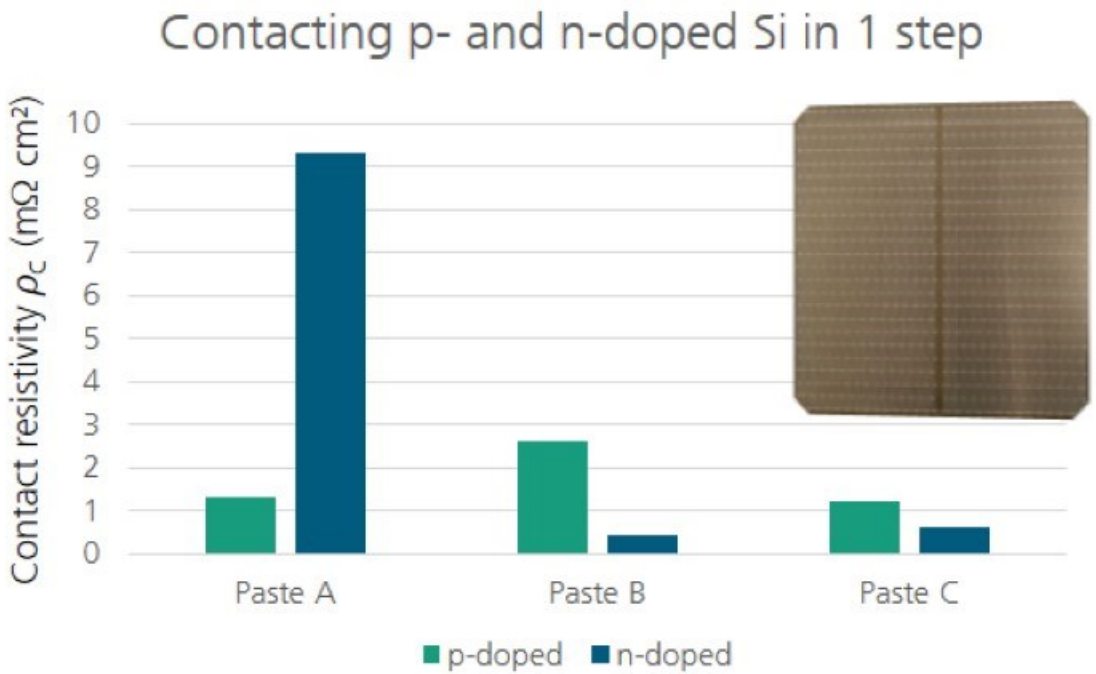
Processes Relevant for Back-Contact Cells at Fraunhofer ISE

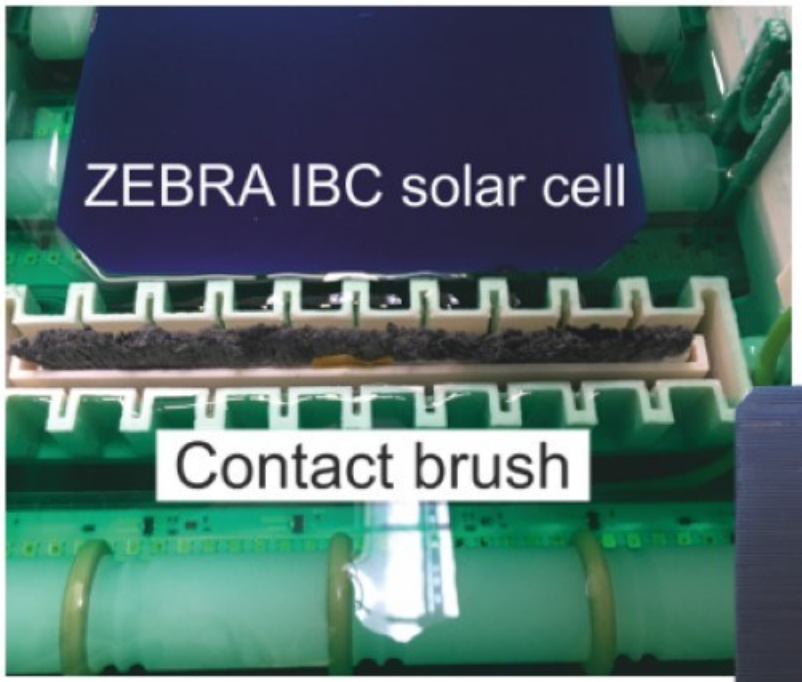
Screen Printed and Plated Metallization

Screen printed Metallization for IBC [1, 2]



Analysis of unipolar metallization using a single screen printing step

Mask-less Plating for IBC [3, 4]



Adjusted plating setup for single-side contacting and mask-less plating

M2-size ZEBRA-IBC with plated Cu-metallization

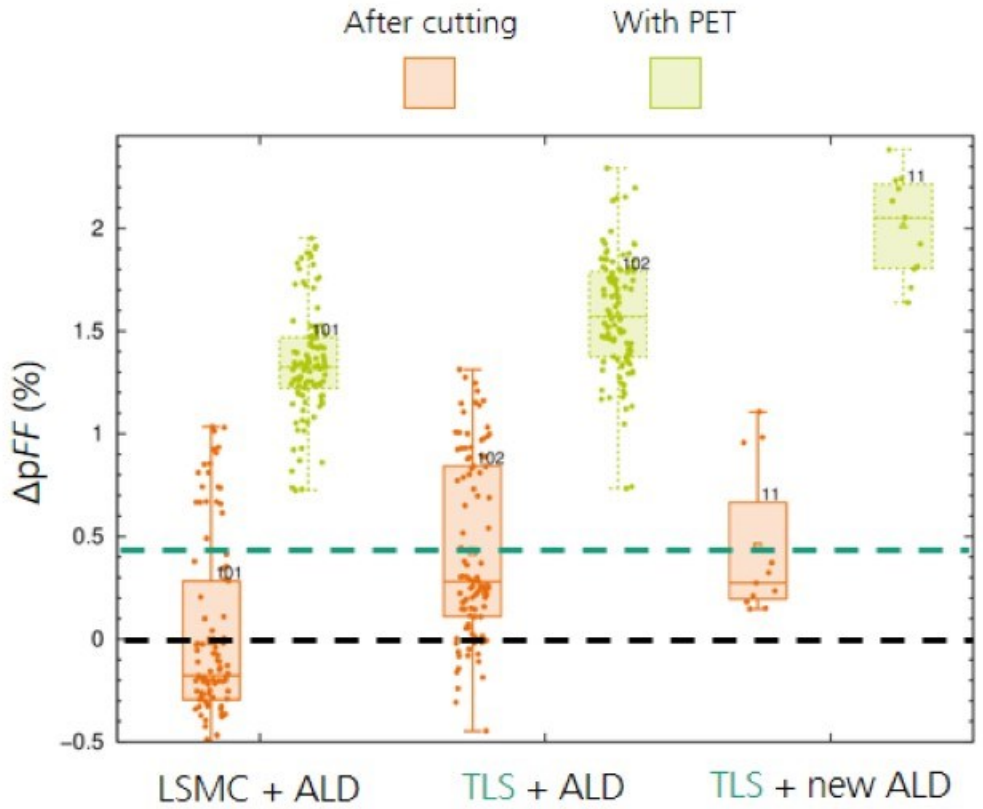
[1] J. D. Huyeng, PhD thesis, 2021.
[2] J. D. Huyeng *et al.*, BCworkshop 2022.
[3] K. Gensowski *et al.*, Metallization Workshop, 2019.
[4] Project "5ct", final report, 2019.

Fraunhofer ISE

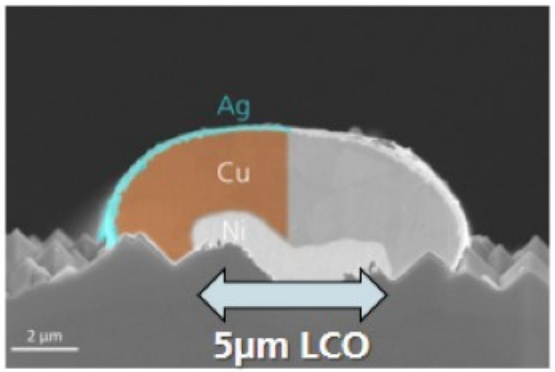
Processes Relevant for Back-Contact Cells at Fraunhofer ISE

Low-damage Cutting and Laser Structuring

Low-damage Cutting and Edge Passivation [1, 2]

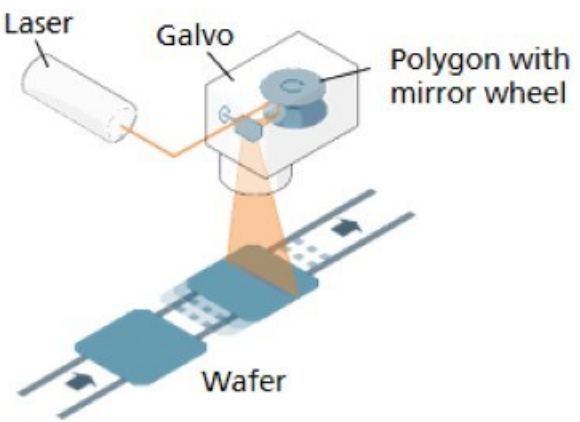


Low-damage Laser Structuring [3, 4]



Super small …
(< 10 µm)

… and super fast
(> 5,000,000 / s
„ on the fly“)



[1] E. Lohmüller *et al.*, PiP, 2023.
[2] J. D. Huyeng *et al.*, IEEE PVSC 2024.
[3] C. Schmiga *et al.*, EUPVSEC 2024.
[4] https://ise.link/laser-otf

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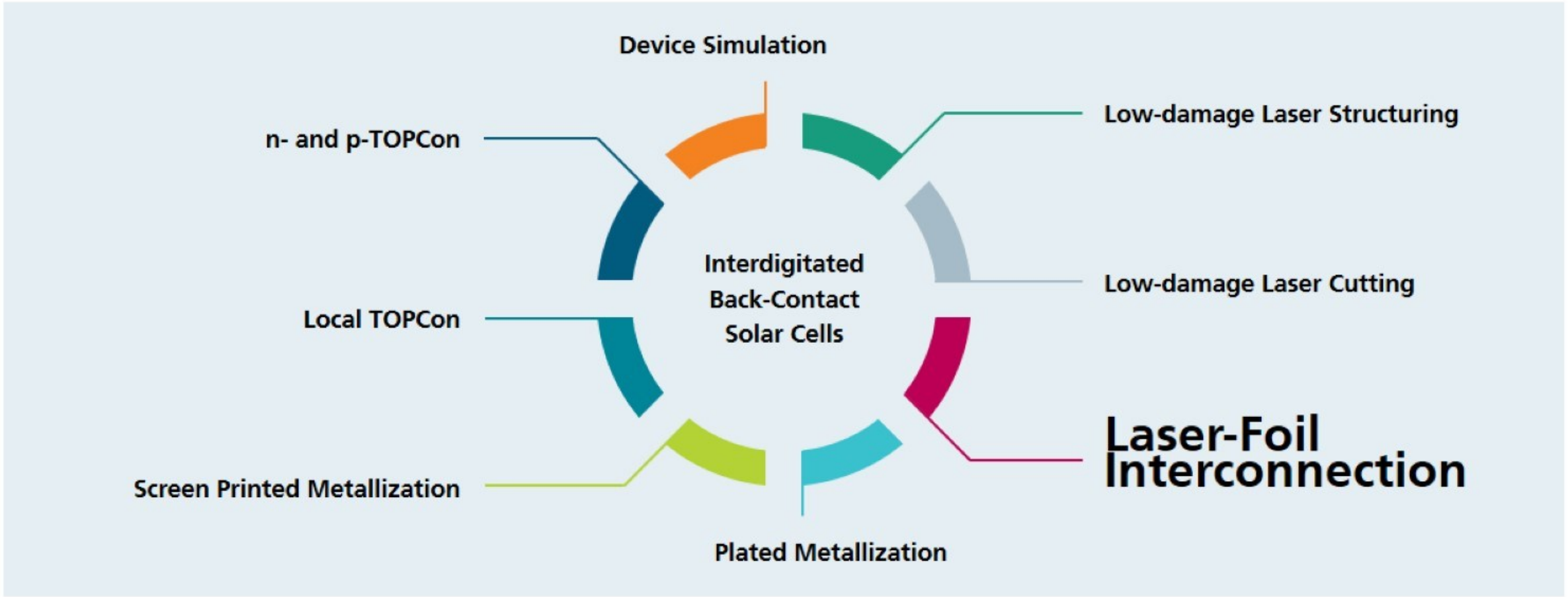
Processes Relevant for Back-Contact Cells at Fraunhofer ISE

Passivation, Structuring, Metallization and Interconnection



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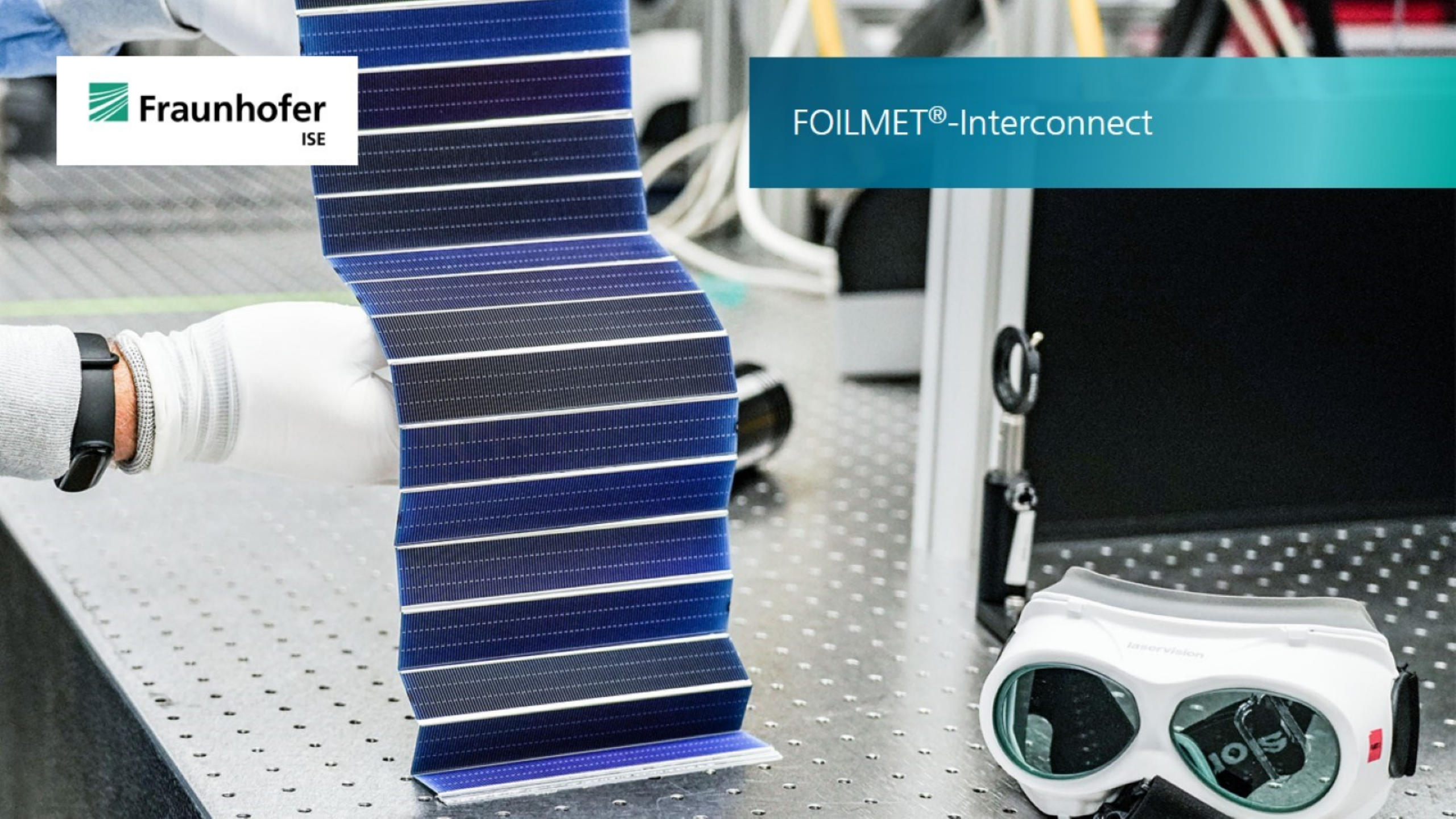
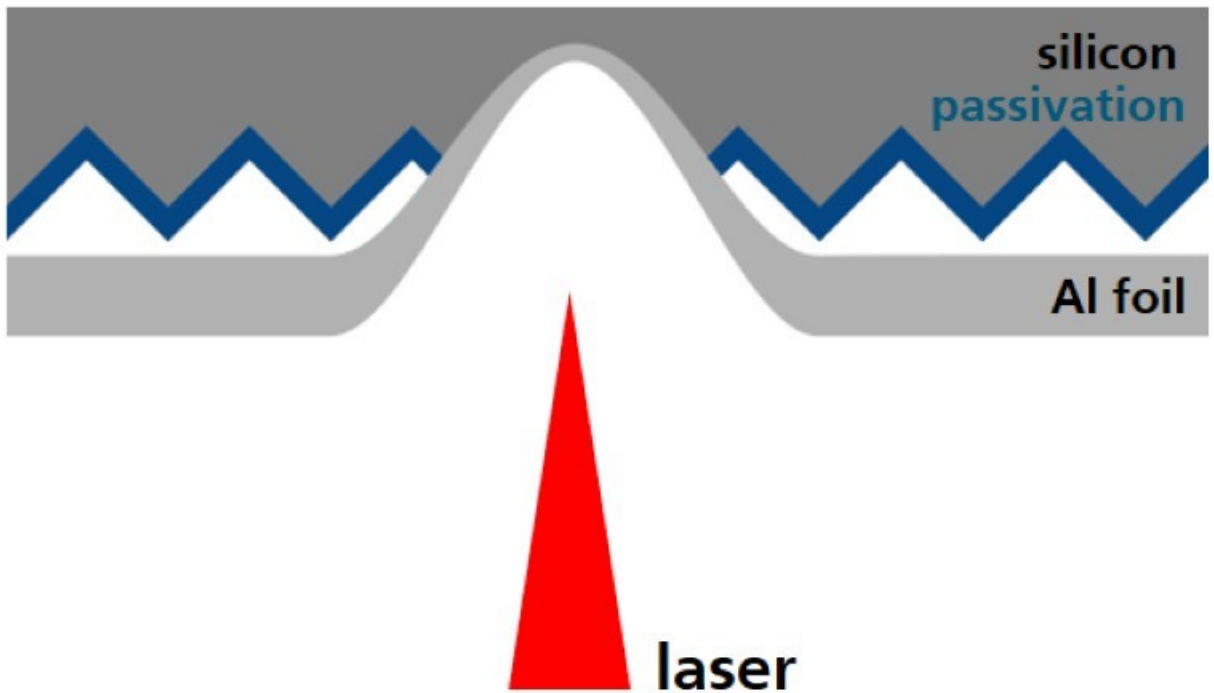
FOILMET®-Interconnect



Laser Joining Processes for Aluminum Foil

Laser Fired Contacts (LFC)

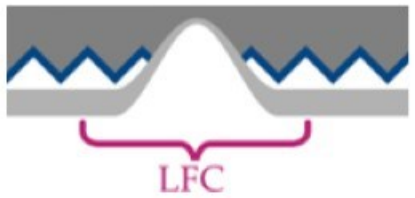


[2], [3]

[2] J.-F. Nekarda, A. Grohe, O. Schultz, and R. Preu, "Aluminum foil as back side metallization for LFC cells," in 22nd EUPVSEC Milano, Italy, 2007, pp. 1499–1501.
[3] M. Graf et. al. "Foil metallization process for PERC solar cells towards industrial feasibility" in 30th EUPVSEC Hamburg, Germany, 2015

Laser Joining Processes for Aluminum Foil

Laser Fired Contacts (LFC)

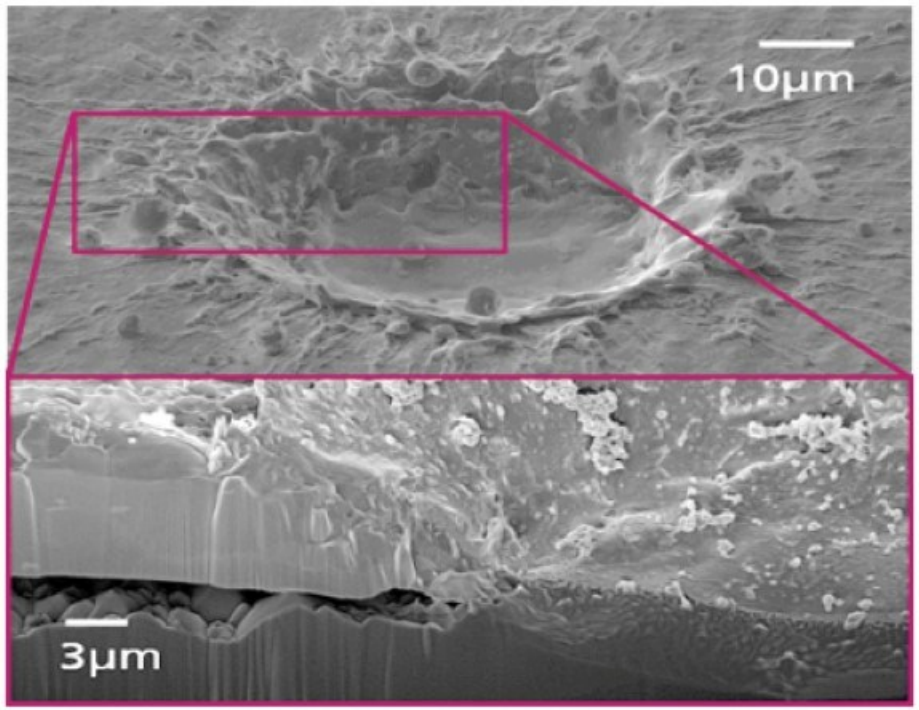


Properties of LFC

- Good electrical performance
- Good module stability

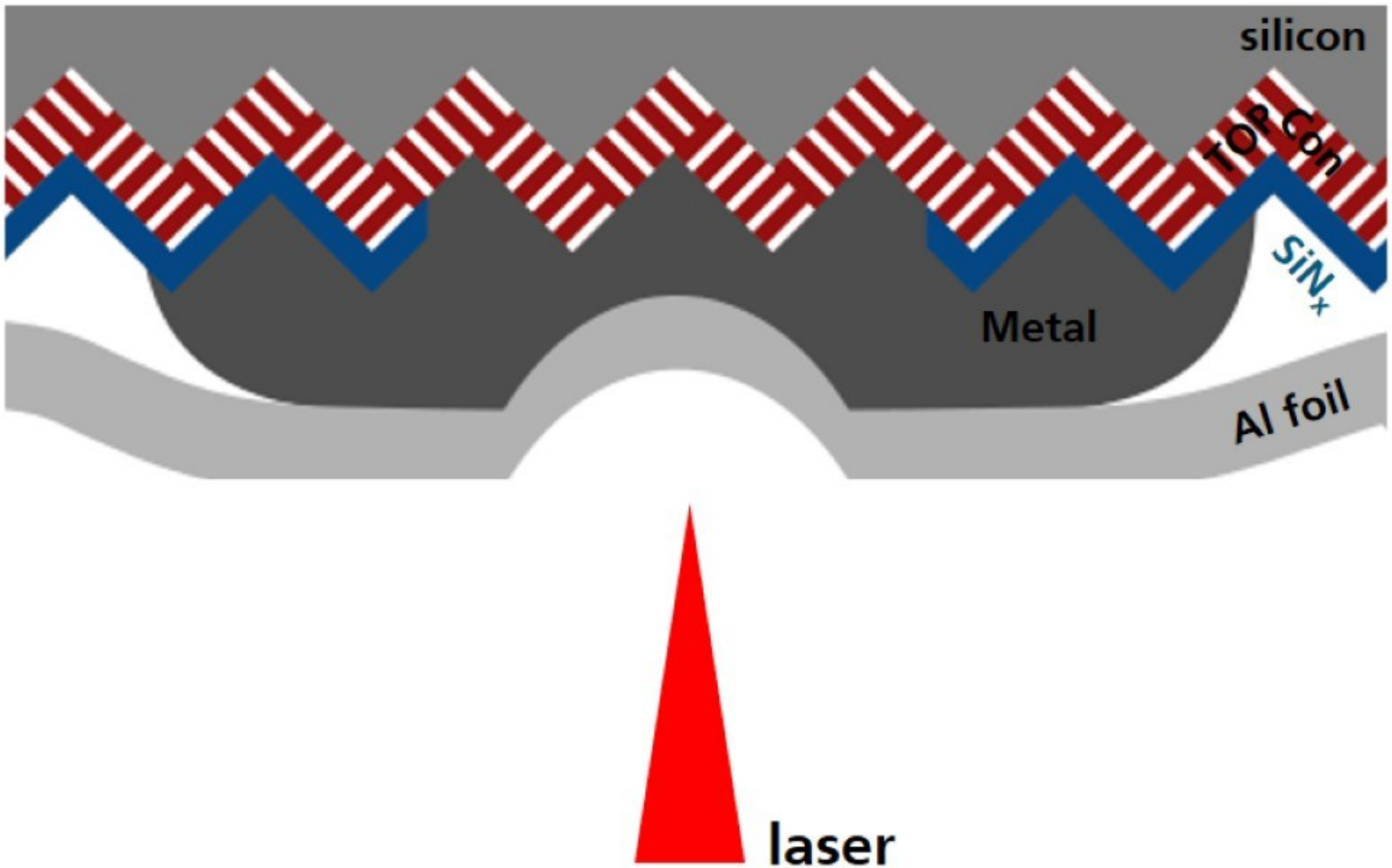
- Okay mechanical adhesion

- High negative impact on V_{OC}



Laser Joining Processes for Aluminum Foil

Laser Metal Welding (LMW)



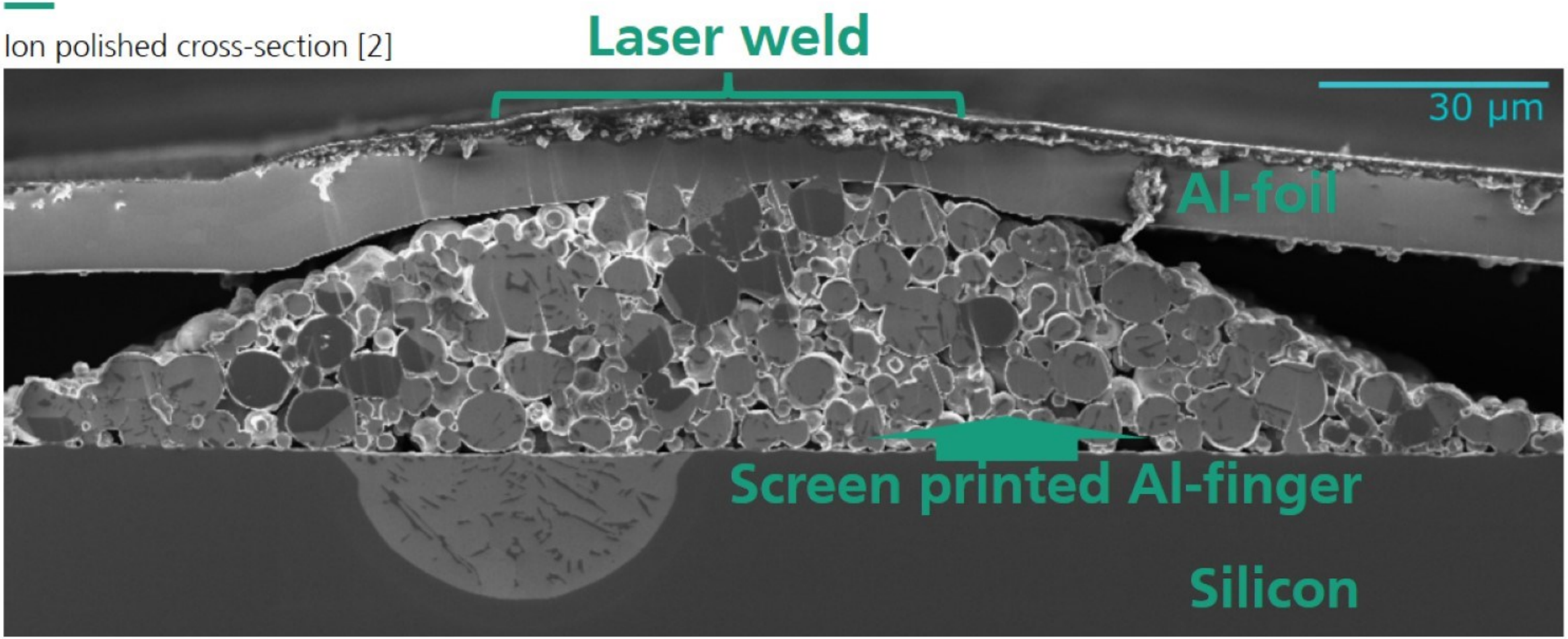
[4], [5]

[4]: J. Paschen, G. Emanuel, A. Brand, T. Fellmeth, O. John, A. DeRose, J. Nekarda "FoilMet-Connect: a new rear metallization Upgrade for PERC and other Cell concepts" in 34th EUPVSEC Marseille, France, 2019. https://doi.org/10.1063/1.5125869:
[5]: J. Paschen, "FoilMet® -Interconnect", 2021 https://doi.org/10.1002/pip.3470

Investigation of Welding Sites

Al-Al Weld

Ion polished cross-section [2]

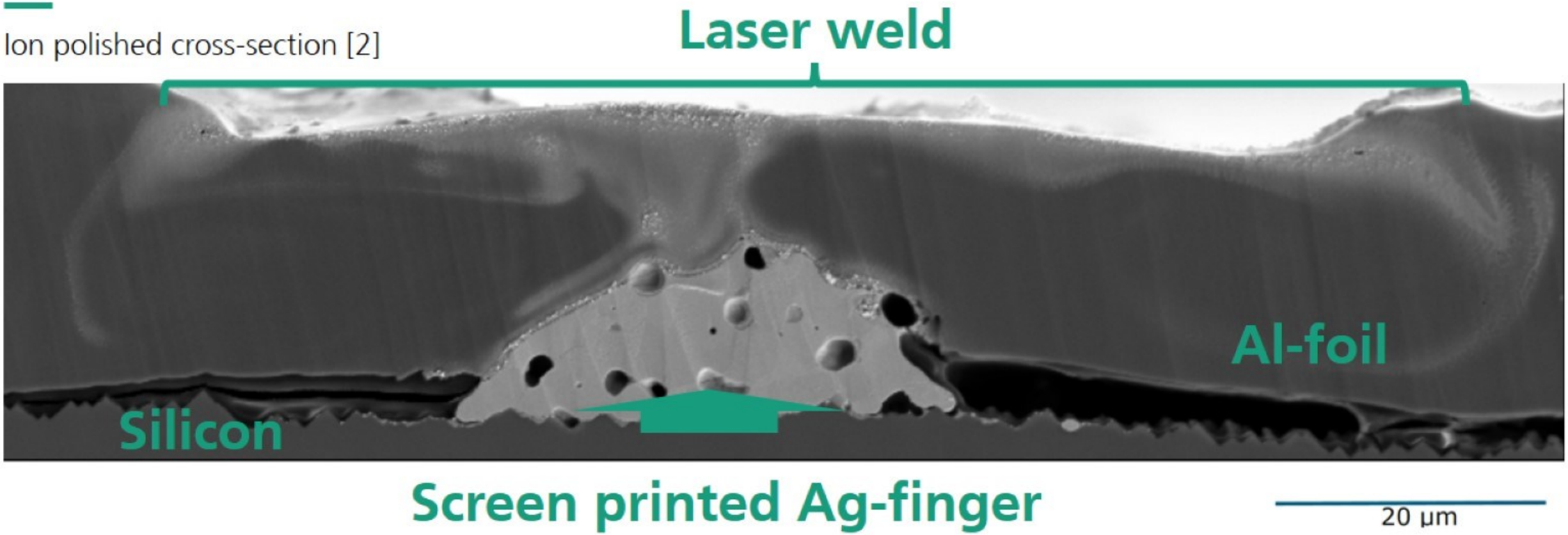


[2] PhD Jan Paschen: "New concepts for solar cell interconnection using laser joining of thin aluminum foil"; tbp

Investigation of Welding Sites

Al-Ag Weld

Ion polished cross-section [2]

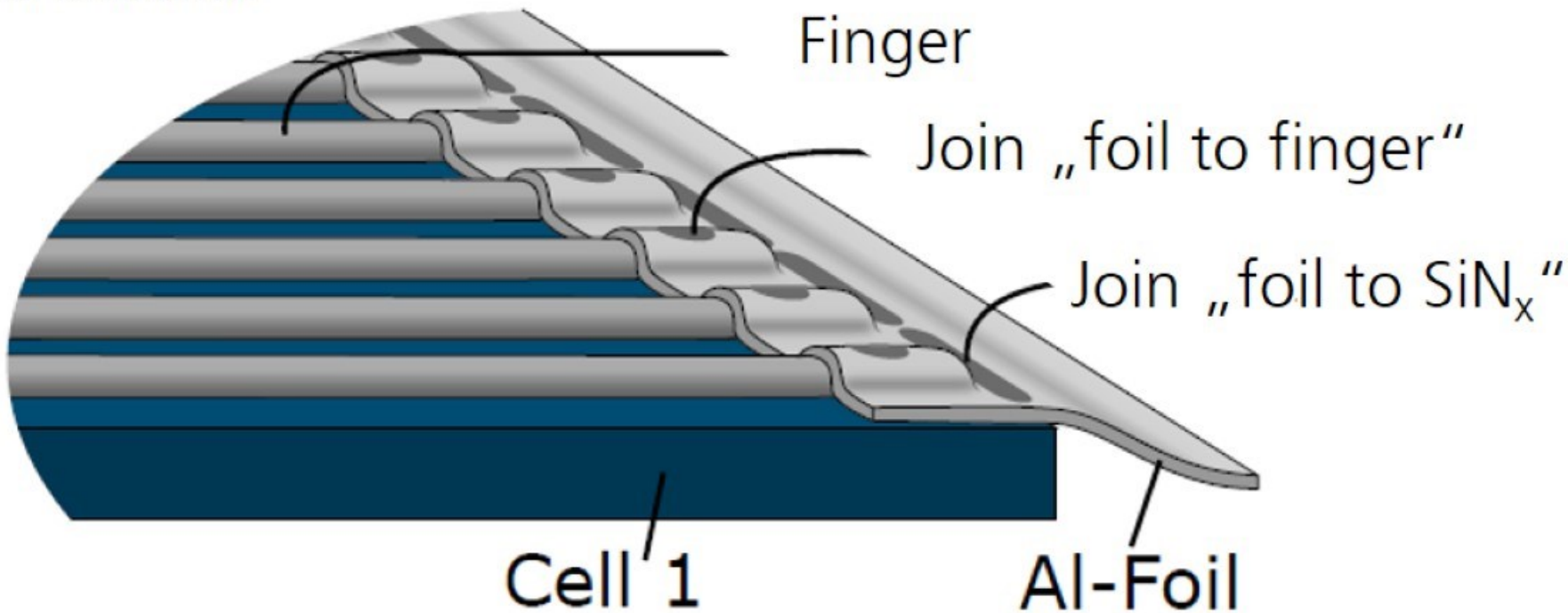


[2] PhD Jan Paschen: "New concepts for solar cell interconnection using laser joining of thin aluminum foil"; tbp

Introduction "FOILMET®-Interconnect"

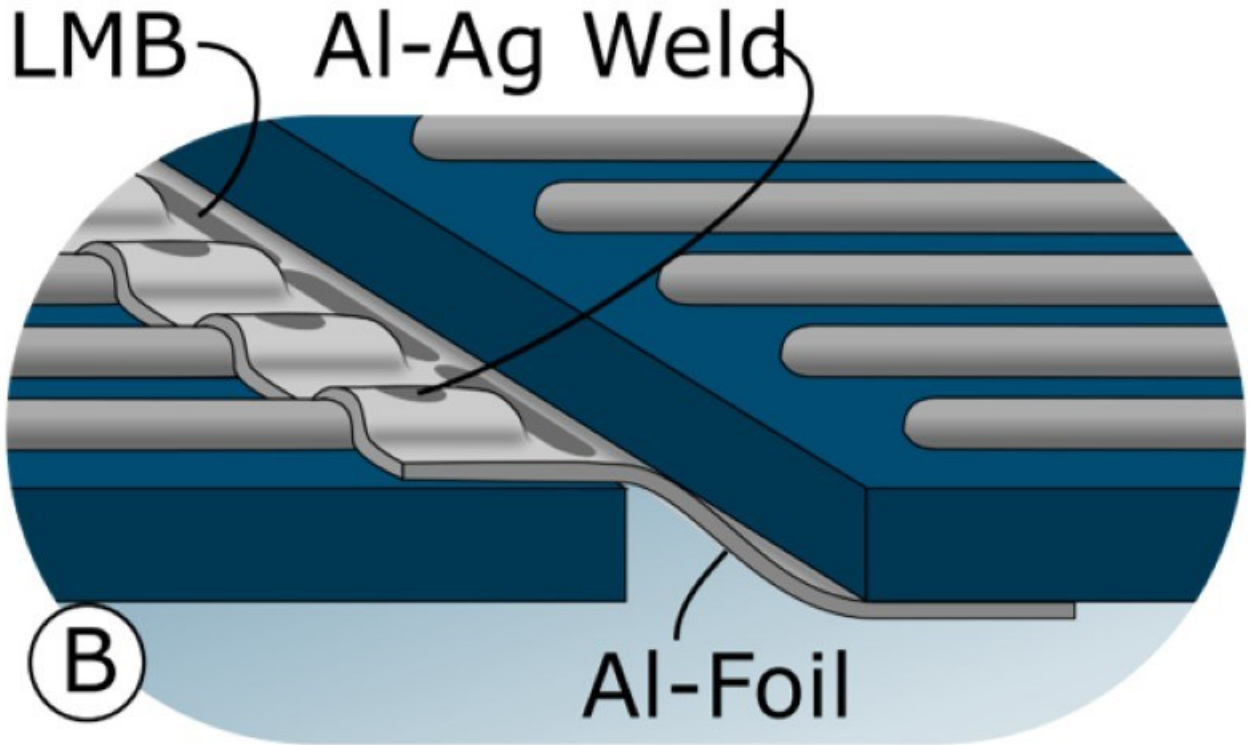
Principle

- Edge-interconnection → cut cell
- Aluminum foil (~ 10 µm)
- Laser joining → mechanical & electrical contacts



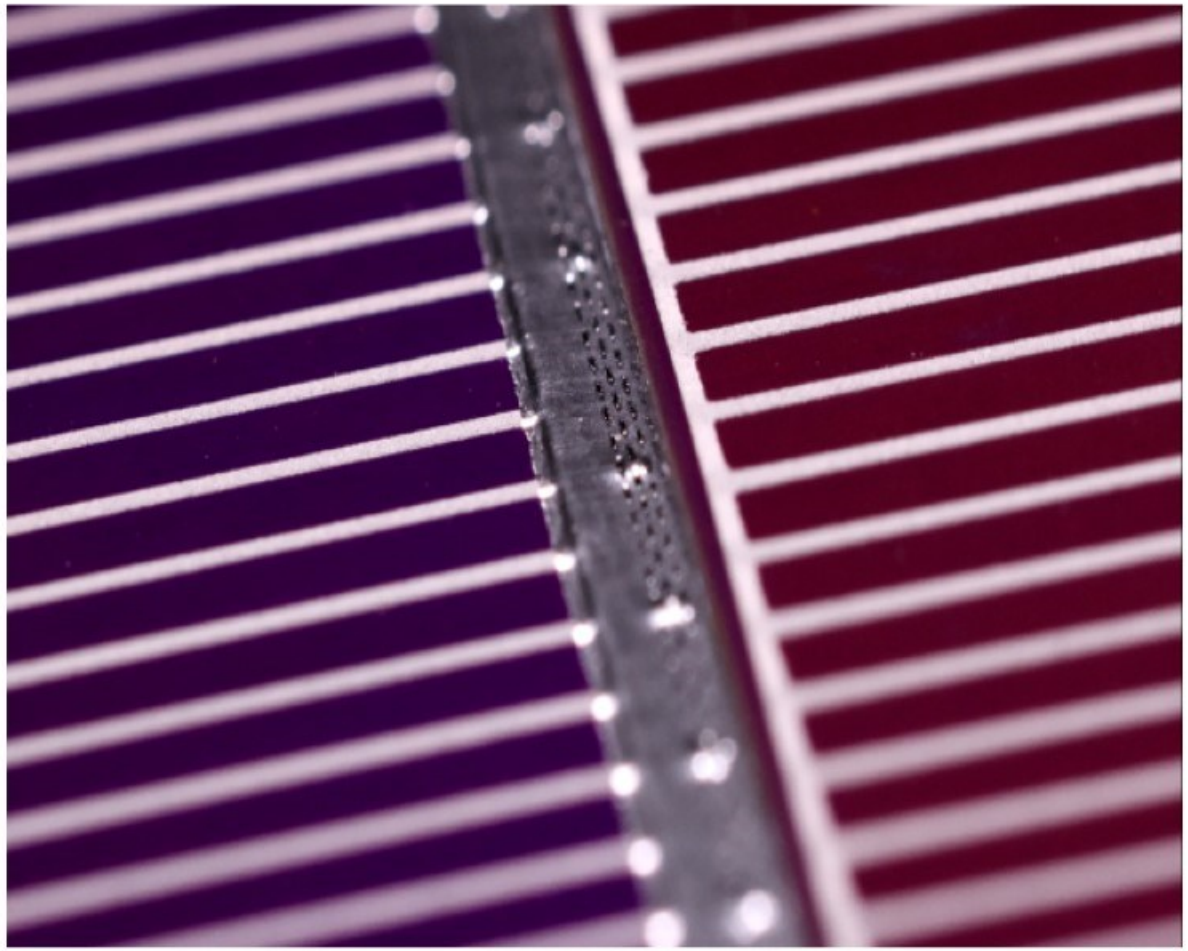
Introduction “FOILMET®-Interconnect”

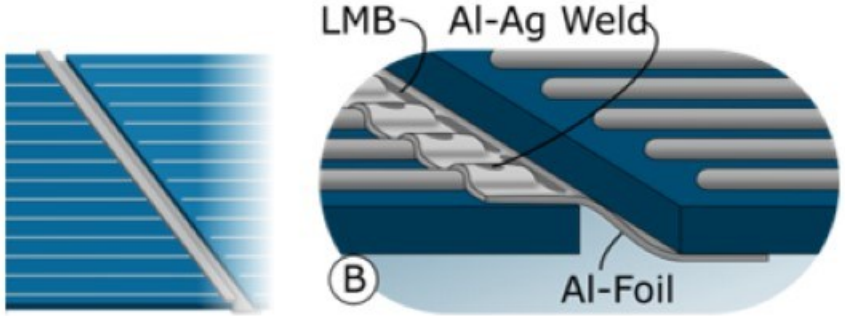
Applications



Introduction “FOILMET®-Interconnect”

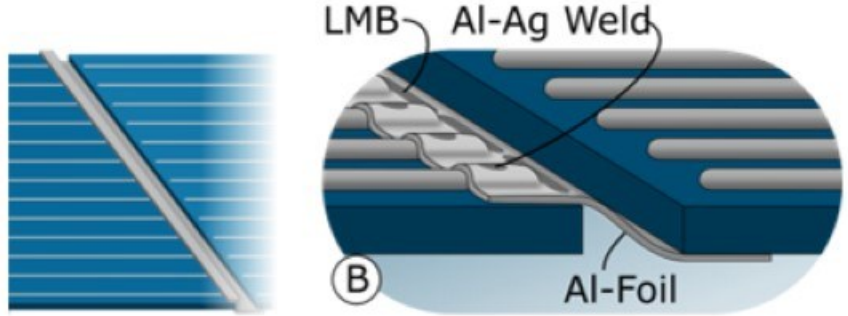
Example

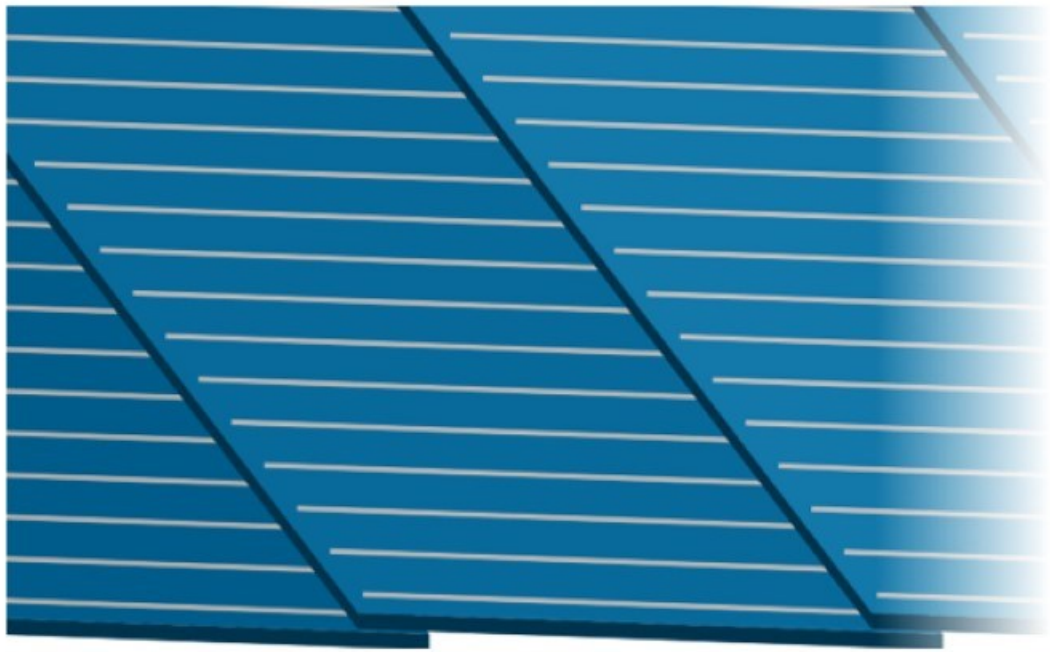


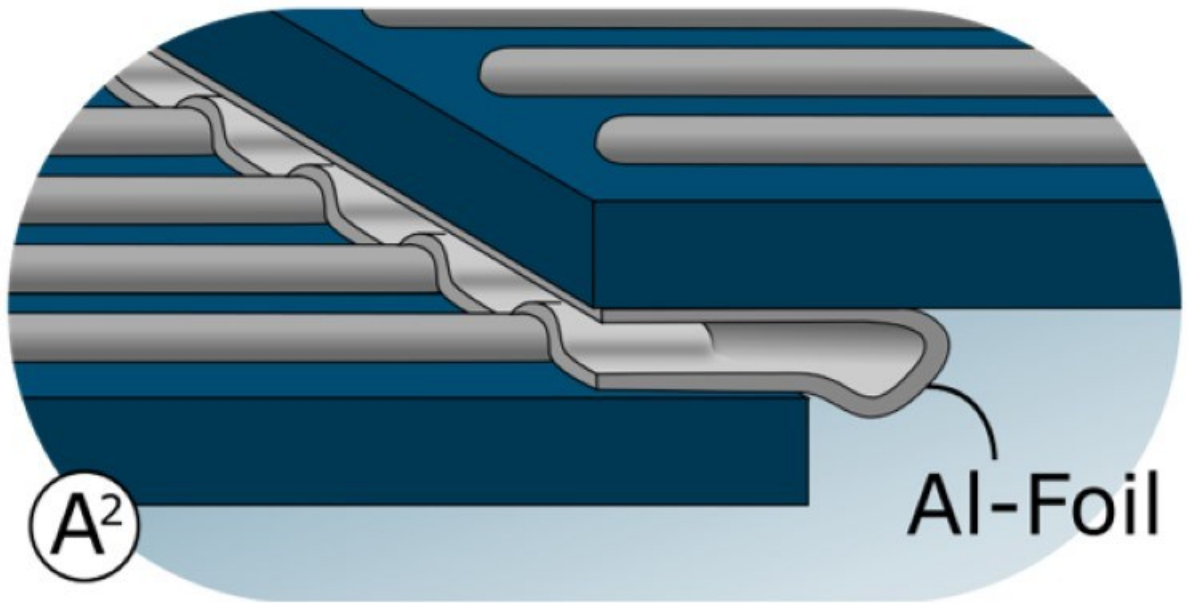


Introduction “FOILMET®-Interconnect”

Combination with Shingling

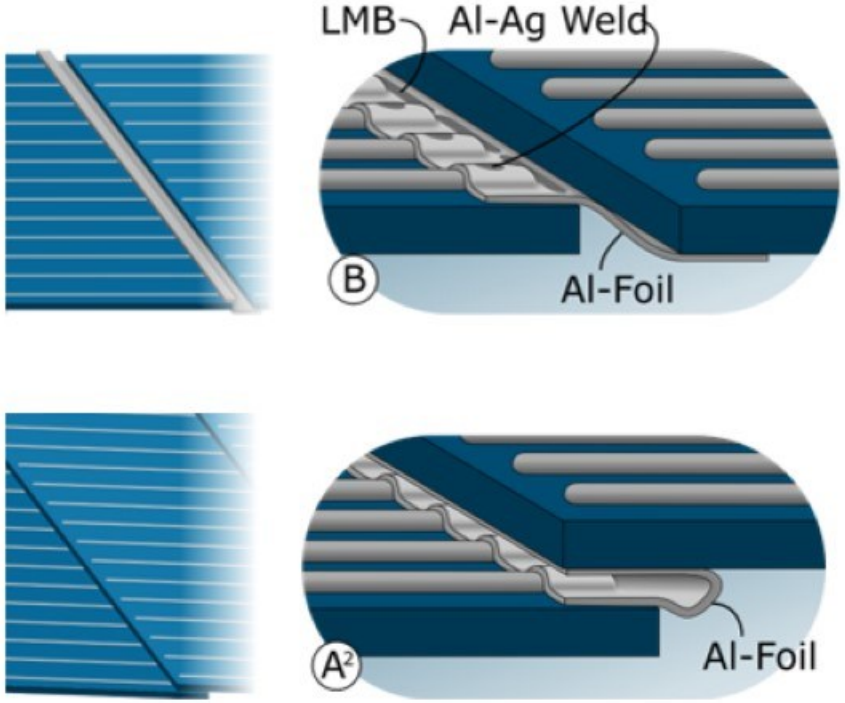






Introduction “FOILMET®-Interconnect”

Shingling Example

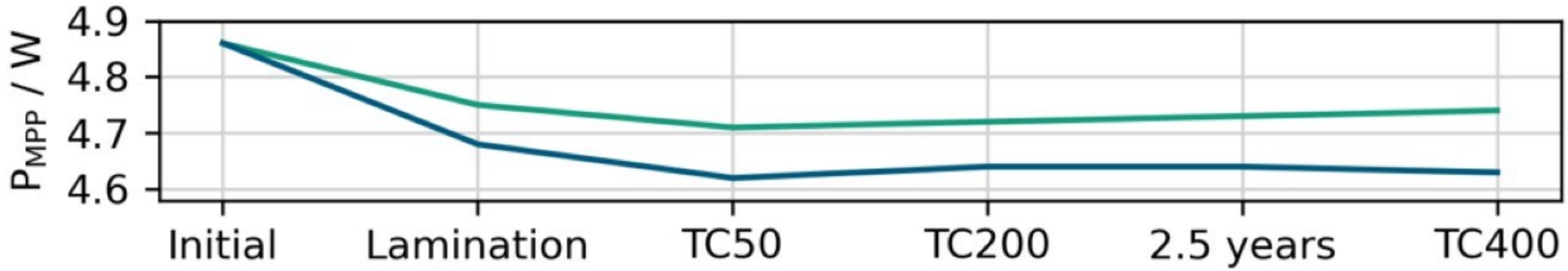


Introduction “FOILMET®-Interconnect”

Practical Adhesion Test

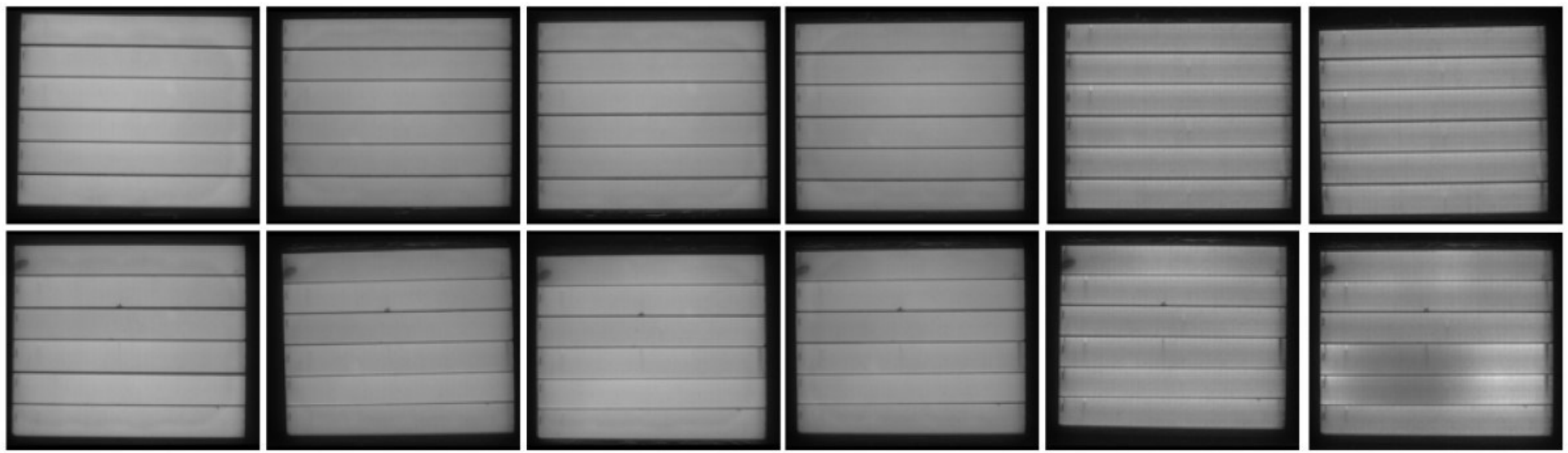
Temperature Cycle Results

Electroluminescence (EL) and Peak Power P_{mpp}



String 1

String 2



[1] Paschen et al. PIP, 2021.

Fraunhofer ISE

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FoilMet meets MWT

FoilMet meets MWT – High Voltages by Simplified Series Interconnection

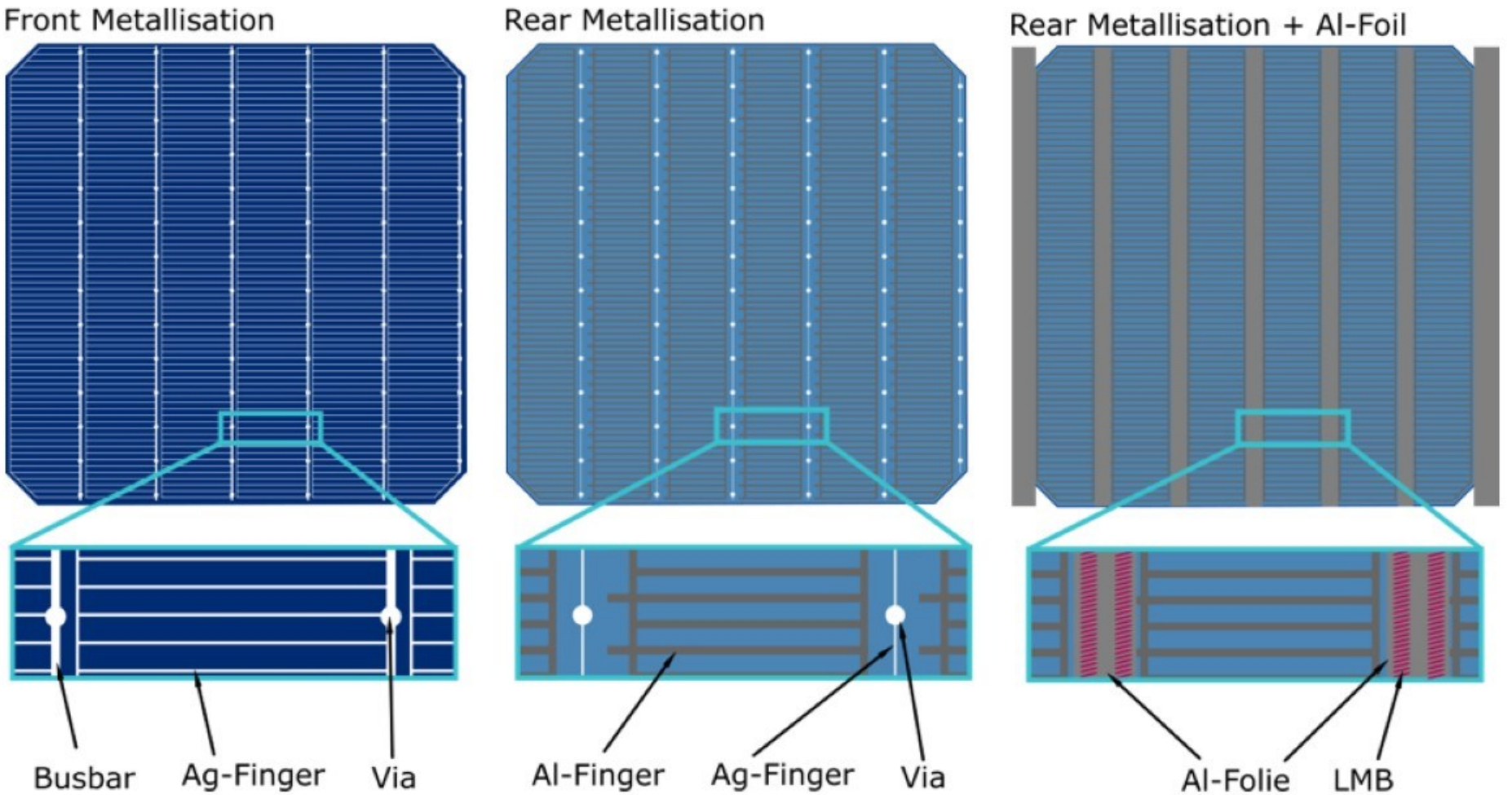
Screen Print Layout

Front
- Finger
- Busbar
- Via

Rear
- Finger
- Via

Al-Folie
- LMB on p-electrode
- LMB on n-electrode
- Cut foil

TLS cell
- No handling of individual sub cells



Fraunhofer ISE

FoilMet meets MWT – High Voltages by Simplified Series Interconnection

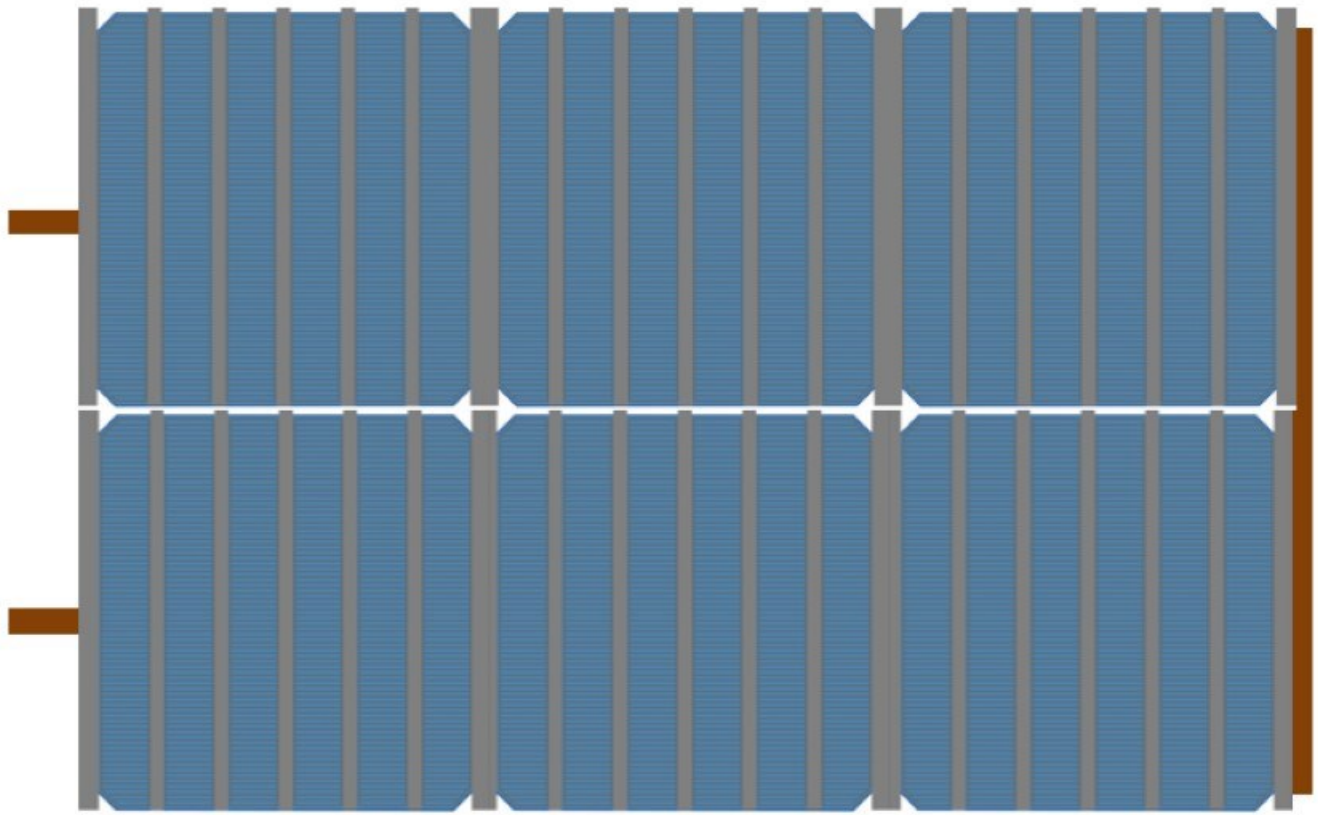
Reduced Handling

Front
- Finger
- Busbar
- Via

Rear
- Finger
- Via

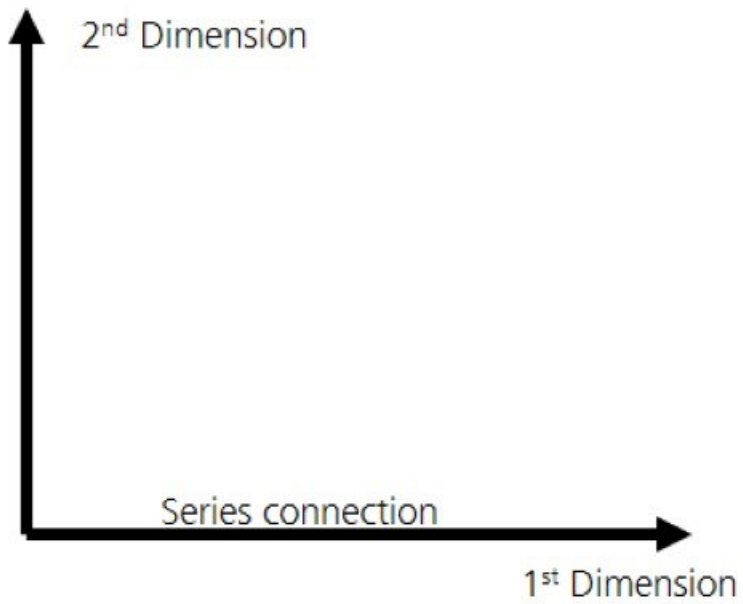
Al-Folie
- LMB on p-electrode
- LMB on n-electrode
- Cut foil

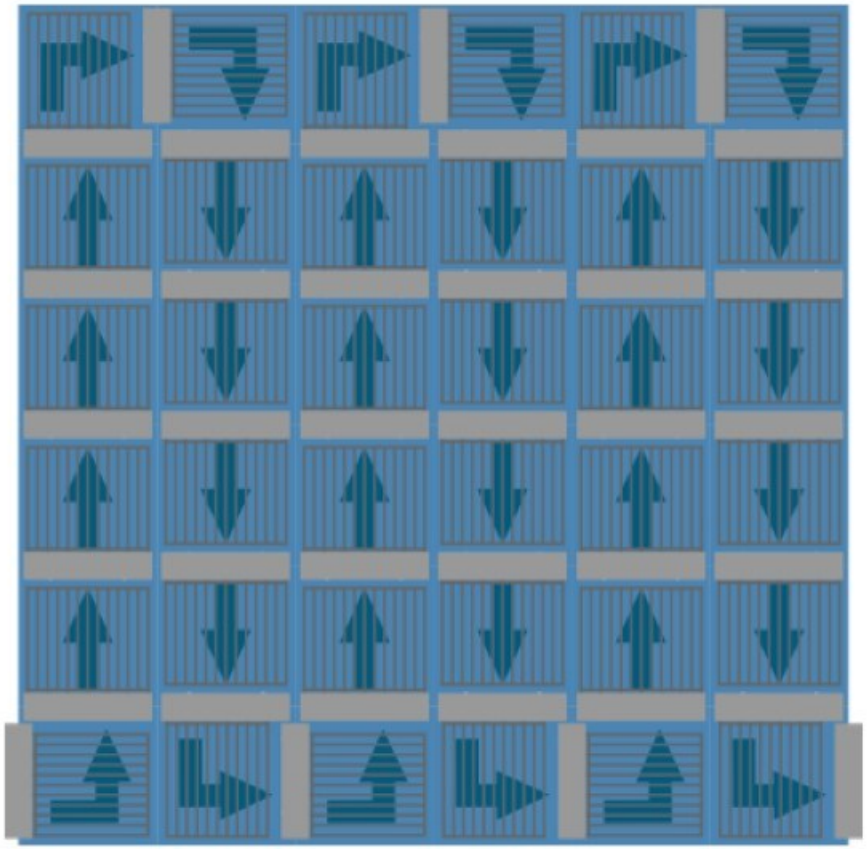
TLS cell
- No handling of individual subcells
- Laser multiple cells at once
- Including terminals



FoilMet meets MWT – High Voltages by Simplified Series Interconnection

Maximizing Voltage by Adjusted Cell Design





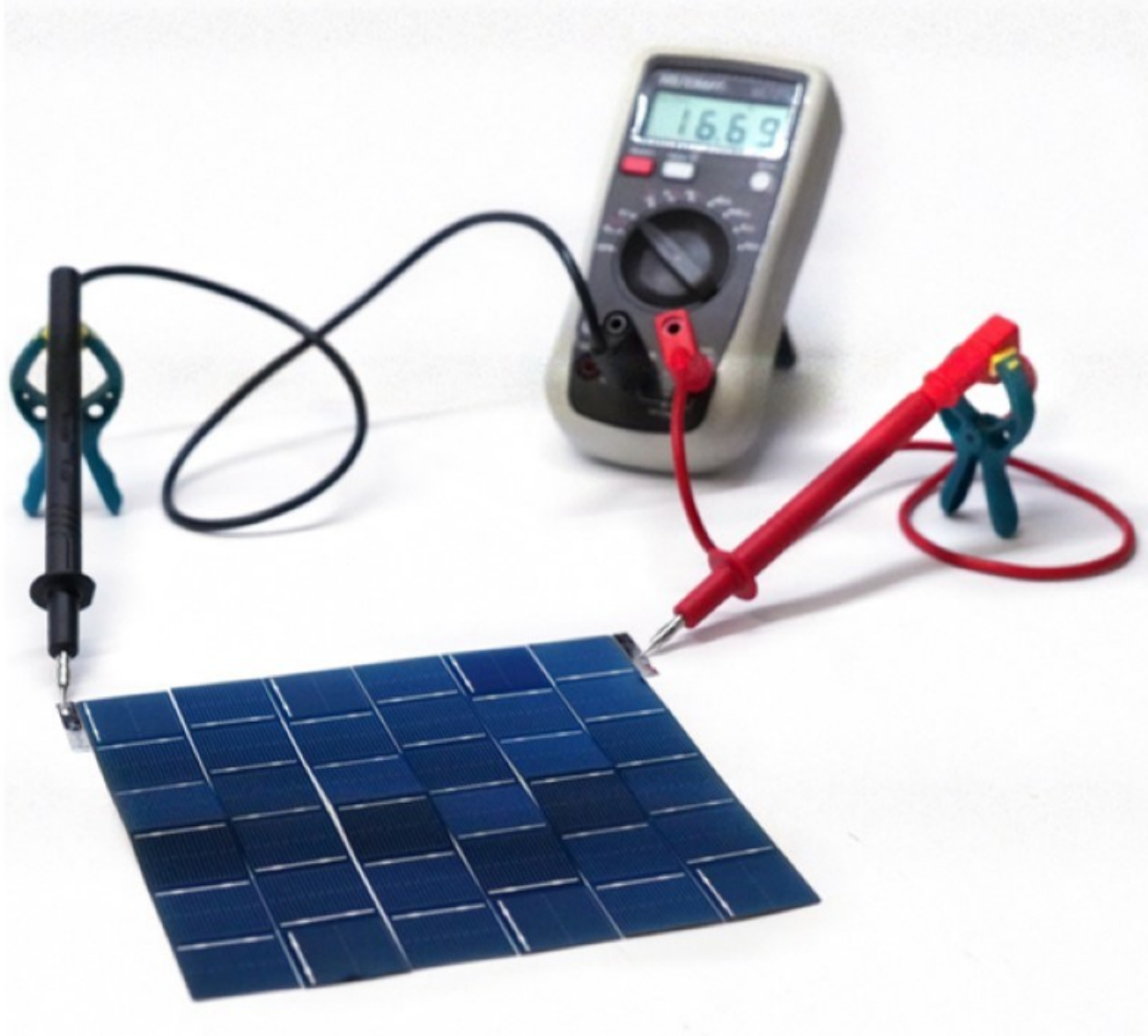
FoilMet „HV Prototype“

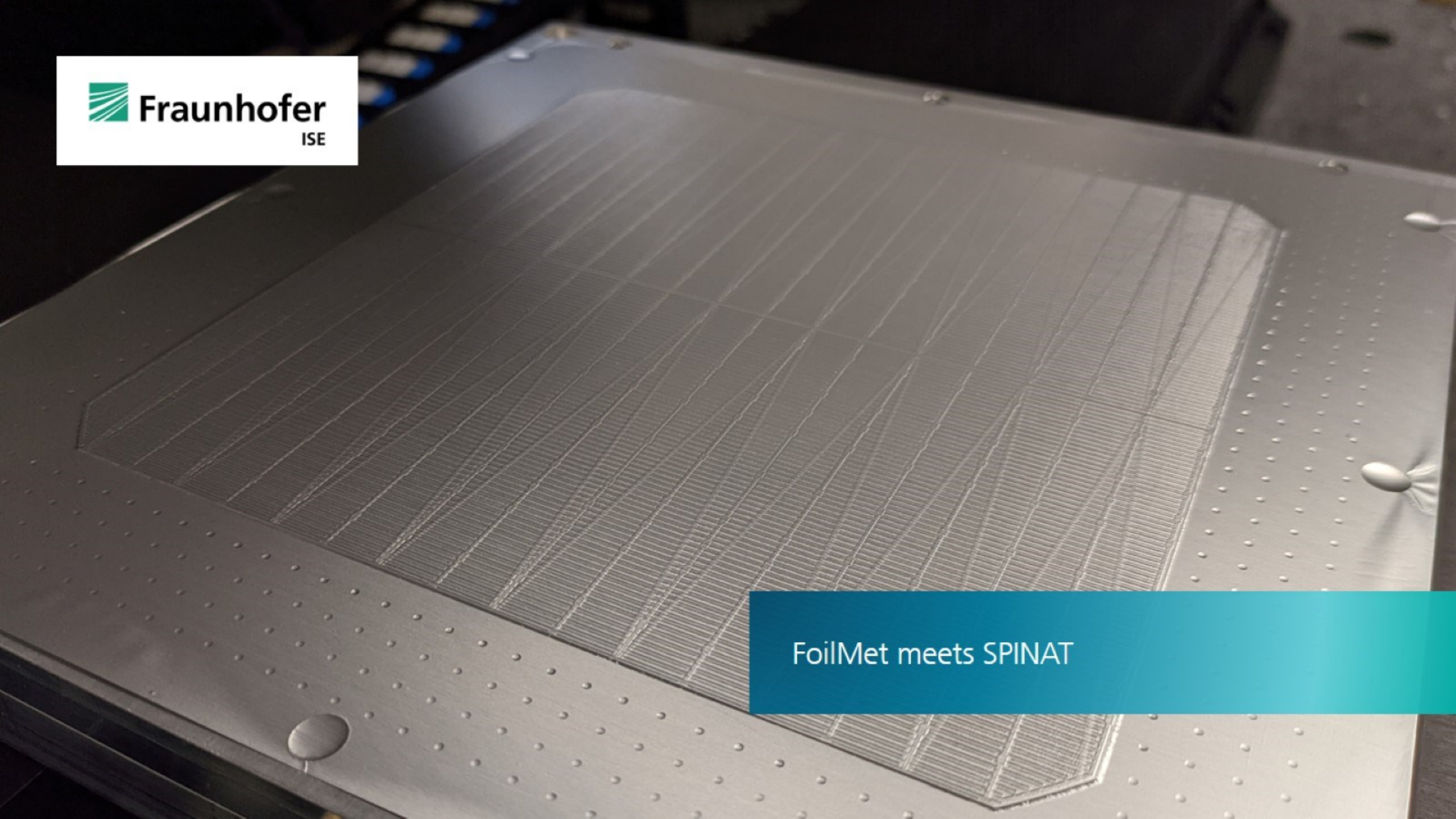
Proof-of-Principle

I-V 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

- **High Voltage from a single wafer**
  - No Handling of small sub cells: Interconnect first, then separate
    → Handling only at host cell level
- **Cost efficient**
  - Reduction of the handling workload, interconnector materials and (manual) pick and place
- **Flexible Foil and Cell Matrix**
  - Can be integrated into custom shaped modules, e.g. curved modules



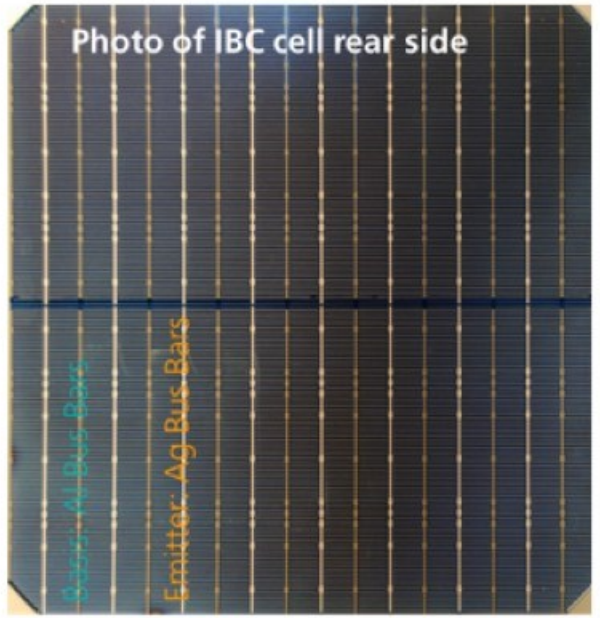

Fraunhofer
ISE
FoilMet meets SPINAT

POPEI and SPINAT: p-IBC meets Foilmet

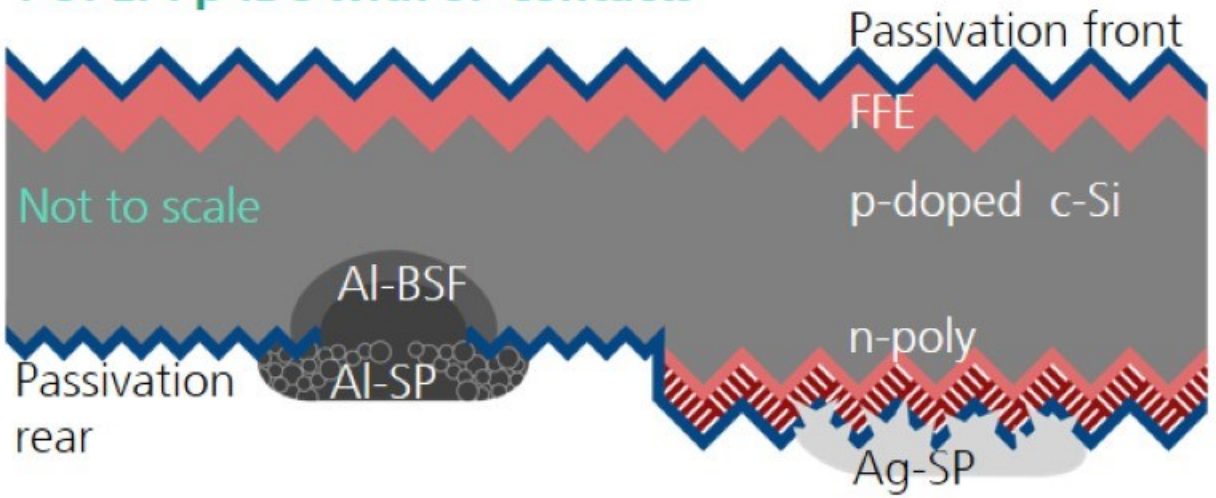
POPEI[1]: Screen printed p-IBC

p-IBC cell:
screen printed Ag & Al contacts

- p-doped Cz-silicon
- Aluminum for base contact (PERC contact)
- Silver fingers for contact to n-poly-Si (TOPCon emitter contact)



POPEI[1]: p-IBC with SP contacts



[1]POPEI: project by BMWK under contract number FKZ 03EE1102

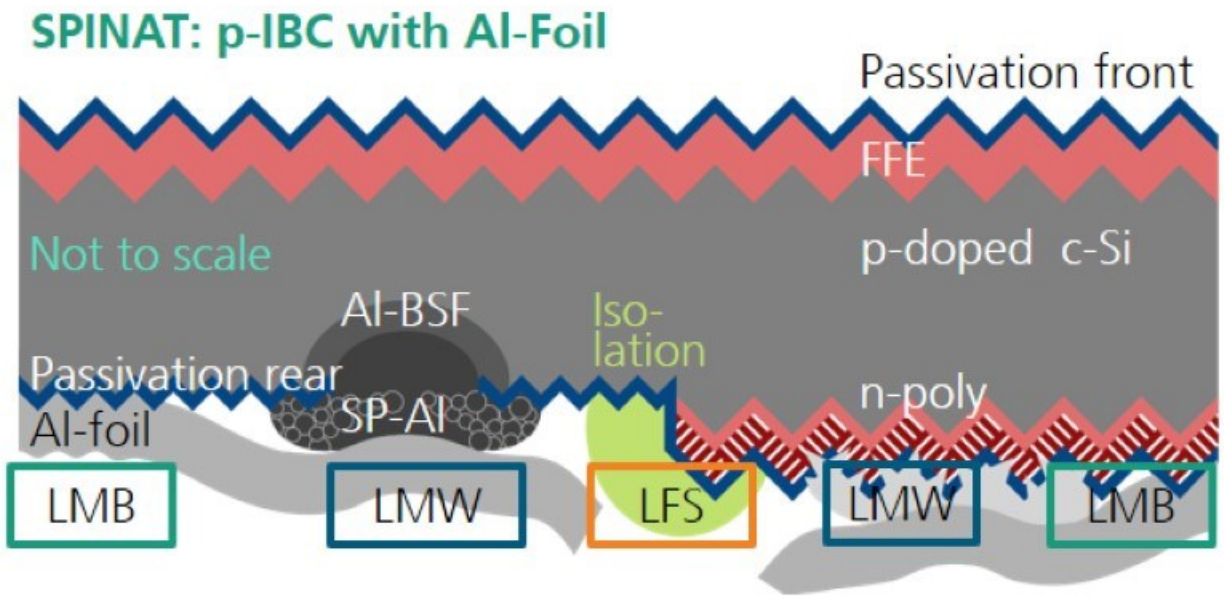
ISC International Solar Energy Research Center Konstanz centrotherm Fraunhofer ISE

POPEI and SPINAT: p-IBC meets Foilmet

SPINAT[1]: Foilmet Interconnection for Al and Ag contacts + bonds for adhesion (+ foil cutting)

Required laser processes - overview

- LMB: Laser-Metal-Bonding
  adhere foil damage free to passivation layer
- LMW: Laser-Metal-Welding (Al-foil to Al-SP)
  connect foil with screen printed Al paste
- LMW: Laser-Metal-Welding (Al-foil to Ag-SP)
  connect foil with screen printed Ag paste
- LFS: Laser-Foil-Separation (separate sheet)
  electrically isolate p- and n-regions



[1]SPINAT: project by BMWK under contract number FKZ 03EE1124

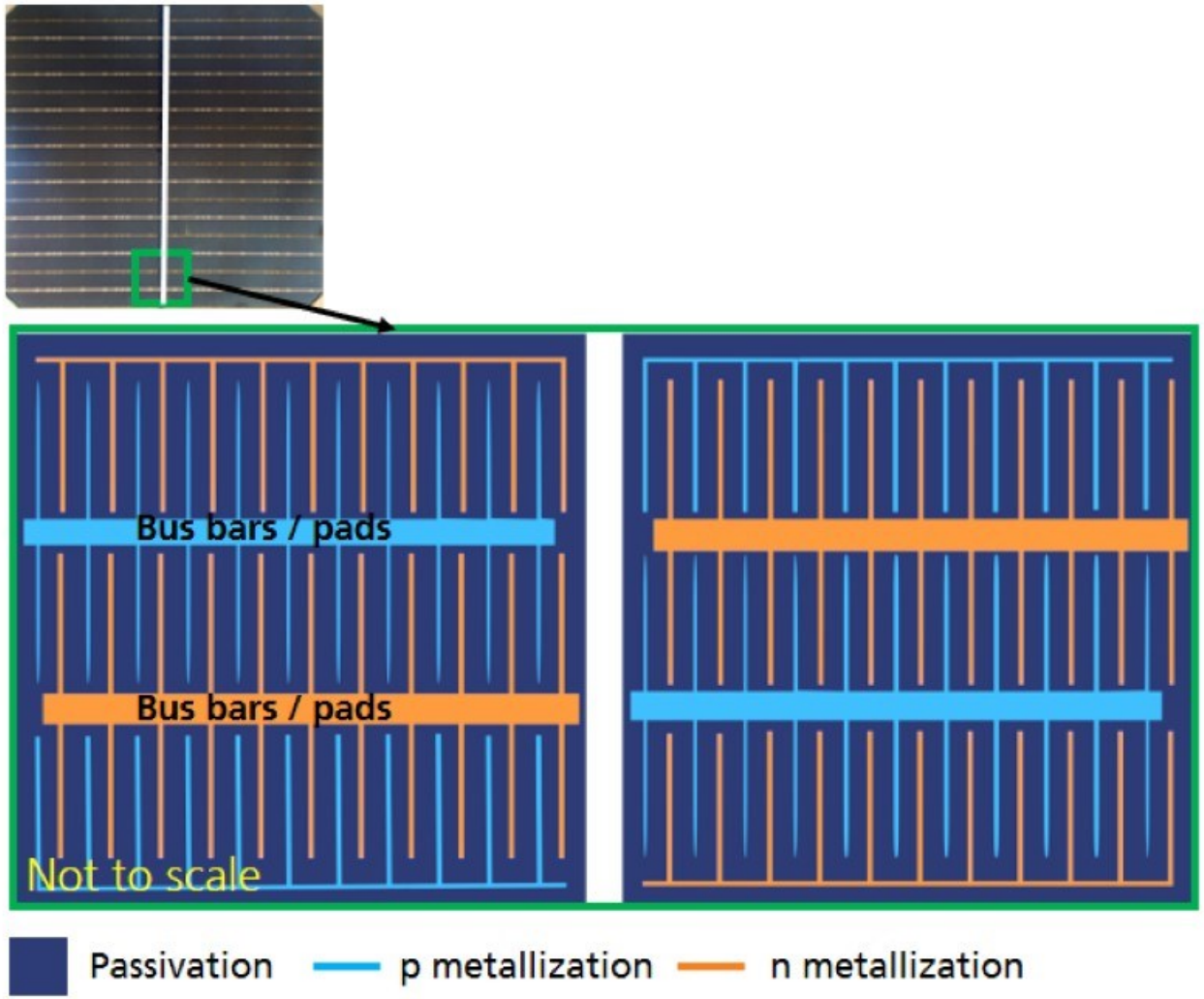
ISC International Solar Energy Research Center Konstanz centrotherm Fraunhofer ISE

POPEI and SPINAT: p-IBC meets Foilmet

Interconnection Concepts by Al foil

Use one sheet of Al-foil for cell connection & interconnection of cells

- From fully screen printed contacts to FoilMet®



[1]SPINAT: project by BMWK under contract number FKZ 03EE1124

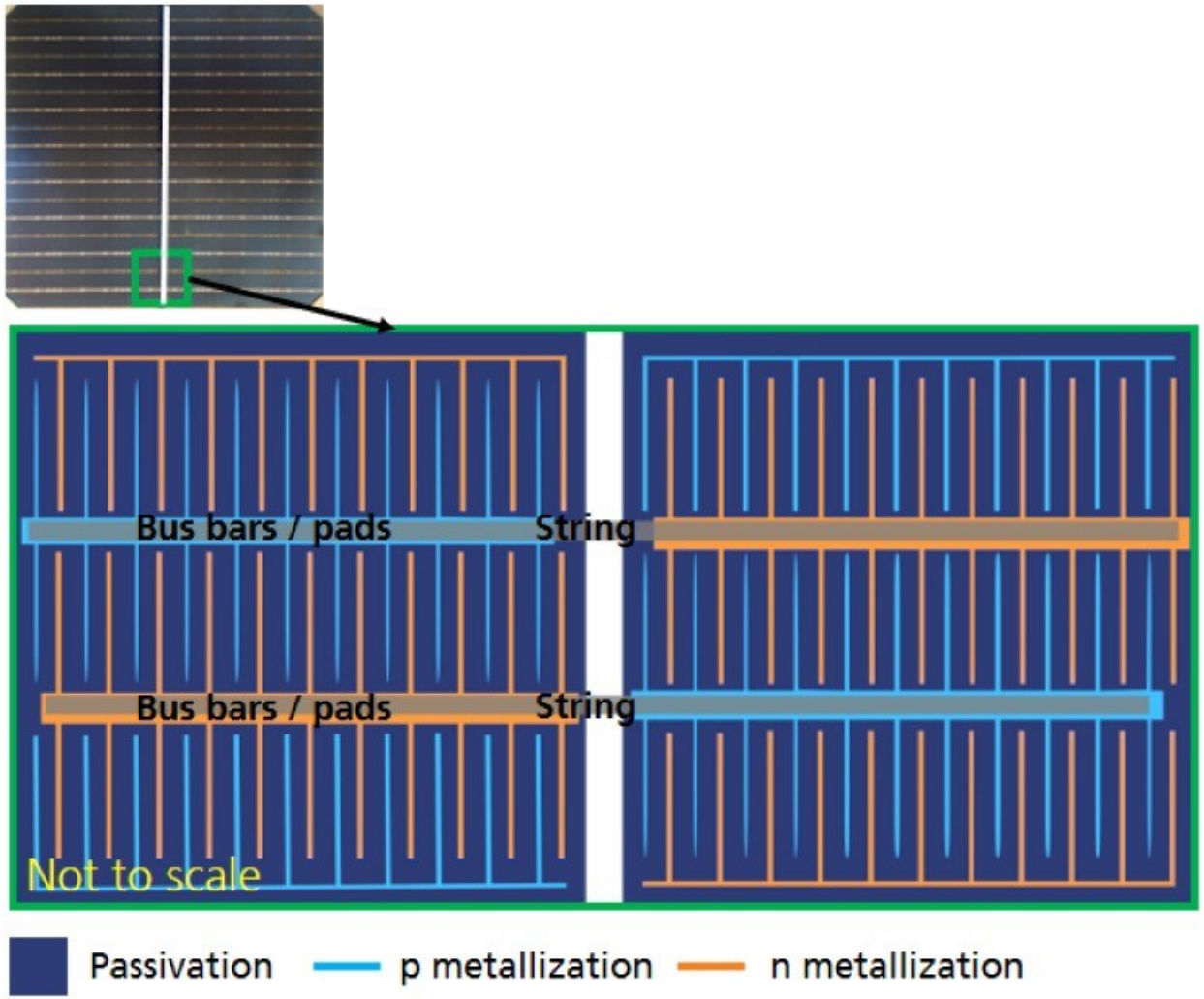
ISC International Solar Energy Research Center Konstanz centrotherm Fraunhofer ISE

POPEI and SPINAT: p-IBC meets Foilmet

Interconnection Concepts by Al foil

Use one sheet of Al-foil for cell connection & interconnection of cells

- From fully screen printed contacts to FoilMet®
- Including interconnection of cells



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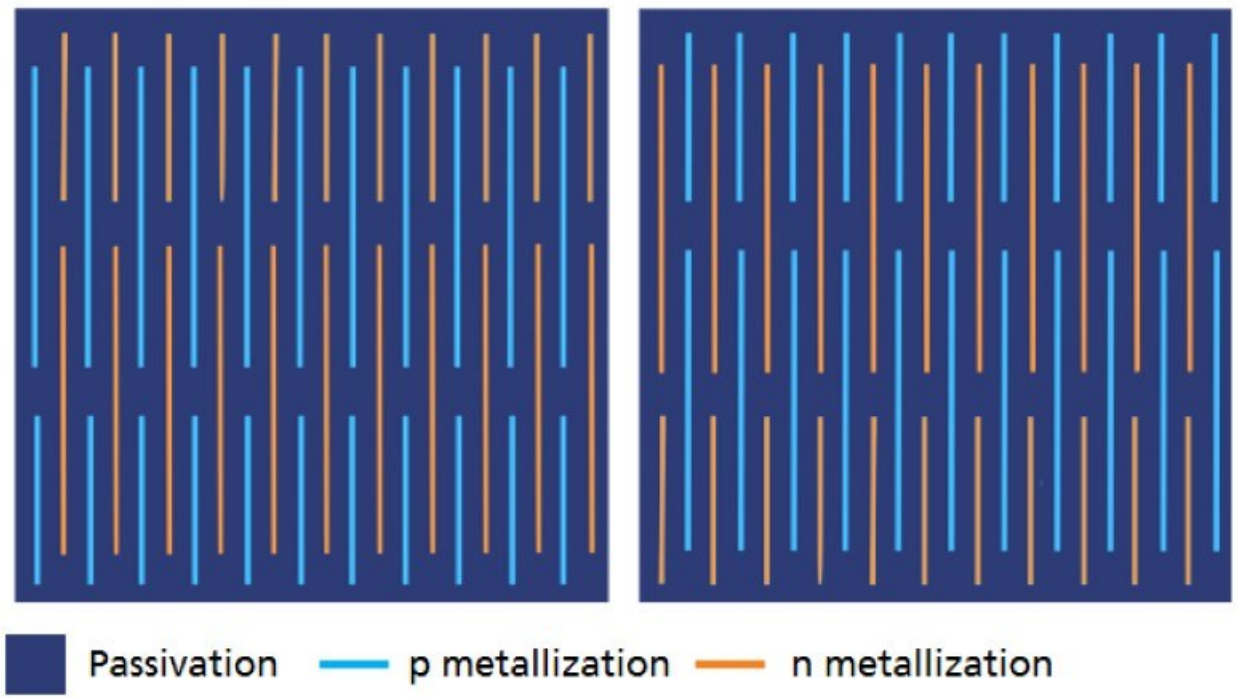
POPEI and SPINAT: p-IBC meets Foilmet

Interconnection Concepts by Al foil

Use one sheet of Al-foil for cell connection & interconnection of cells

- From fully screen printed contacts to FoilMet®
- Including interconnection of cells
- Leaving out bus bars, redundant lines, pads



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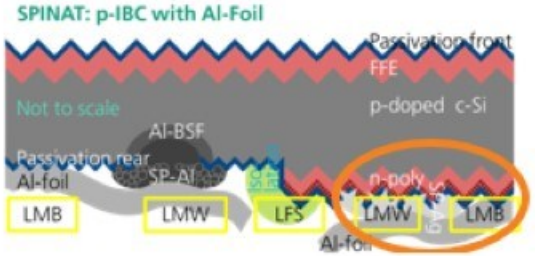
Proof of Concept for Foil Metallization on (p-IBC) Cell Structure

LMB / LMW on TOPCoRE solar cells



Proof-of-concept

- Front-and-rear contacted TOPCoRE cell (p-Si wafer, front surface field, rear TOPCon emitter)
- Screen printed vs. FoilMet emitter contacts

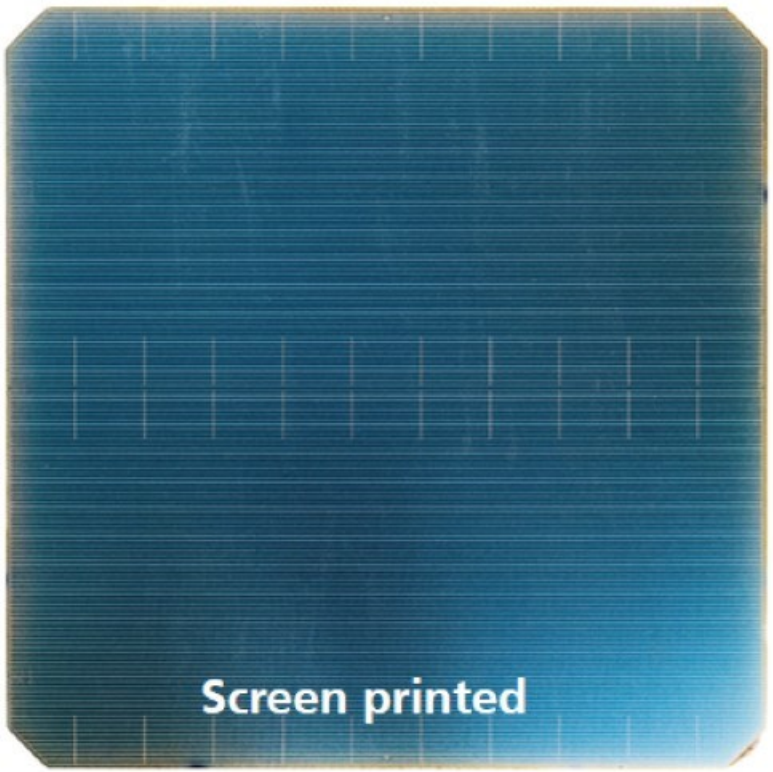


Photo:
Rear side TOPCoRe cells:
Screen printed / FoilMet

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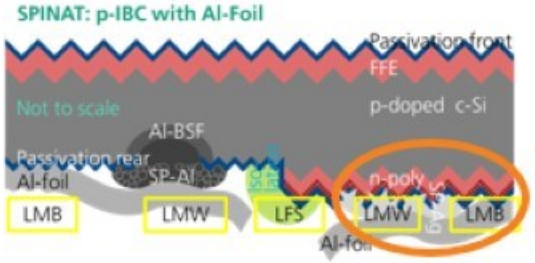
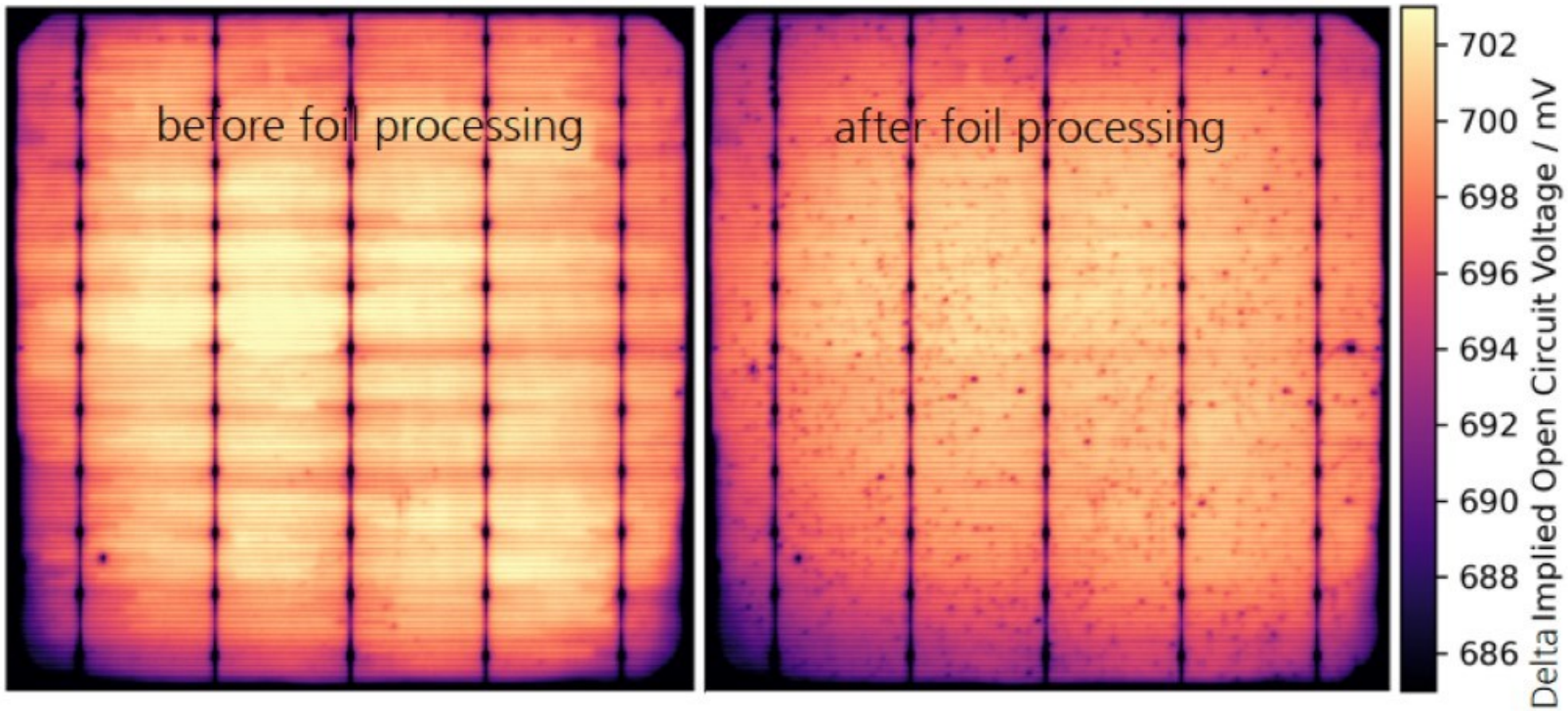


Results

- Peel tests for adhesion successful
- Analysis of iV_{oc} (Δ iV_{oc} images) loss of ~ 1.3 mV (± 1.1 mV)

→ **Low impact LMB / LMW process**

- *I-V* Measurements performed on the best solar cell



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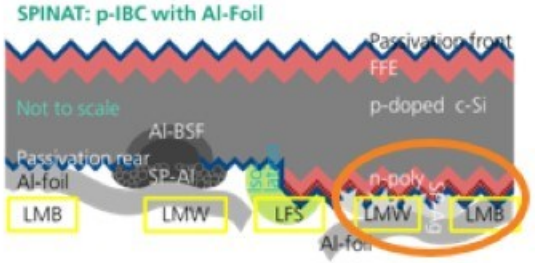
Proof of Concept for Foil Metallization on p-IBC Cell Structure

LMW of Ag contacts on TOPCoRE solar cells



Results

- Demonstration of screen printed and FoilMet® metallized TOPCoRE solar cells
- *I-V* parameter equal to the screen printed reference
  (low level due to precursor issues)

→ **Proof of successful combination of LMB and LMW on TOPCoRE solar cells**

	V_{oc} (mV)	J_{sc} (mA/cm²)	η (%)	FF (%)
Screen printed reference	698.8	39.0	21.5	79.1
Foil metallized cell	701.2	39.0	21.5	78.5

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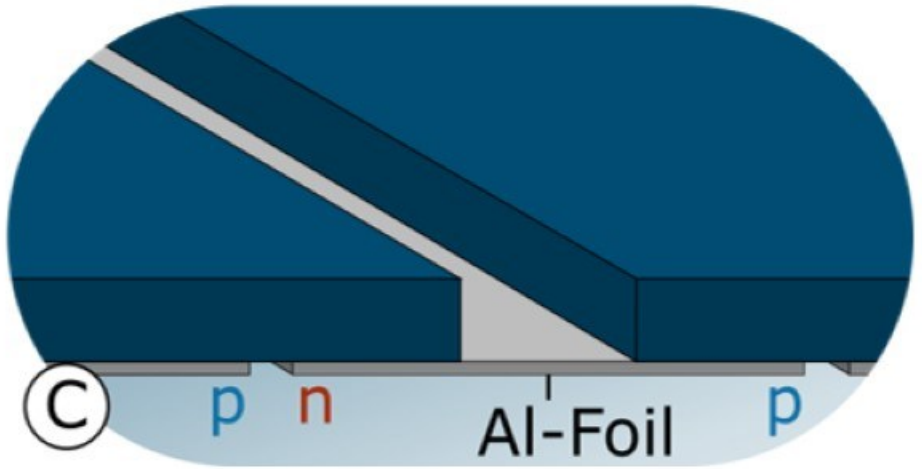
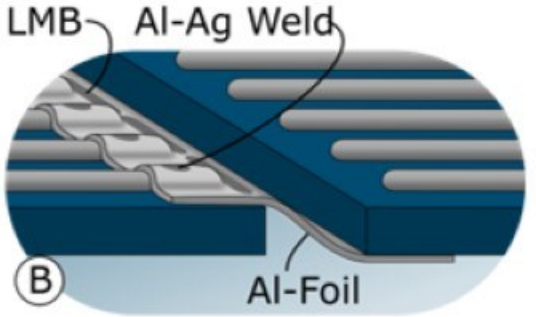
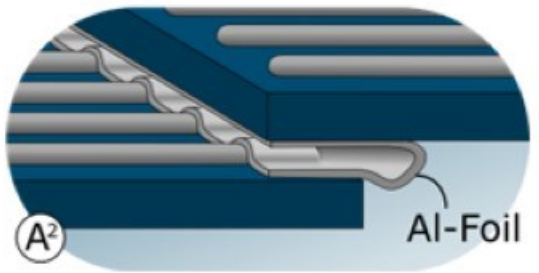
“FOILMET®-Interconnect” for IBC

One-sided Edge Interconnection for Cell Stripes







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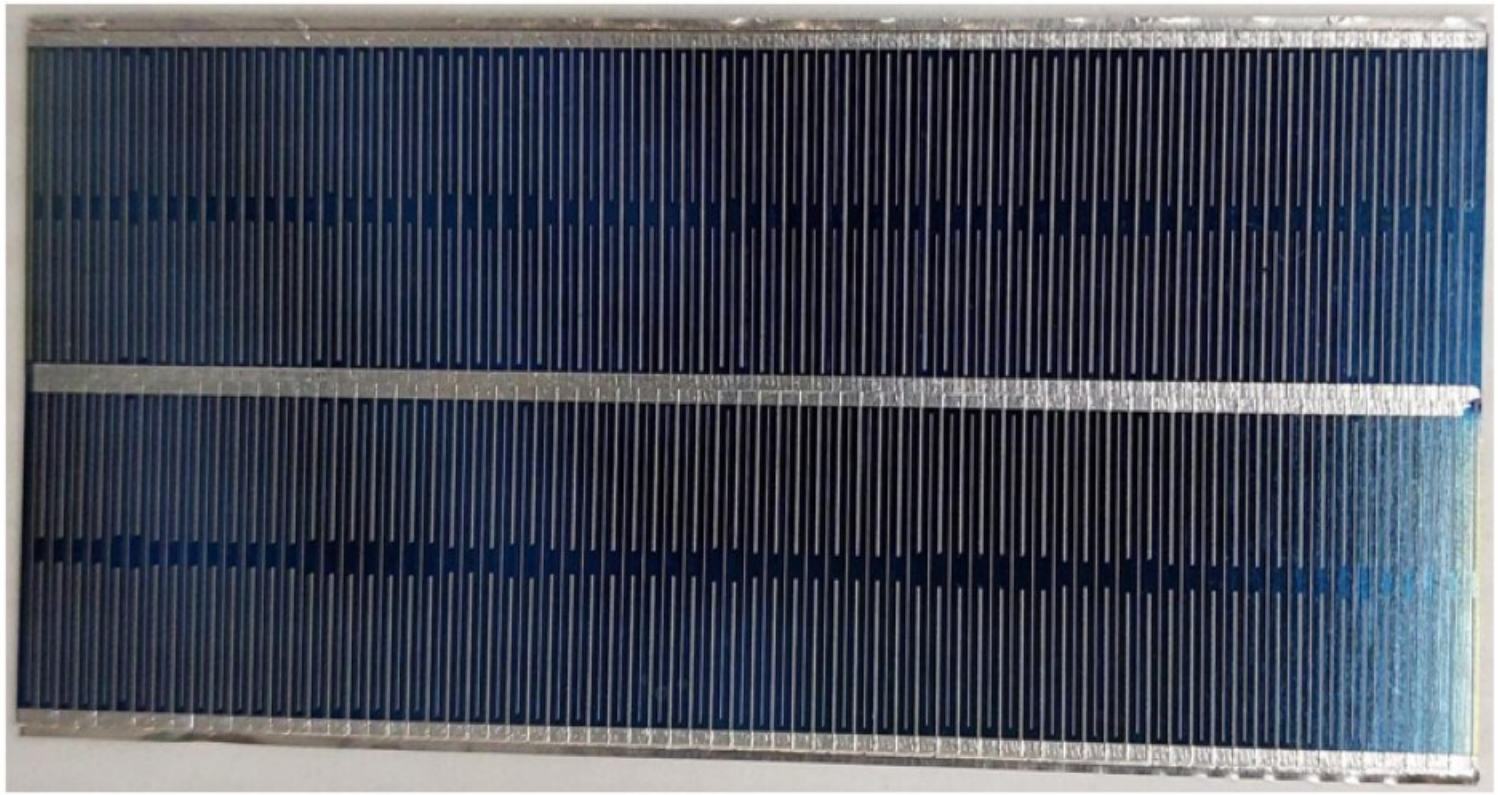
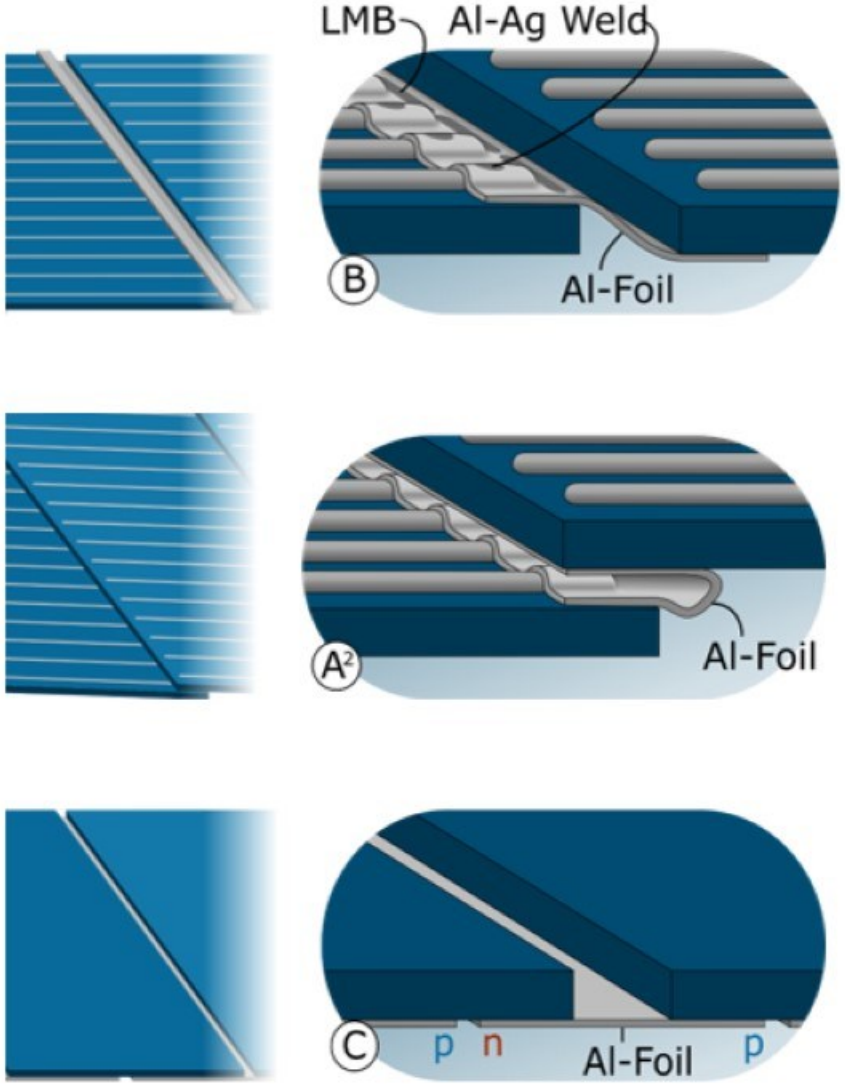
“FOILMET®-Interconnect” for IBC

Proof-of-Concept





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Summary and Outlook

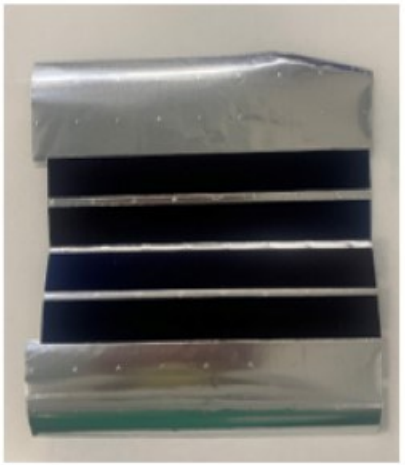
Flexible Cell Interconnection Using Al-Foils and Laser Processing

FoilMet-Interconnection

- Utilizing Al-foil to eliminate costly materials (e.g. Cu-ribbons)
- Good electrical performance, strong mechanical adhesion by adjusted processes
  - Weld Al to Al, Ag for electric contacts or bond Al to surfaces for adhesion
- Reduce Ag consumption, by eliminating the need for busbars
  - Reliable interconnection on each finger

FoilMet meets Back-Contact

- Single sided interconnection allows new cell designs (e.g. high voltages)
  - 24 V from a single wafer
- Replace ribbons by Al-foil or go for edge interconnection
- Less handling / higher throughput by interconnection first, cutting second



Interested? Feel free to reach out for samplings, customization or collaborations!

Thank you for your attention!

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