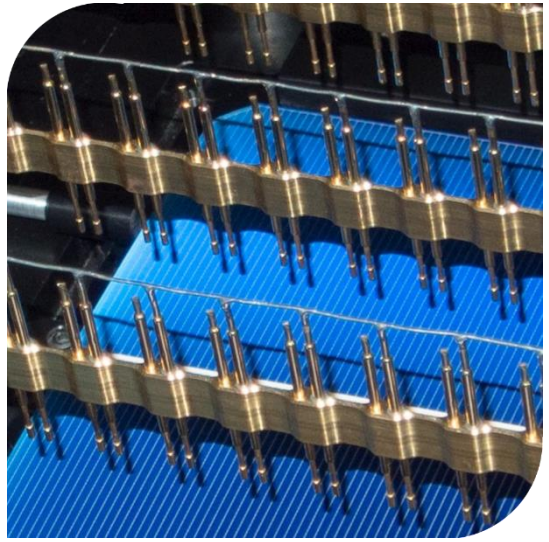



Laser structured p-IBC cells interconnected by Al-foil

J. Lossen[1], L. Rachdi[1] , T. Meßmer[1] , L. J. Koduvelikulathu[1], A. Wolf[2],
S. Schneider[2], O. John[2], G. Emanuel[2] and T. Pernau[3]

[1]ISC Konstanz e.V., [2]Fraunhofer ISE

[3]Centrotherm International AG

11th BC Workshop, Hamelin, 29th Nov. 2023

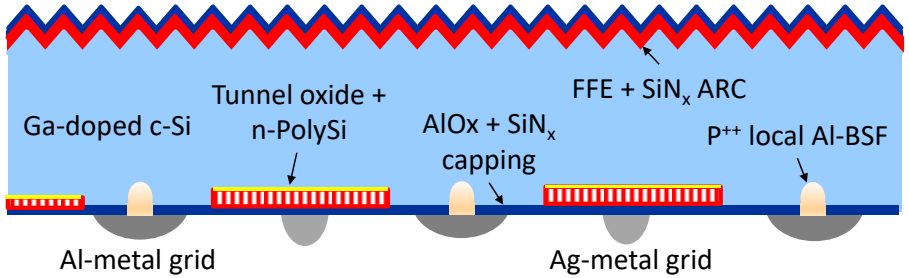
ISC research for a sunny future

Fraunhofer ISE

centrotherm

p-IBC – lean path to XBC cells

- p-IBC solar cells, as initially proposed by E. Bende [1], are probably the leanest type of IBC cells with two (mostly) passivated contacts
- High efficiency potential of this cell of 24.5% demonstrated by simulation [2]

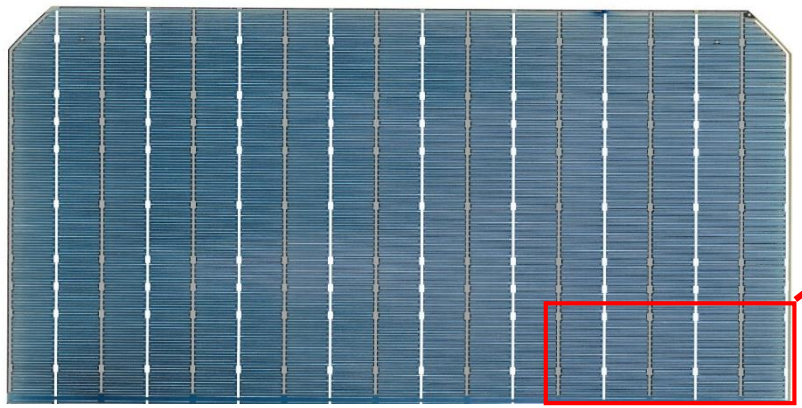


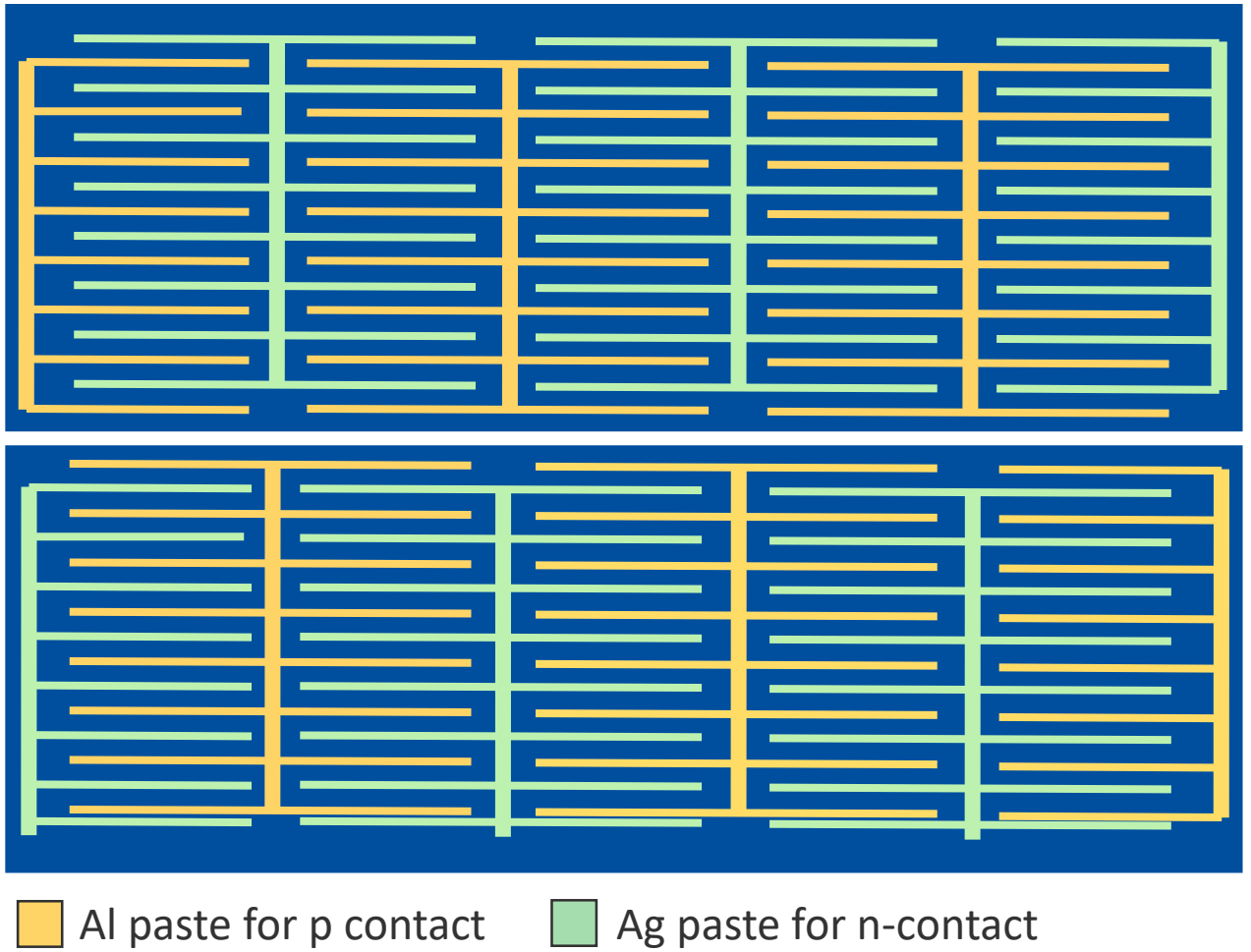
- Industrialization announced by Longi in 2022[3]. Back contact modules Hi-Mo 6 Explorer LR5-54 are meanwhile available on the market with 440 Wp.
- However, Al-paste is not solder able

[1] E. E. Bende, et.al. , PERC-like p-type IBC Solar cells, 7th Metallization and Interconnection Workshop, (2017)
[2] F. Haase, et al., Transferring the record p-type Si POLO-IBC cell technology towards an industrial level. In 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), 2200–2206.
[3] Shen Peijun, Longi: HPBC - The best practices for module technologies, 10th BC workshop, Konstanz, 2022

Concepts for interconnection

- p-IBC half cells
- 9BB per polarity





- Finger length ~8.5 mm

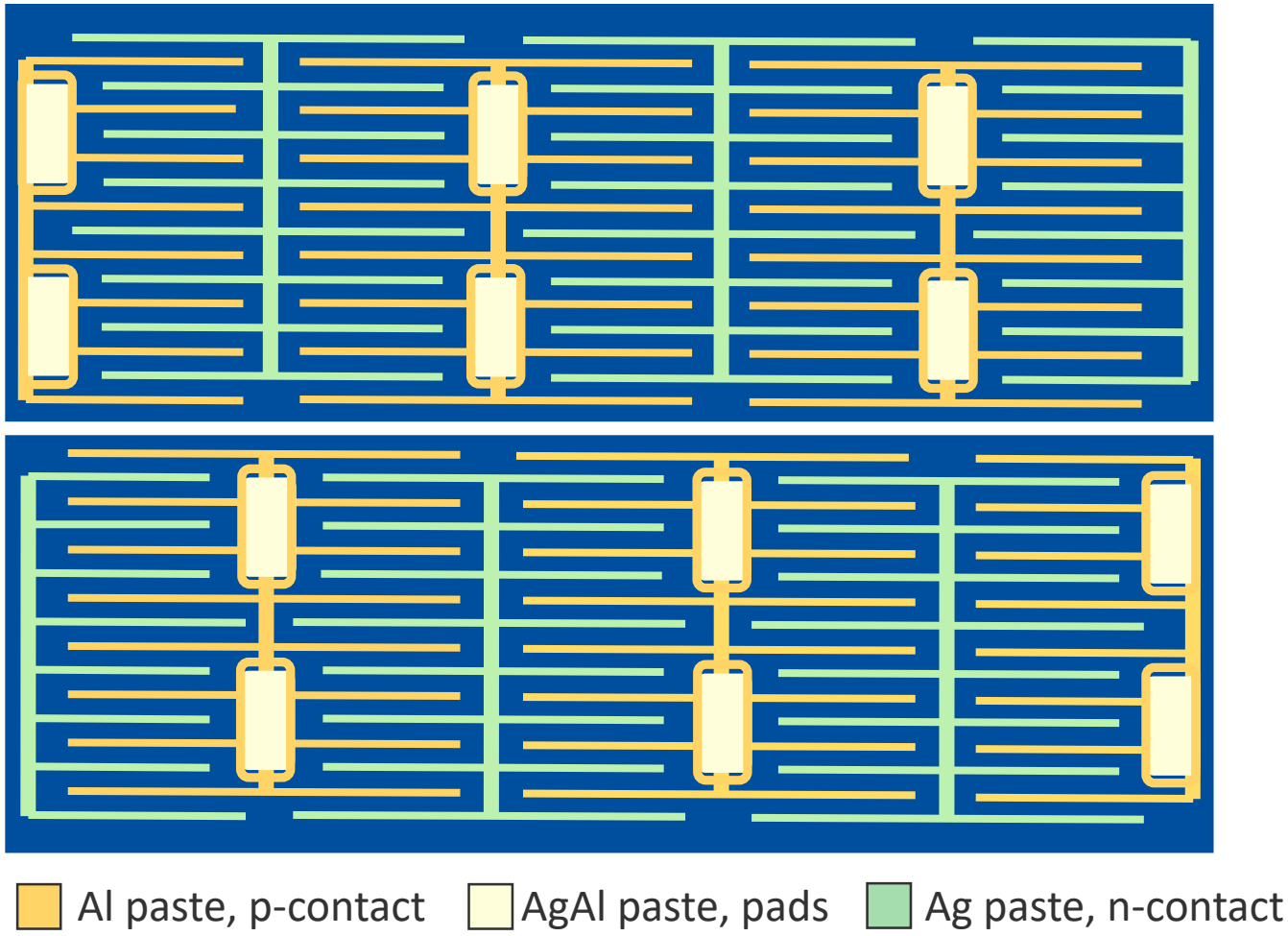
Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Concept for interconnection – classical soldering

Interconnection with ribbons

- Al paste not solder able
- Introduction of Ag-solder-pads required
- Typical pad size: 1.5 x 6 mm

-> Significant BB shading loss



Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

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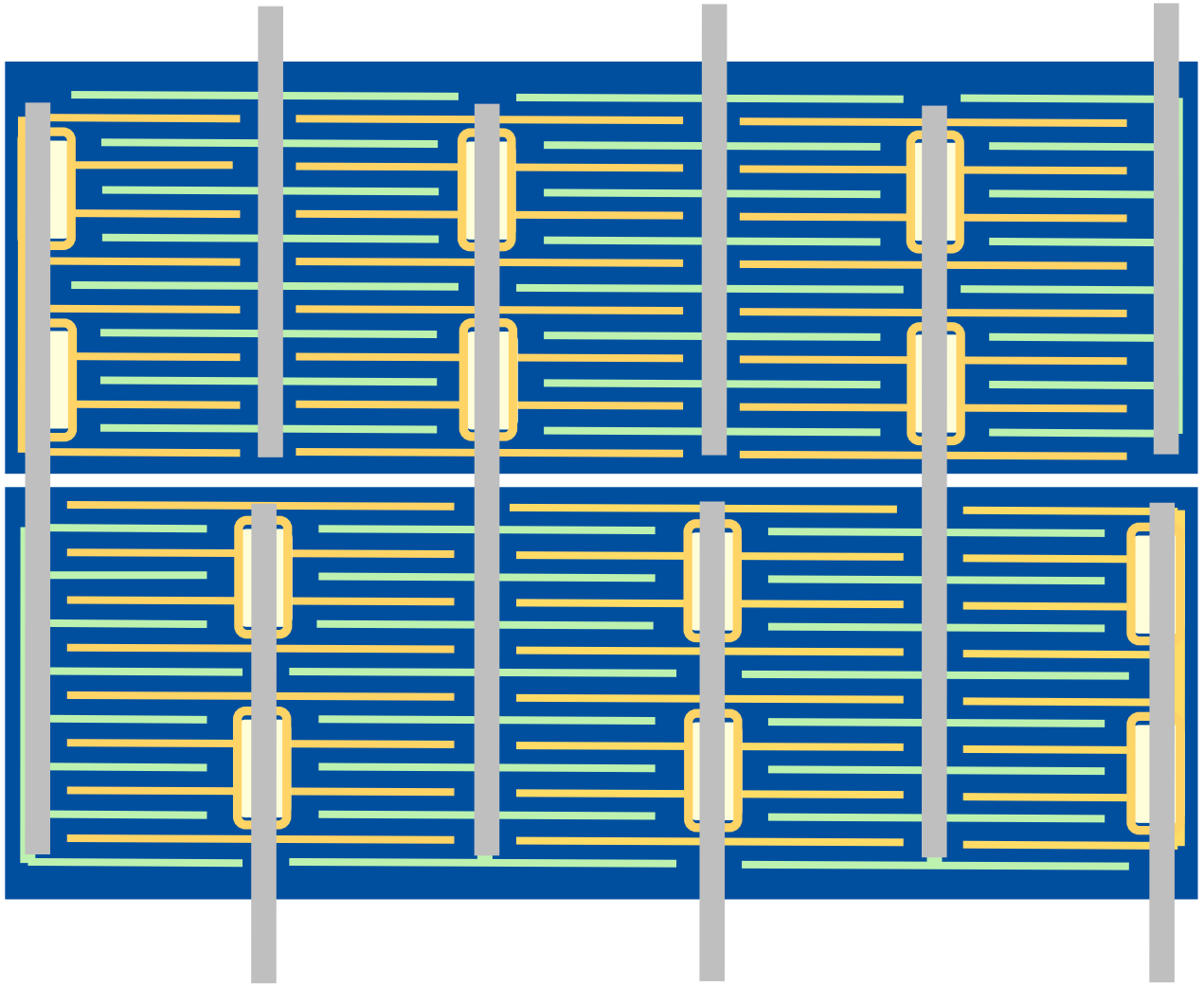
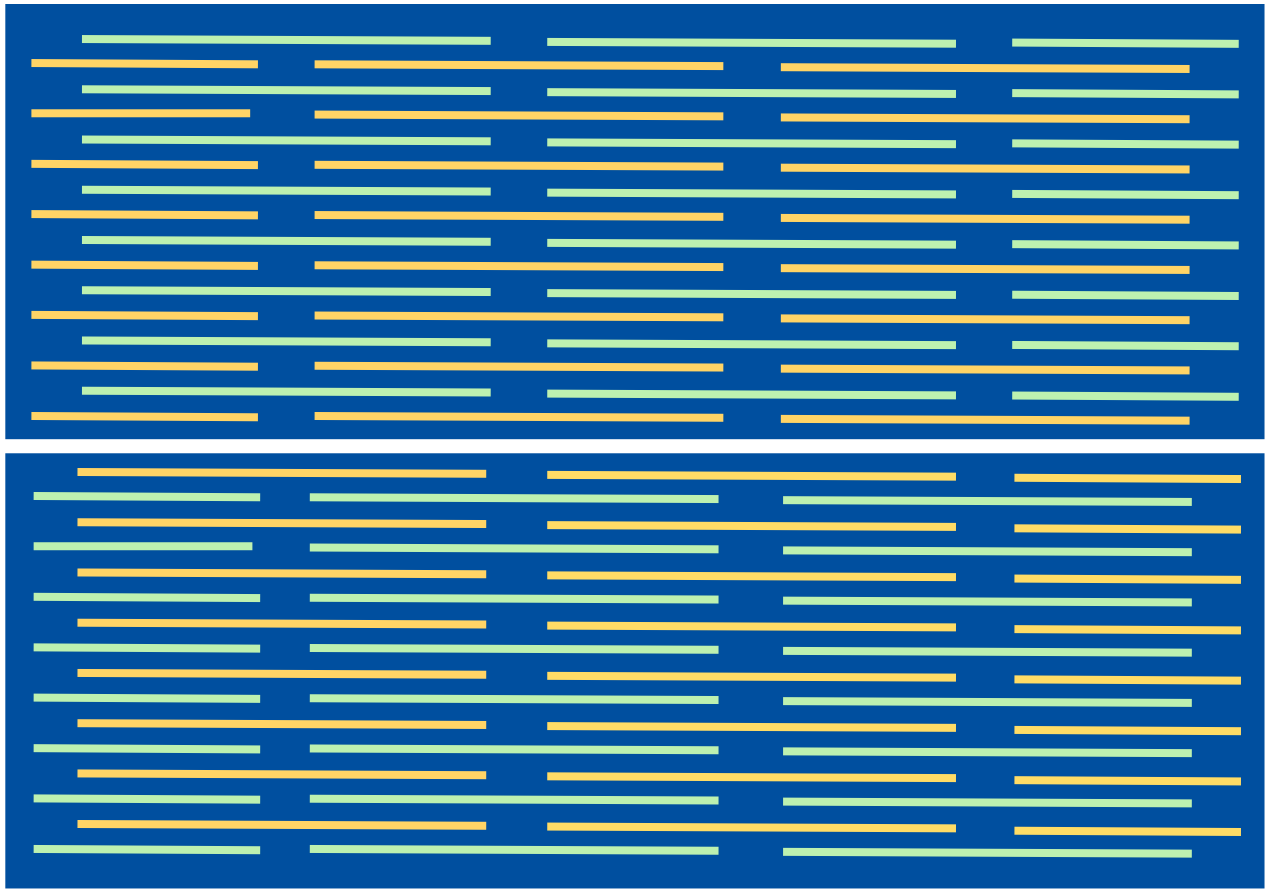


Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Concept for interconnection with AL foil

Alternative: Al foil interconnection

- Omitting bus bars

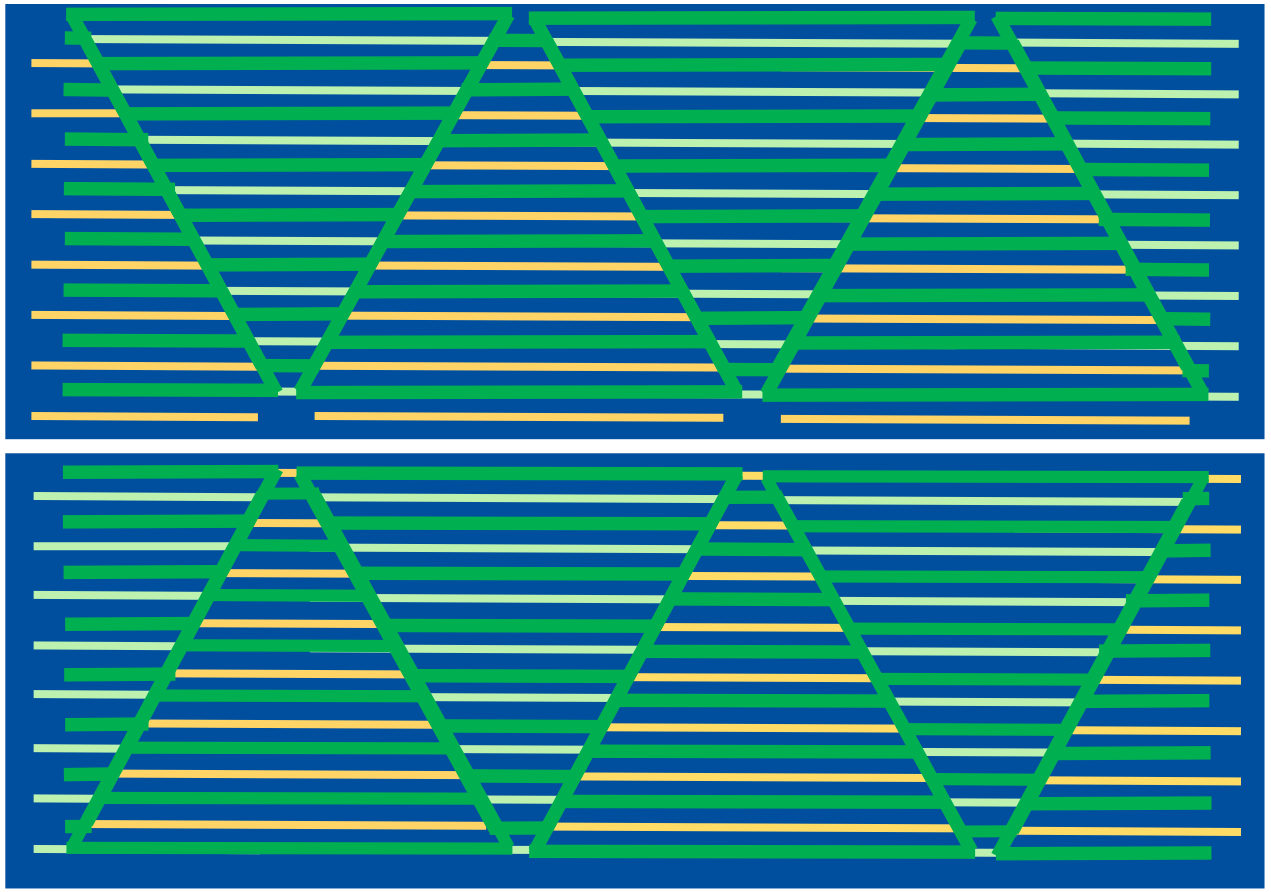


Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Concept for interconnection with AL foil

Alternative: Al foil interconnection

- Omitting bus bars
- Print of isolation paste layer

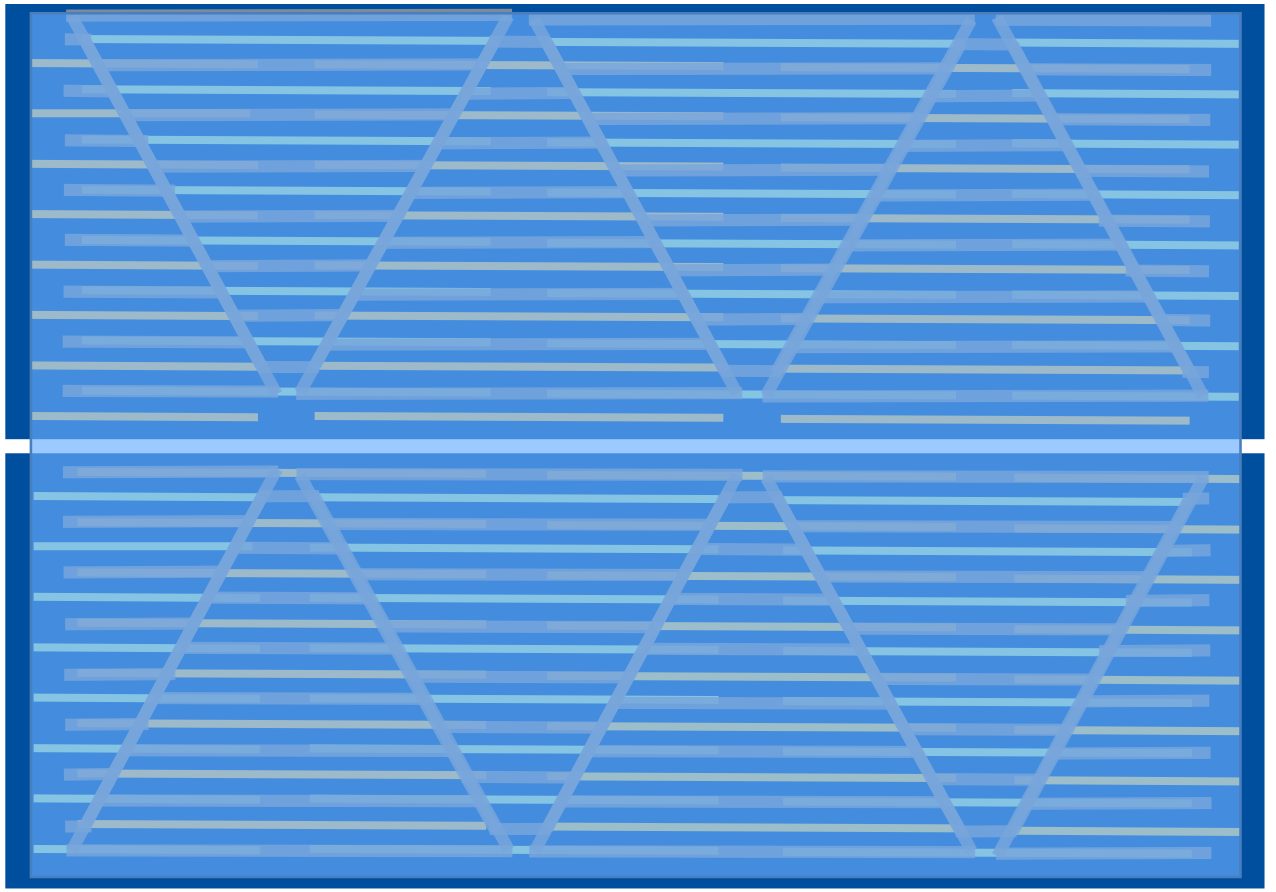


Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Concept for interconnection with AL foil

Alternative: Al foil interconnection

- Omitting bus bars
- Print of isolation paste layer
- Place Al-Foil

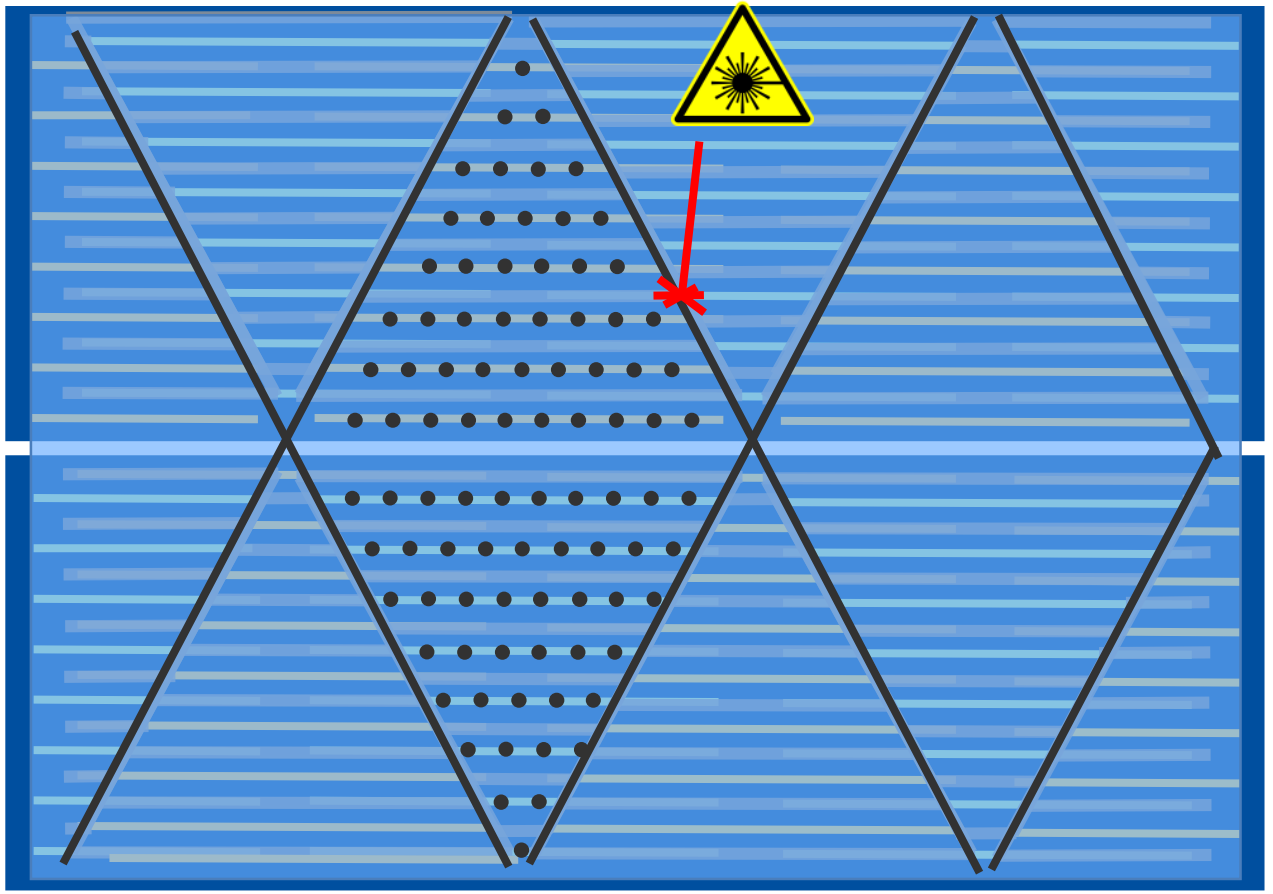


Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Concept for interconnection with AL foil

Alternative: Al foil interconnection

- Omitting bus bars
- Print of isolation paste layer
- Place Al-Foil
- Laser-Metal-Bonding (LMB) to attach Al foil on cell [4]
- Laser-Foil-Separation (LFS) to electrically isolate p- and n-regions

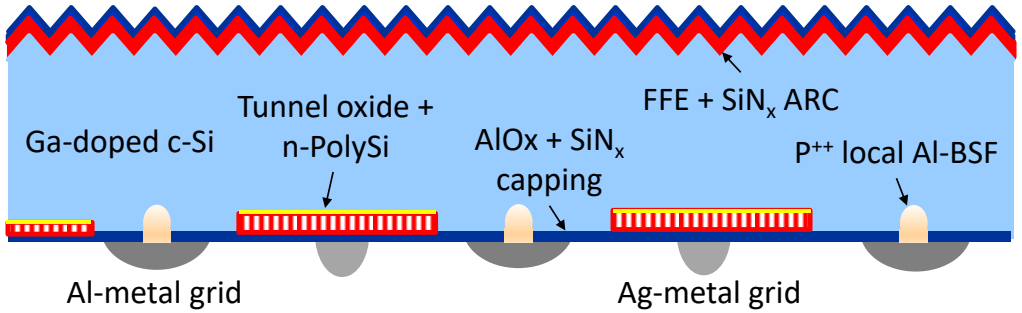


[4] Oliver John, Jan Paschen, Angela De Rose, Bernd Steinhauser, Gernot Emanuel, Andreas A. Brand, Jan Nekarda, Laser Metal Bonding (LMB) - low impact joining of thin aluminum foil to silicon and silicon nitride surfaces, Procedia CIRP, Volume 94, 2020, Pages 863-868, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2020.09.109.

Progress with cell development

ISC/ISE process flow for p-IBC [5]:

- Ga-doped Cz-wafers
- PECVD deposition of n+-poly in CT c.PLASMA
- Combined poly-Si annealing + FFE formation
- Structuring by Laser-Ablation

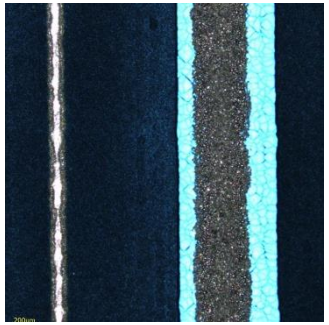


Cz-Si:Ga (M2 format, ρ_B = 1-2 Ω.cm)
Single side texturing / Cleaning
Thermal oxidation
PECVD n-PolySi
Poly-Si annealing / FFE
Laser structuring
Chemical etching / Cleaning
Thermal oxidation
FS PECVD ARC (SiN_x)
RS PECVD passivation (AlO_x+SiN_x)
Laser contact opening (LCO)
Silver screen printing
Aluminum screen printing
Contact firing
IV measurements

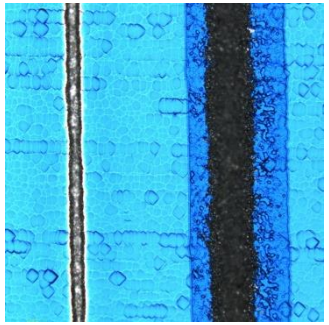
[5] L. Rachdi, J. Lossen, D. Rudolph, Y. P. Sharma, L. J. Koduvelikulathu, J. I. Polzin, S. Schmidt, A. Wolf and T. Pernau, Development and Process Optimization of a p-IBC Solar Cell with PECVD Deposited Passivated Contacts, 1AO.5.6, EU-PVSEC 2023, DOI: 10.4229/EUPVSEC2023/1AO.5.6

Rear side surface morphology

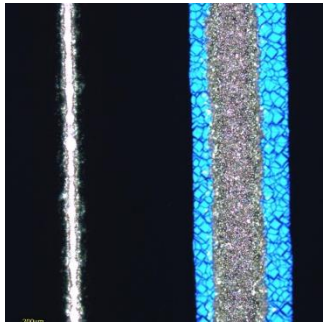
- Fillfactor (FF) highly sensitive to surface morphology of n-poly emitter



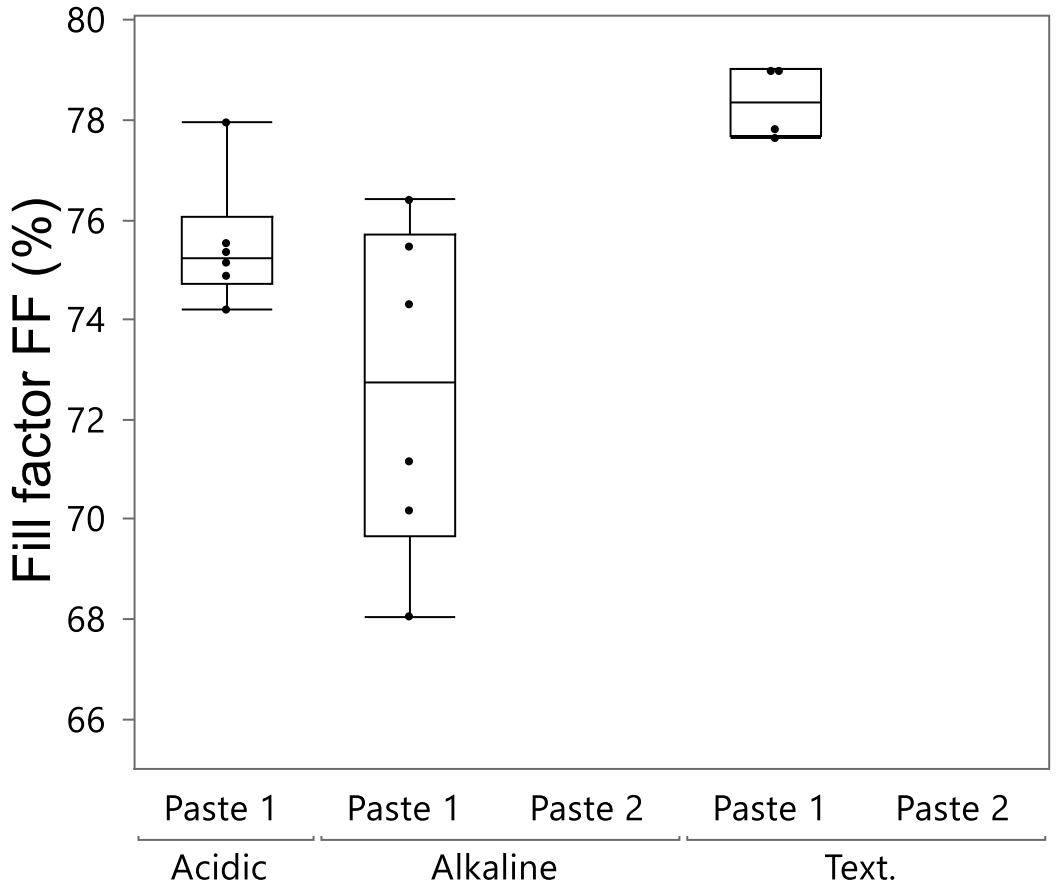
Acidic



Alkaline

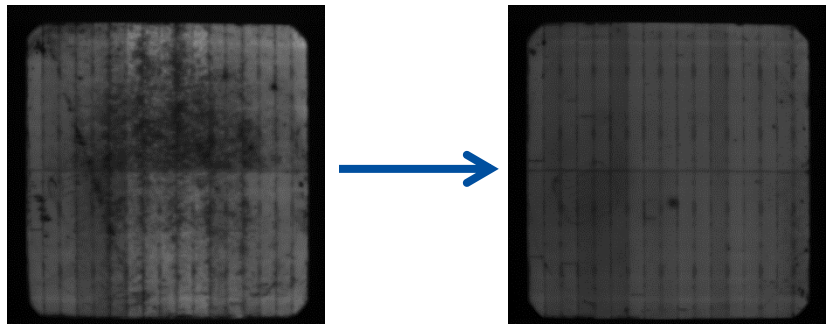


Text.



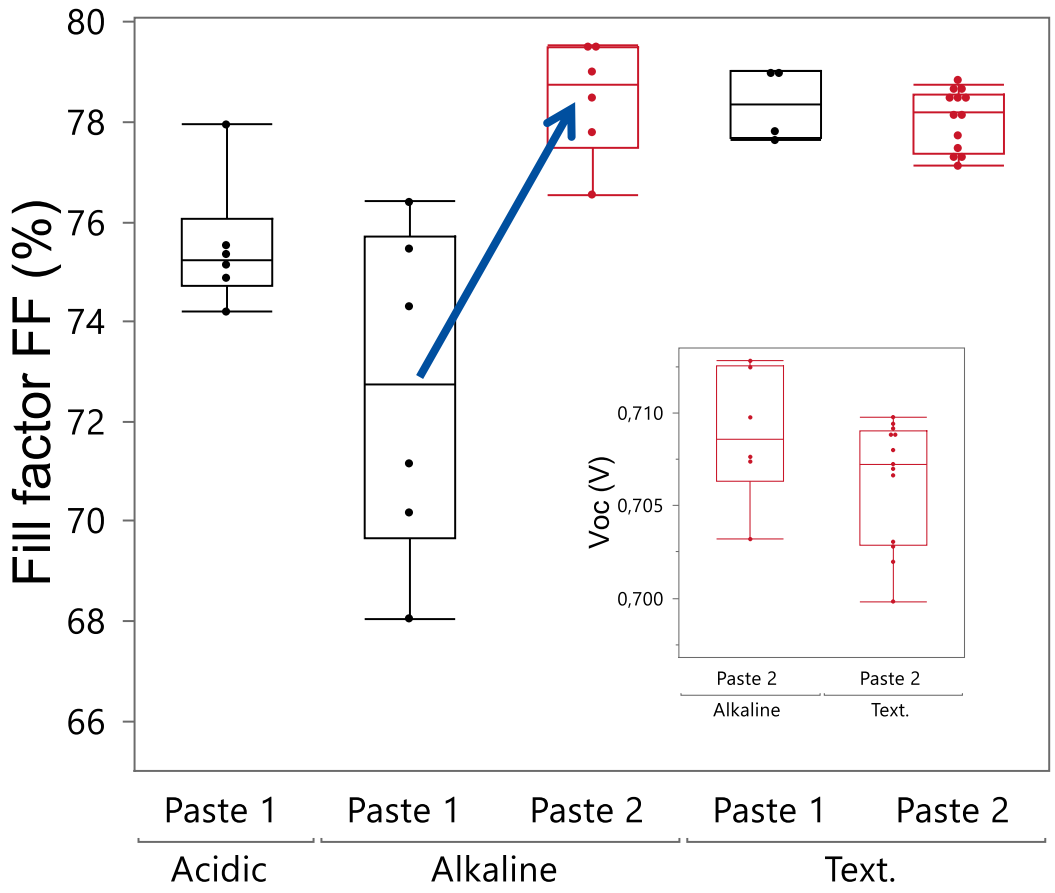
Rear side surface morphology

- Fillfactor (FF) highly sensitive to surface morphology of n-poly emitter
- Initial FF drop with alkaline rear side recovered with optimized Ag paste
- Improved passivation on flat surface



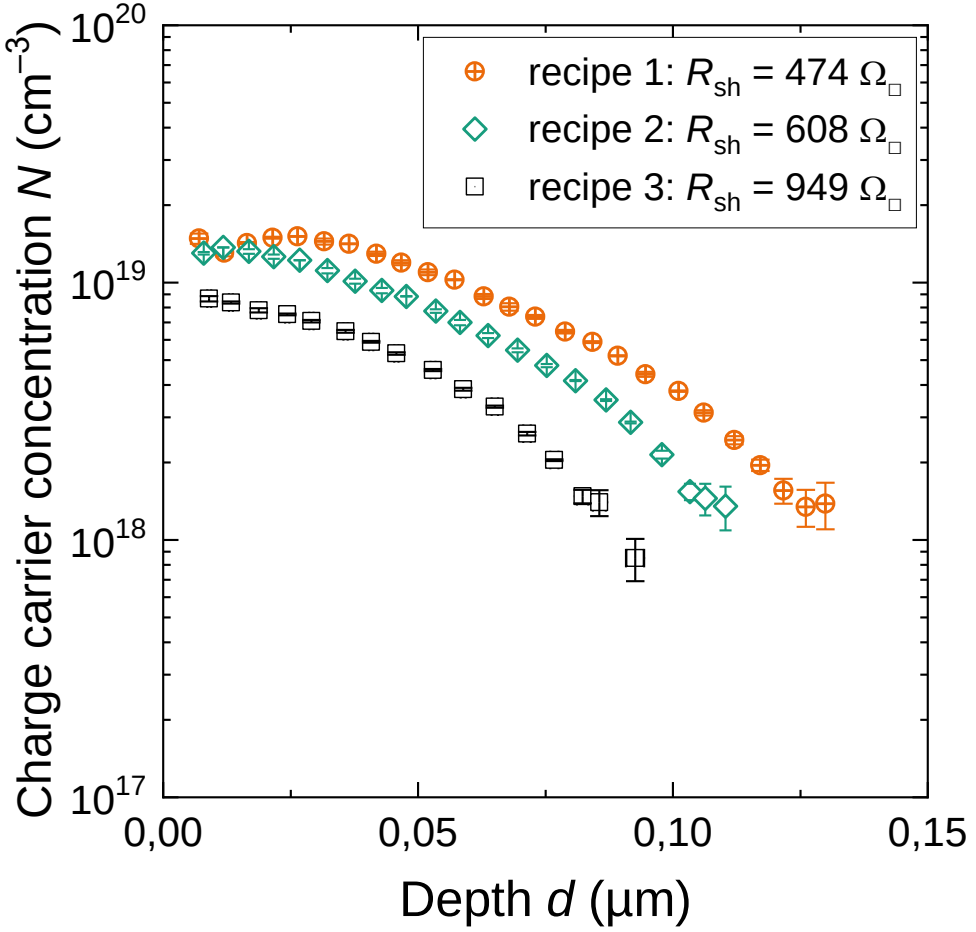
Paste 1 Paste 2

EL imaging



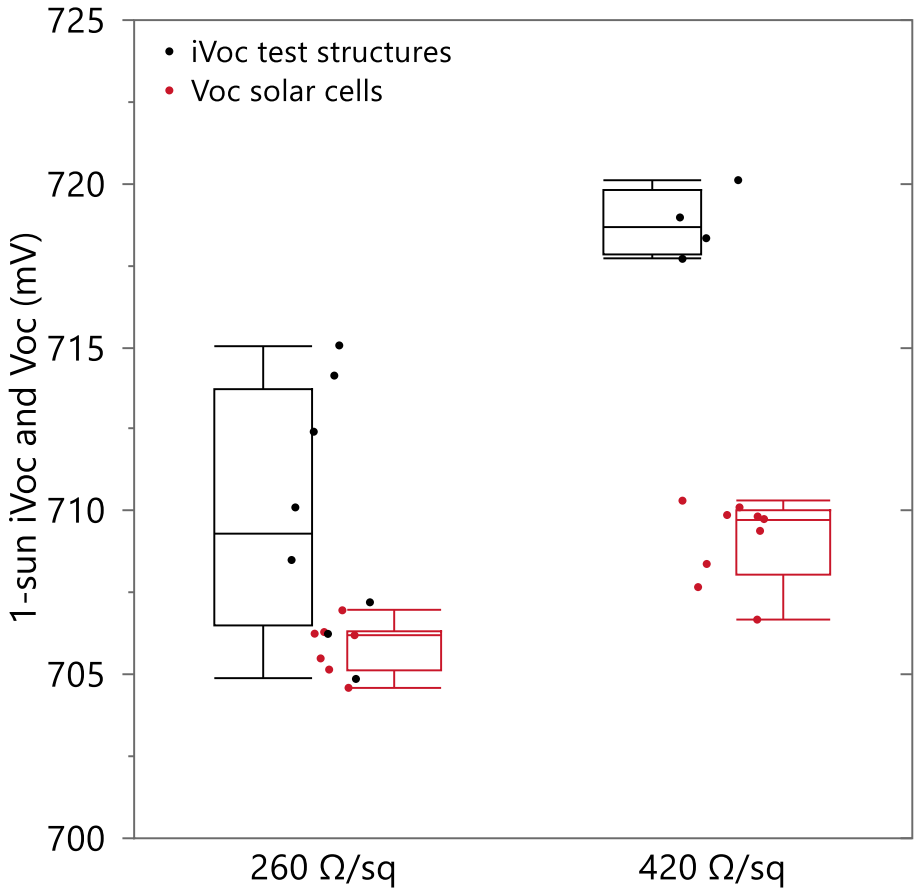
Front floating emitter (FEE) optimization

- Challenge : To decouple peak annealing temperature of poly-Si with FFE process
- Lightly doped FFE profiles obtained despite high temperature for poly anneal



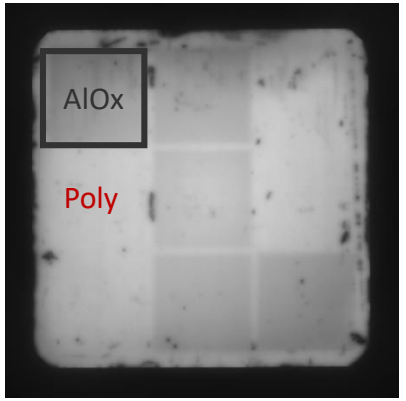
Front floating emitter (FEE) optimization

- Challenge : To decouple peak annealing temperature of poly-Si with FFE process
- Lightly doped FFE profiles obtained despite high temperature for poly anneal
- Higher iV_{oc} (QSSPC) with higher R_{sheet}
- Improved solar cell V_{oc} with optimized front floating emitter

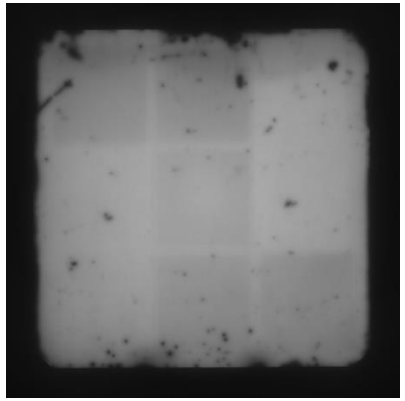


Lifetime structures

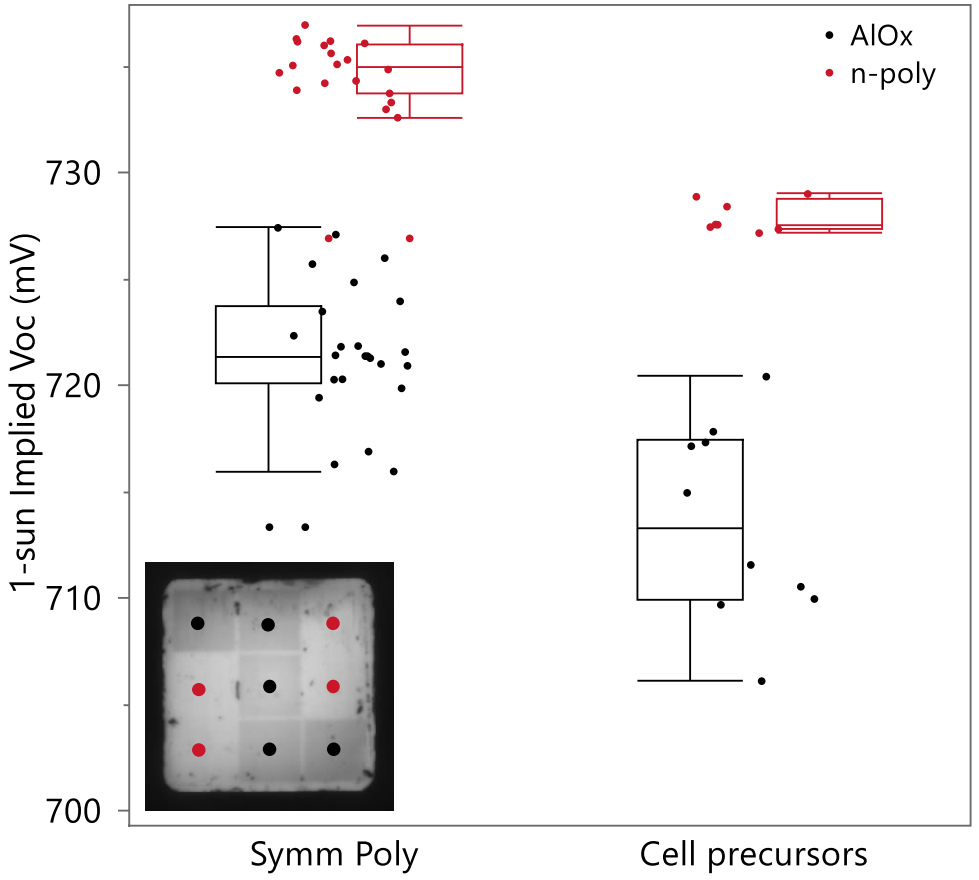
- iV_{oc} limited by front side passivation / FFE
- Ablated squares represent base region
- iVoc about 15 mV lower in base region compared to n-poly emitter region



FS Poly („Symm Poly“)

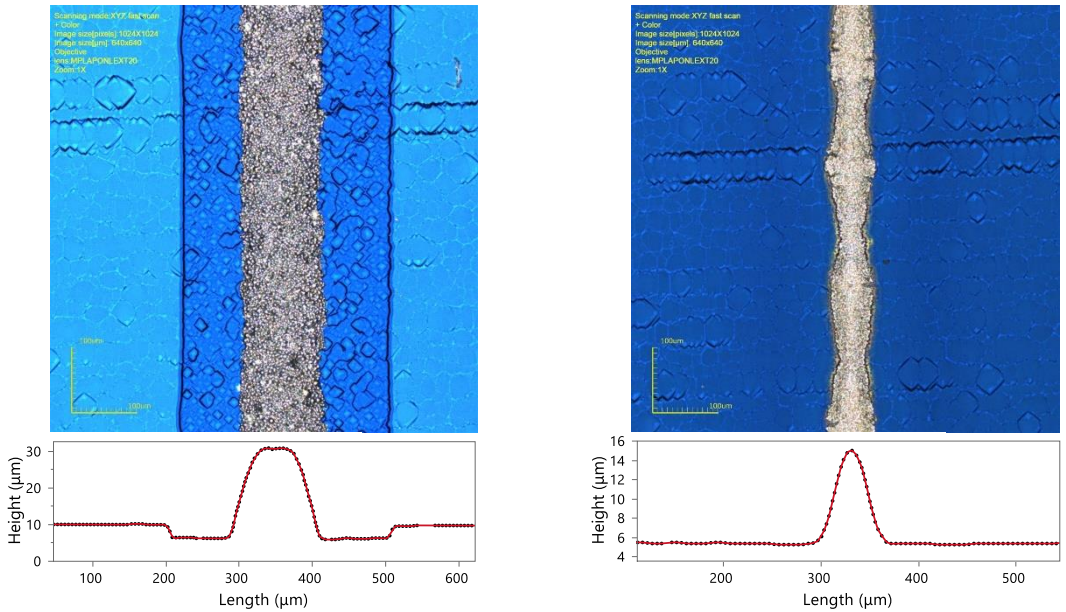


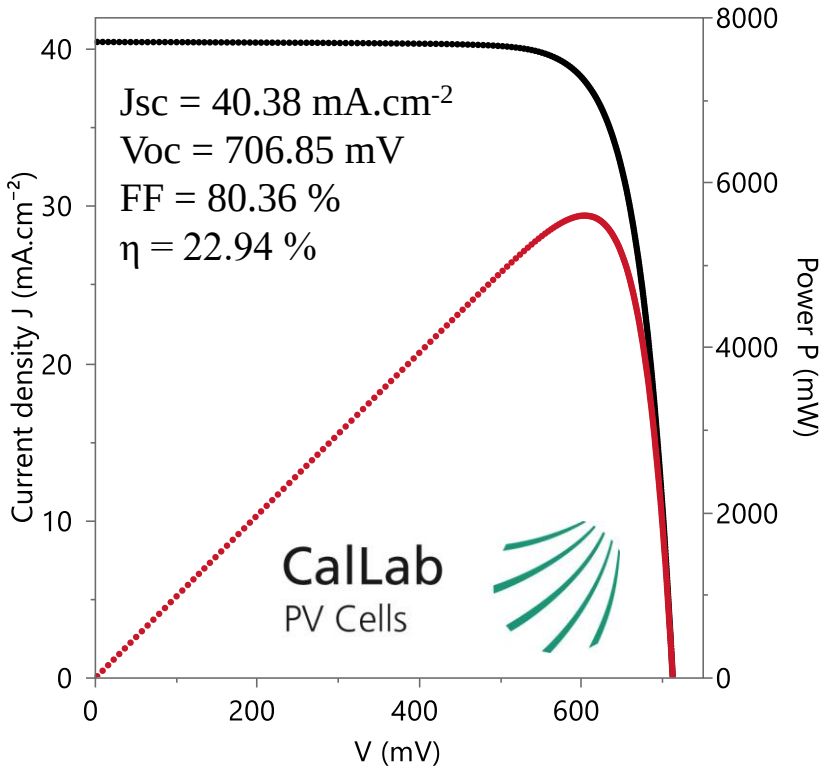
FFE (Cell precursor)



Champion p-IBC solar cell

- Current champion cell on M2 at 22.94%
- Further optimization planned: screen printing, FS passivation, AlOx passivation

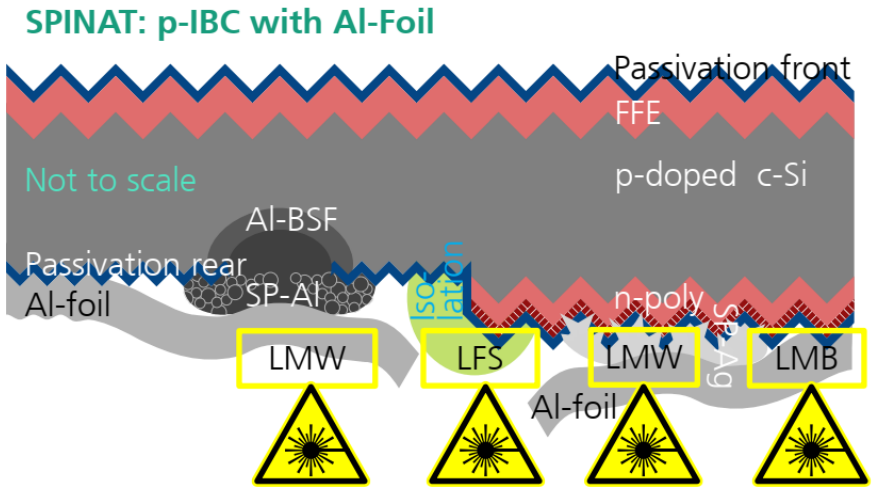




Progress with Al-Foil interconnection [6]

Required processes:

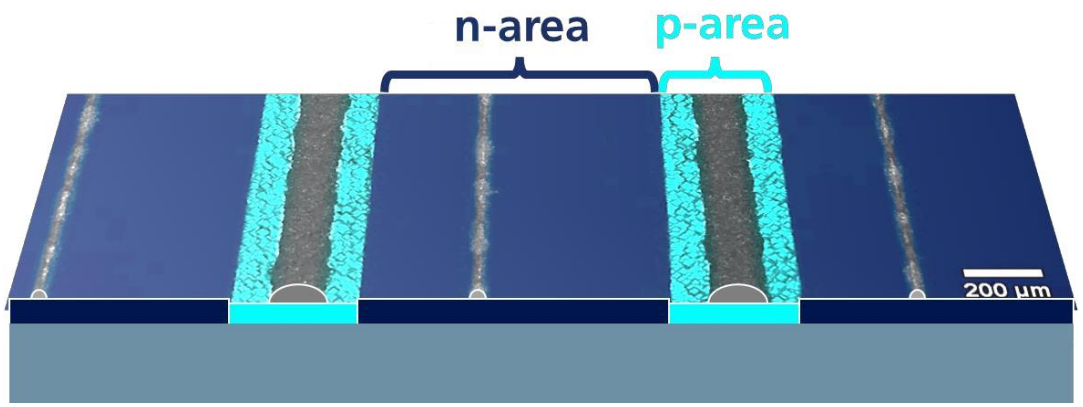
- LMB: Laser-Metal-Bonding to adhere the foil damage free to the passivation layer
- LMW: Laser-Metal-Welding to connect the foil with screen printed Al paste and Ag paste
- LFS: Laser-Foil-Separation to electrically isolate p- and n-regions

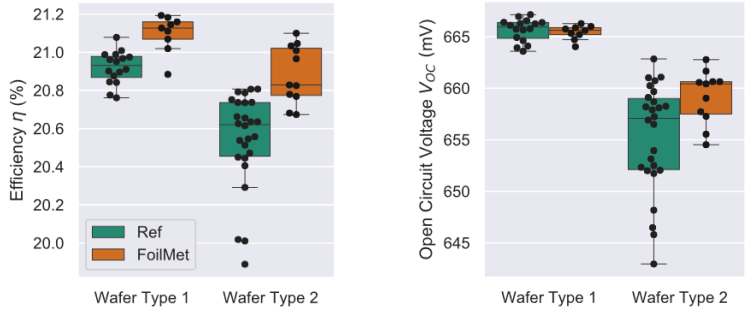


[6] G. Emanuel, O. John, J. Paschen, M. M. Menegassi, A. Nägele, J. Lossen, T. Messmer, T. Pernau, J. D. Huyeng, J. Nekarda, Demonstration of an Industrial Concept for the Metallization and Interconnection of p-IBC Cells Using Aluminum Foil by Laser Processes, EU-PVSEC 2023, 1BO.3.5 , DOI 10.4229/EUPVSEC2023/1BO.3.5

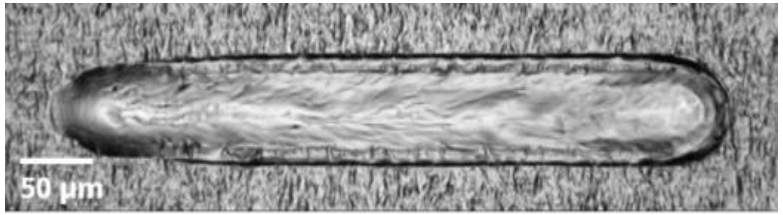
Bonding and Welding of Al-Foil

- Laser Metal Bonding (LMB) and Laser-Metal Welding (LMW) have been developed and demonstrated by Fh-ISE since many years [4], [7], [8]
- However, the limited space and the height profile of the p-IBC cell are challenges





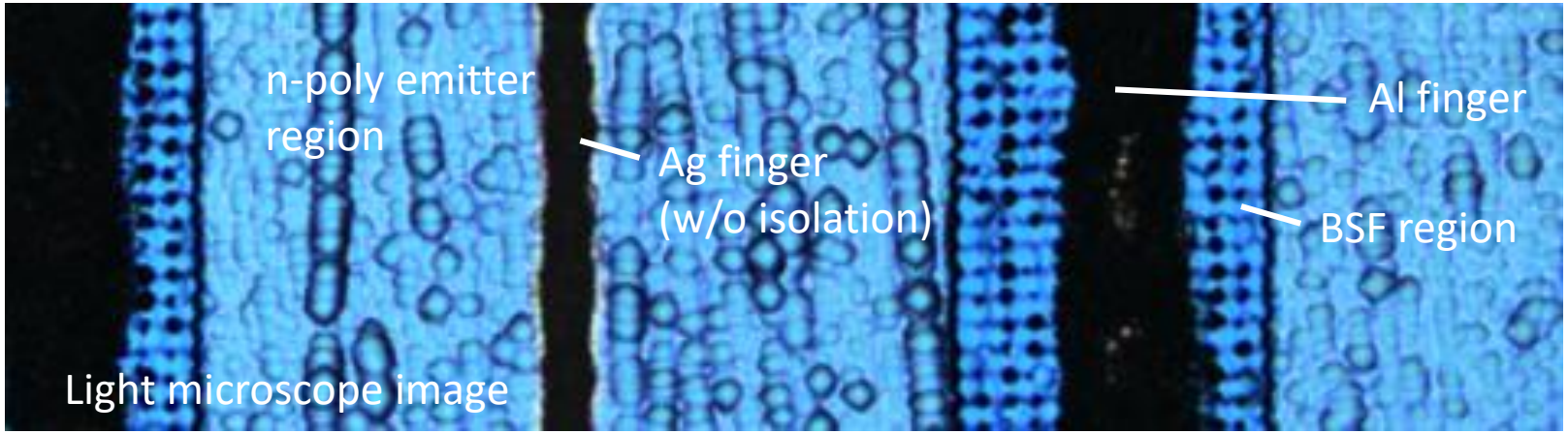
Efficiency and Voc of FoilMet connected CZ PERC cells, from [4]



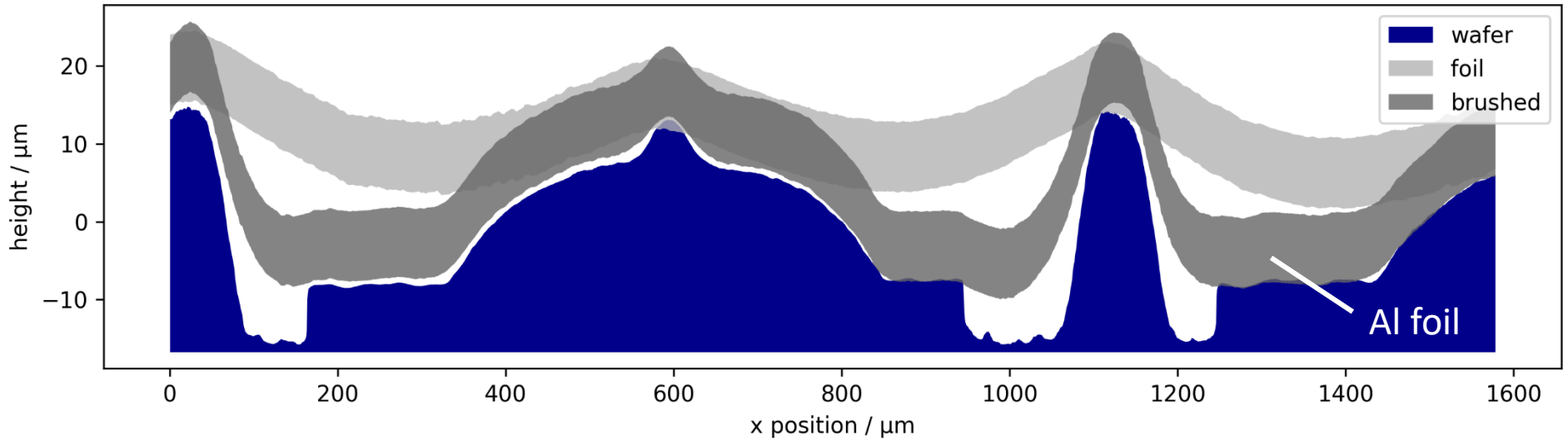
Microscope image from Al bond to SiNx coated wafer [7]

[4] O. John, et al., Procedia CIRP 94 (2020) 863–868
[7] O. John, et al., *2020 47th IEEE PVSC*, Calgary, AB, Canada, 2020, pp. 0063-0066
[8] J. Paschen, et al., *FoilMet® - Connect*: A new rear metallization upgrade for PERC and other cell concepts. *AIP Conf. Proc.* 18 September 2019; 2156 (1): 020004.

Bonding and Welding of Al-Foil



For good attachment it is important to suck and brush the foil tightly to the cell surface!

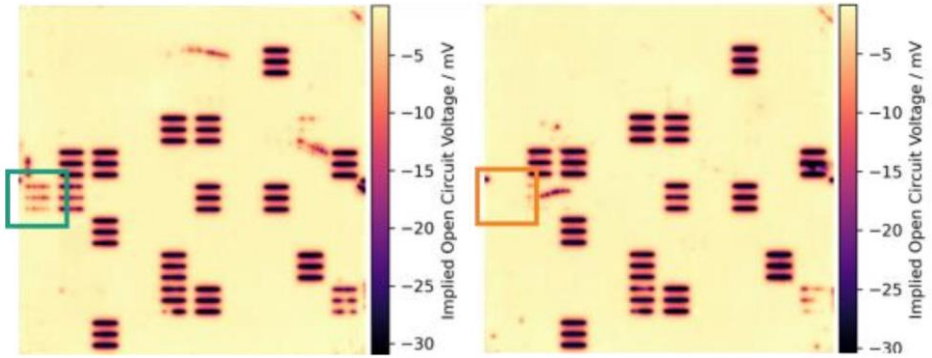


Height profile

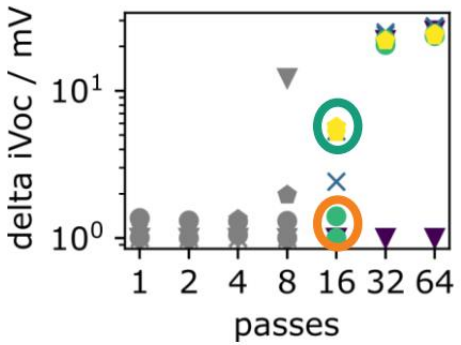
Laser foil separation (LFS)

Test on TOPCon life time structures printed with isolation paste

- Grey symbols displaying parameters without complete separation of the foil
- Some parameters result in low damage
- ΔiVoc analysis to quantify impact
  - Low damage LFS process for both TOPCon layers
  - Less then 10mV drop in iVoc for 5µm thick isolation layer
  - Nearly damage free for 10µm thick isolation layer



Differential implied Voc images before and after LFS



Deposition process and isolation paste height

- LPCVD | 10µm
- LPCVD | 5µm
- PECVD | 10µm
- PECVD | 5µm

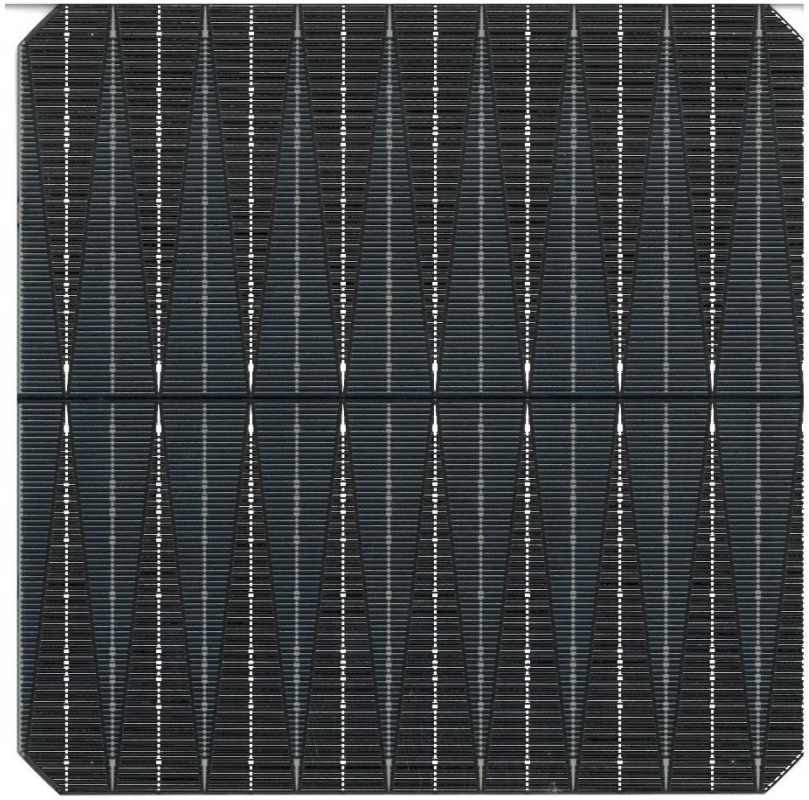
Damage of laser separation for laser process with best power setting for different number of passes. (More details on selection of laser parameters in: G. Emanuel, et al., EU-PVSEC 2023, 1BO.3.5)

Summary

- Development of p-IBC solar cell process by PECVD deposition and laser structuring
- Best cells ~23% with further potential for improvement

Eff. [%]	V_{oc} [V]	Jsc [mA.cm^{-2}]	FF [%]
22.94	0.707	40.38	80.36

- Lean interconnection approach using laser welding of Al-Foil under development
- Single laser steps successfully demonstrated



p-IBC cell with printed isolation paste for Al-foil interconnection

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Lossen et al., Laser structured p-IBC cells interconnected by Al-foil, BC-WS23

Acknowledgments:
Cell development was performed in project **POPEI** (grant No. 03EE1102), and development of Al foil interconnection in project **SPINAT** (grant No. 03EE1124C), both supported by the Bundesministerium für Wirtschaft und Klimaschutz (BMWK), Germany.

ISC research for a sunny future

Thank you for your attention