Fraunhofer ISE

Back-contact solar cells at Fraunhofer ISE

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Major advantages and challenges for IBC

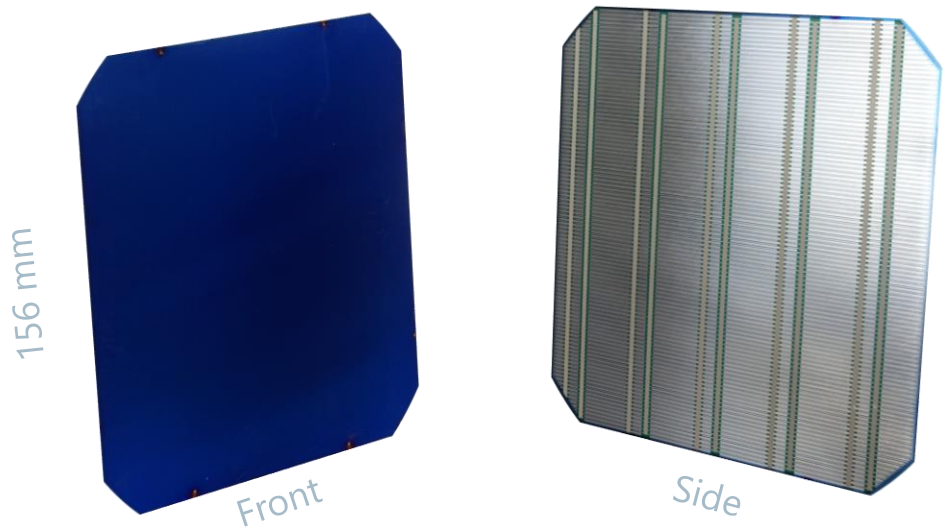
Back-contacted solar cells

Advantages of IBC solar cells

- Improved front side light absorption
- Very appealing aesthetics
- One sided interconnection, tighter spacing
- Soft breakdown in reverse bias
- …

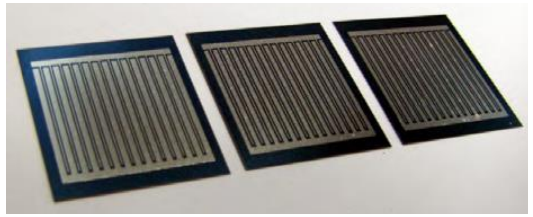
Challenges for IBC mass manufacturing

- More complex processing, increased number of process steps
- Higher accuracy in manufacturing necessary
- Adjusted interconnection and module integration
- …



Back-Contact Back-Junction Silicon Solar Cells

Development at Fraunhofer ISE



- Fraunhofer ISE picked up BCBJ 25 years ago
- Development of homojunction silicon solar cells
  - Diffused junctions
  - Metallization by PVD
  - Structuring by photolithography
  - More than 50 process steps involved …

		Area (cm²)	j_{SC} (mA/cm²)	V_{OC} (mV)	*FF* (%)	η (%)
1997	Glunz *et al.*	1	40.1	688	77.8	21.4
2002	Dicker *et al.*	1	39.8	698	79.4	22.1
2008	Granek *et al.*	4	38.8	665	82.5	21.3
2010	Reichel *et al.*	4	41.0	706	78.5	22.7
2012	Reichel *et al.*	4	41.2	697	80.0	23.0

Preparation (9 steps)

Wafer cleaning, texturing, …

Junction Formation (28 steps)

Cleaning, Diffusion, Structuring, …

3 Photolithography
3 Diffusion processes

Surface Passivation (9 steps)

Cleaning , Front- and Rear passivation

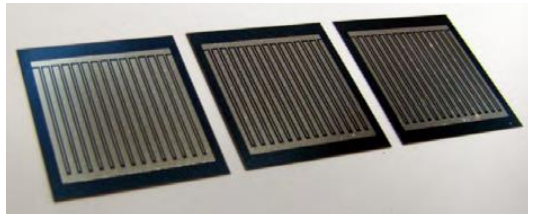
Metallization (12 steps)

Contact opening, evaporation and separation

2 Photolithography

Back-Contact Back-Junction Silicon Solar Cells

Development at Fraunhofer ISE



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Preparation (9 steps)

Wafer cleaning, texturing, …

Junction Formation (28 steps)

Cleaning, Diffusion, Structuring, …

3 Photolithography
3 Diffusion processes

1 Pre-deposition
1 Co-Diffusion

Surface Passivation (9 steps)

Cleaning , Front- and Rear passivation

Metallization (12 steps)

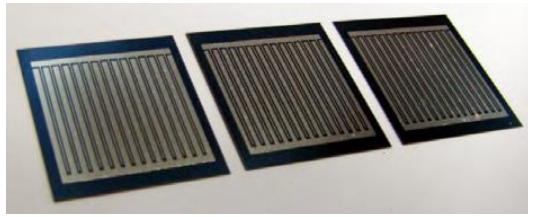
Contact opening, evaporation and separation

2 Photolithography

1 Screen printing

Back-Contact Back-Junction Silicon Solar Cells

Leanest process option

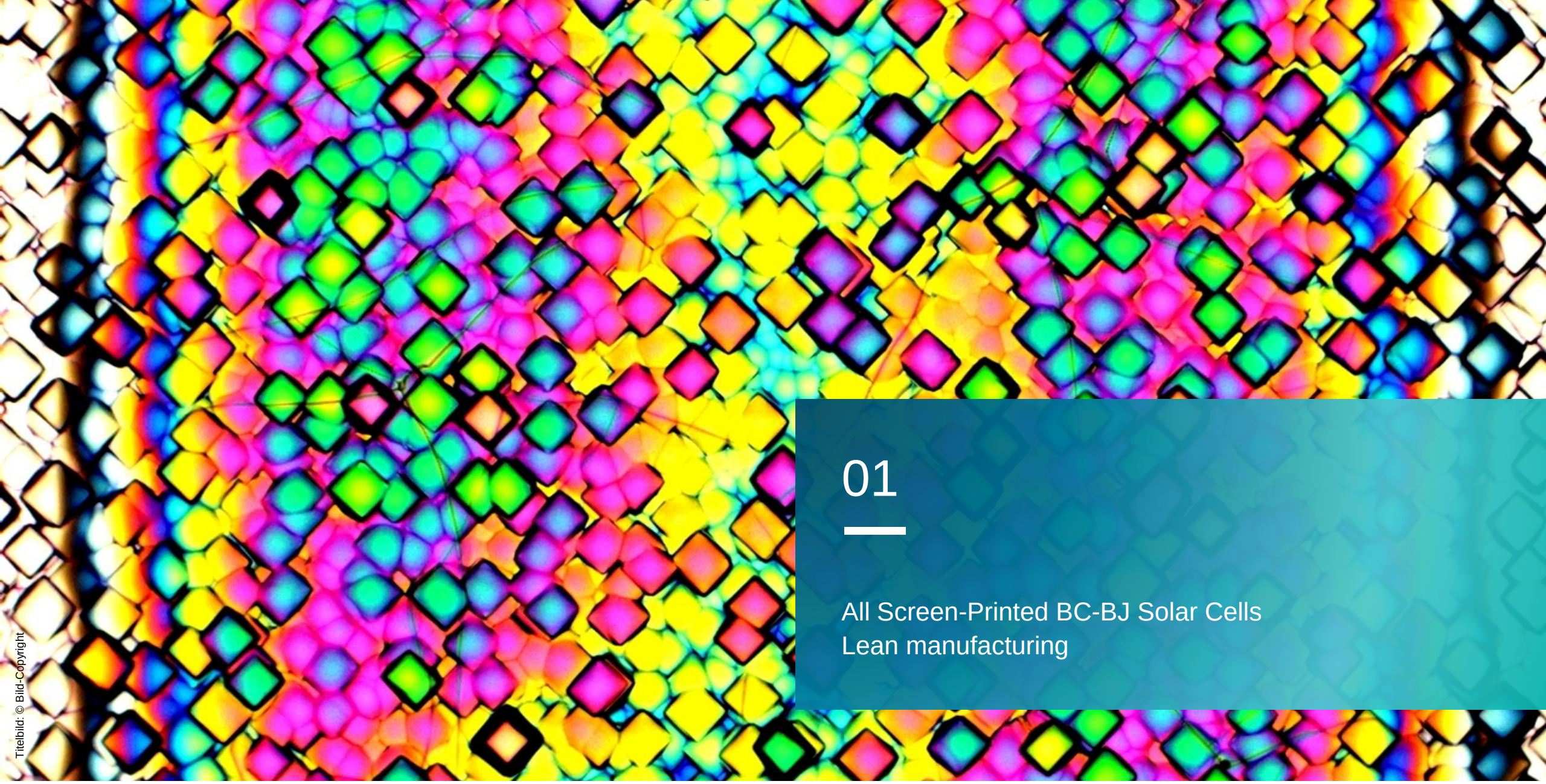


Our approach to minimize production effort

- Utilize one-sided inline processes for wet chemistry*
  - Texturing, front side etch-back
- Implement Co-Diffusion with screen-printed BSG
  - Co-Diffusion with $POCl_3$ (2-in-1, 3-in-1)
  - 3-in-1: Profile optimized for front side etch-back
- Use high quality surface passivation
  - ALD Al_2O_3 / PECVD SiN_x stack for rear side
- Realize metallization with single screen printing step
  - Suitable metallization and pattern for interconnection

* Not demonstrated, realized with masked batch processes

Preparation (9 steps) Wafer cleaning, texturing, …	**Preparation (3 steps)**
Junction Formation (28 steps) Cleaning, Diffusion, Structuring, …	**Junction Formation (4 steps)**
Surface Passivation (9 steps) Cleaning, Front- and Rear passivation	**Surface Passivation (5 steps)**
Metallization (12 steps) Contact opening, evaporation and separation	**Metallization (2 steps)**



01

All Screen-Printed BC-BJ Solar Cells
Lean manufacturing

Titelbild: © Bild-Copyright

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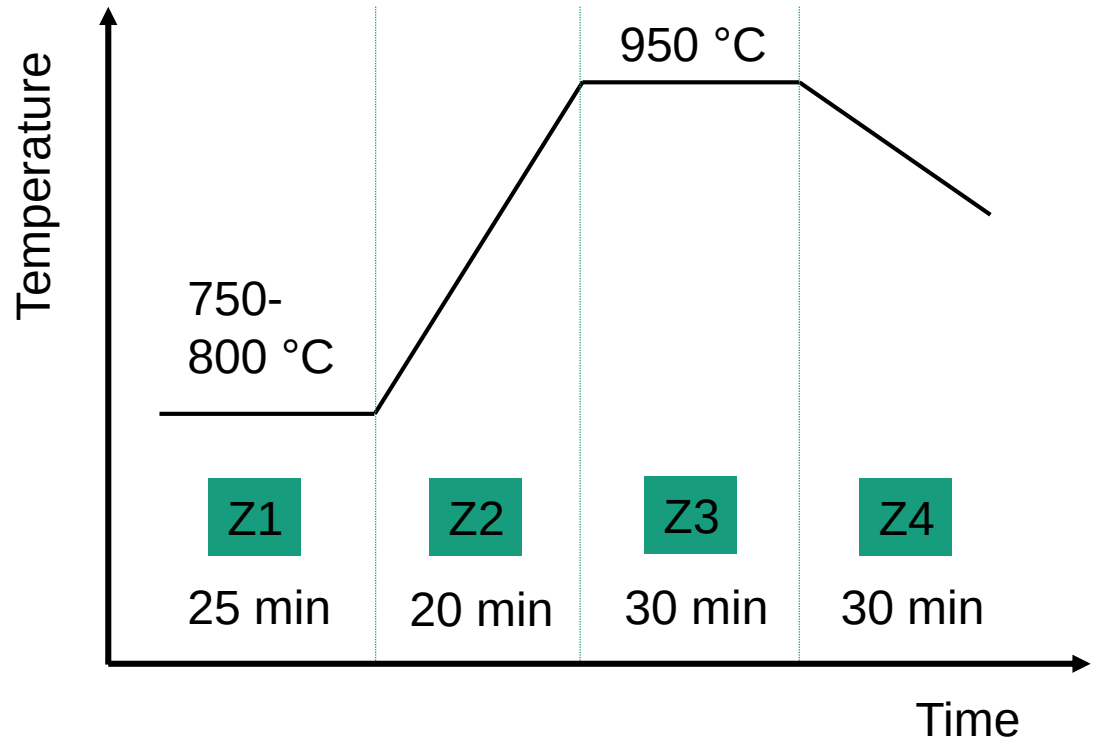
Back-Contact Back-Junction Silicon Solar Cells

Leanest process option

Co-diffusion setup

- Pre-deposition of (suitable) dopant sources
  - PVD, PECVD, APCVD, Functional materials (printing), …
  - Structuring if necessary
- Additional pre-deposition *in-situ* as an option
  - *e.g.* using POCl3 at medium elevated temperatures (750 °C – 800 °C)
- Drive-in of dopants at elevated temperature
  - *e.g.* at 950 °C for proper boron doping
- Challenges
  - Higher doping of P than B
  - Interference of B and P sources
  - Stability of sources
  - …

Schematic of Co-Diffusion



Back-Contact Back-Junction Silicon Solar Cells

Leanest process option

Sol-Gel based BSG-paste

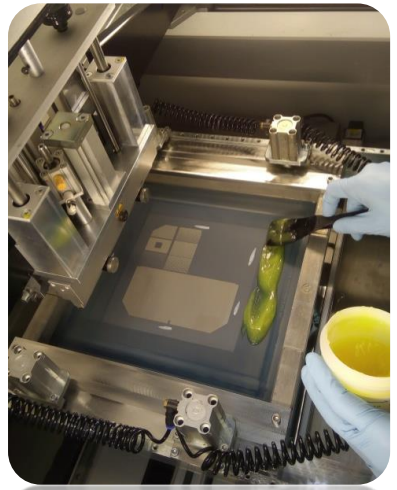
- Adjusted synthesis process aiming at screen printing
- Drying / Solidification after printing at medium temperatures

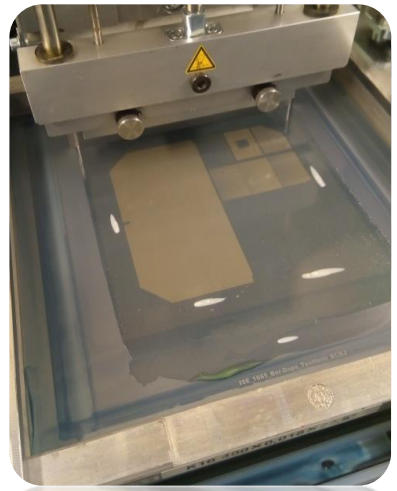
- Achieved feature sizes
  - Positive: 89 µm ± 5 µm
  - Negative: 71 µm ± 4 µm
- Much smaller than necessary for BCBJ

- Diffusion of up to 1.8 x 10^{20} cm^{-3} at wafer surface (950 °C, 30 min)
  - Sheet resistance down to 35 Ω/□
- Blocking of $POCl_3$ doping

- Cleaning with HF or adjusted etching
  - Surface passivation down to 62 fA/cm^2 (46 Ω/□, ALD Al_2O_3)

- Also compatible with laser doping



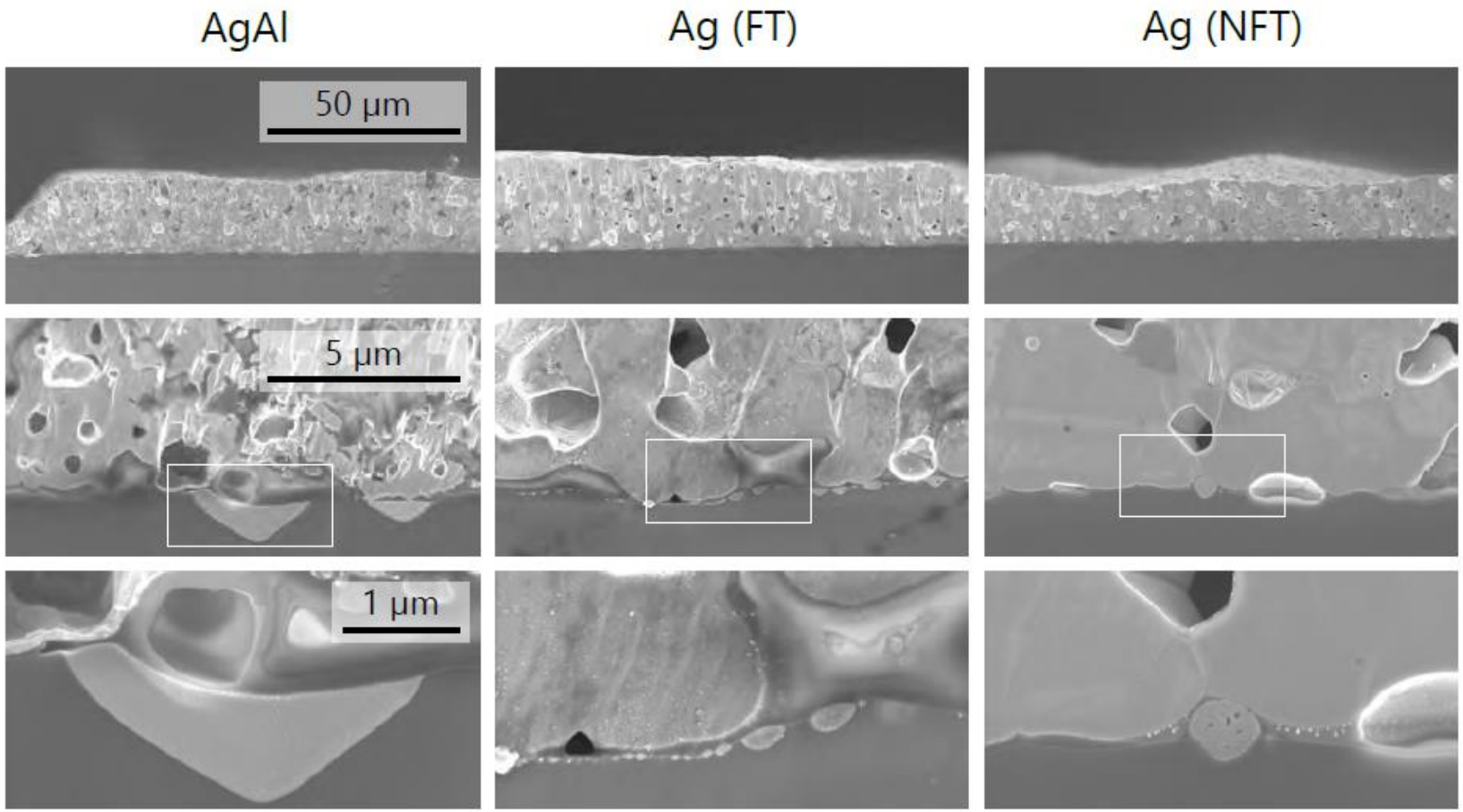


Back-Contact Back-Junction Silicon Solar Cells

Leanest process option

Screen printed metallization

- Testing of Ag and AgAl pastes for p^{++} and n^{++} doping
  - Ag paste with and without “Fire-Through” properties
- Ag contacts on (planar) surfaces with p^{++} doping
  - AgAl: 1.3 mΩ / cm²
  - Ag (FT): 1.2 mΩ / cm²
  - Ag (NFT): 2.6 mΩ / cm² (w/ LCO)
- Contact resistivity on n^{++} doping much lower
- Developed layout for half cell interconnection and 24 wires



Back-Contact Back-Junction Silicon Solar Cells

Leanest process option

- Implementation of different process modules into baseline
  - Destruction of baseline due to PV-TEC fire (2017)

	Area (cm²)	j_{SC} (mA/cm²)	V_{OC} (mV)	*FF* (%)	η (%)	
Co-Diffusion PECVD PSG, BSG	4	40.8	664	78.0	21.1	*
Co-Diffusion PECVD PSG + printed BSG	4	40.2	659	77.7	20.6	*
Co-Diffusion $POCl_3$ + printed BSG + etch-back	4	40.2	634	74.4	19.0	
Co-Diffusion $POCl_3$ + printed BSG + etch-back	4	40.5	614	71.4	17.8	◊
All screen printed + etch-back	4	40.5	626	66.1	16.8	◊

Very precise printing accuracy necessary

* Results certified by Fraunhofer ISE CalLab

◊ Process in surrogate laboratory after PV-TEC fire

Preparation (3 steps)

Junction Formation (4 steps)

Surface Passivation (5 steps)

Metallization (2 steps)

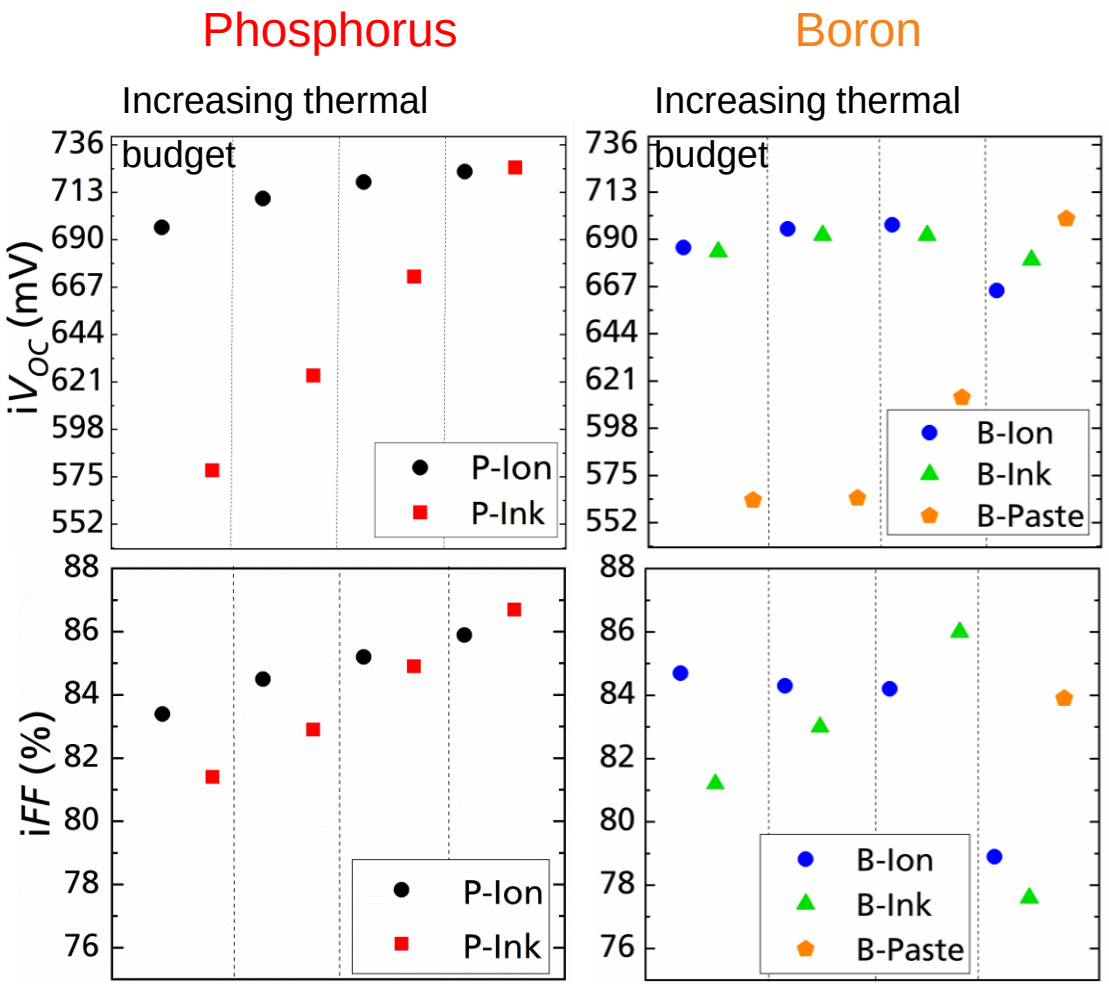
Back-Contact Back-Junction Silicon Solar Cells

TOPCon-IBC with printed dopant sources

- Tested printed dopants on (i) a-Si
- Annealing at different conditions
- iVoc of doped poly-Si can reach similar level as ion implantation

Dopant Source	iV_{oc} (mV)	i*FF* (%)
P-Ion*	732	87.3
P-Ink*	**733**	86.4
B-Ion	698	84.3
B-Ink	**692**	83.2
B-Paste	**700**	83.9

*Results after RPHP



Kiaee *et al.*, EUPVSEC, 2018.

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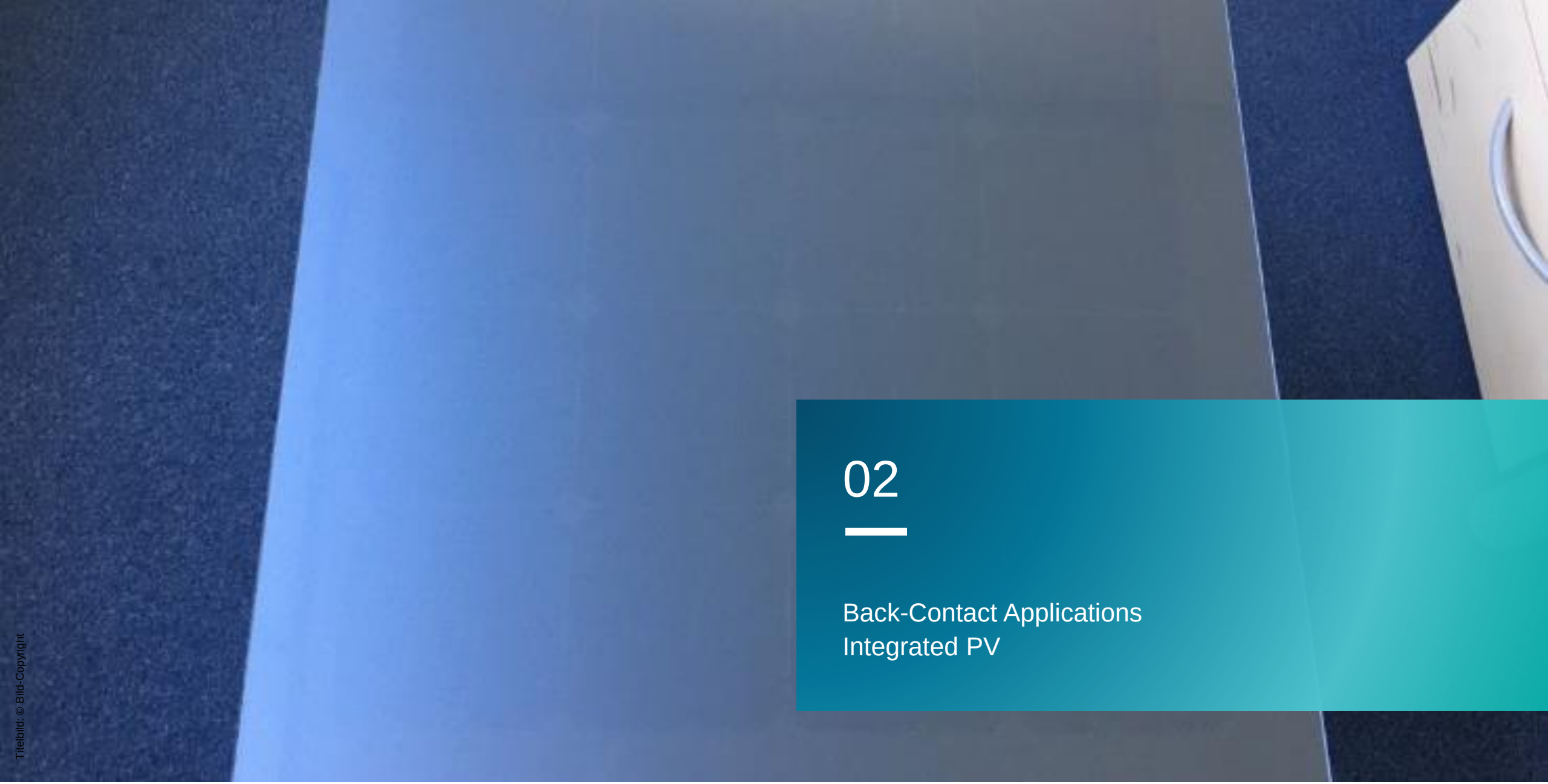

02

Back-Contact Applications
Integrated PV

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Wire interconnection for IBC

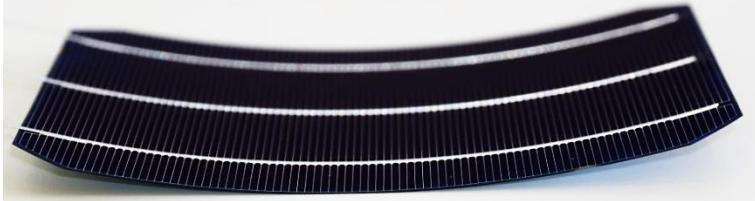
No bow due to super soft wires

Super Soft Wires

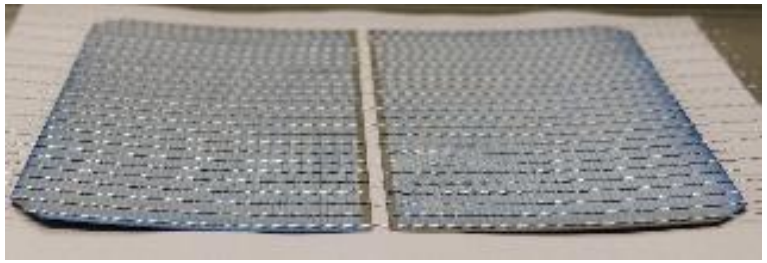
- Developed manufacturing and interconnection process for “super soft wires”
- Wires are wave shaped
  - Reduced stress after soldering process

- Especially useful for back-contact solar cells
  - Demonstrated for BCBJ and MWT

3 ribbons on busbars

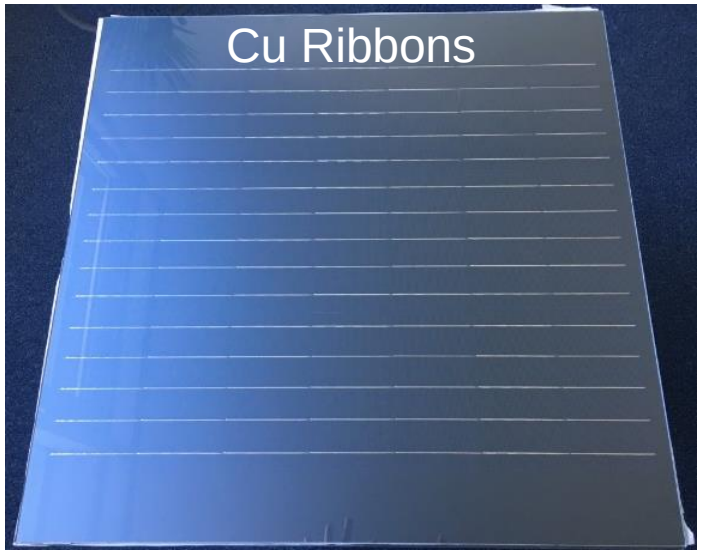


30 wave-shaped wires on fingers



PV everywhere
Integrated PV

- Small sized demo modules
- Different cell interconnection
- Laminates with MorphoColor®



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PV everywhere
Integrated PV

- Supreme architectural options: MorphoColor® coating and low reflective PV components (*i.e.* black)

- BIPV market in Germany
  - Roofs and facade: 37 700 km²
  - Economic potential: 1400 – 4400 GWp (22 % facade)

Wirth *et al.*, 36. PV-Symposium, 2021.

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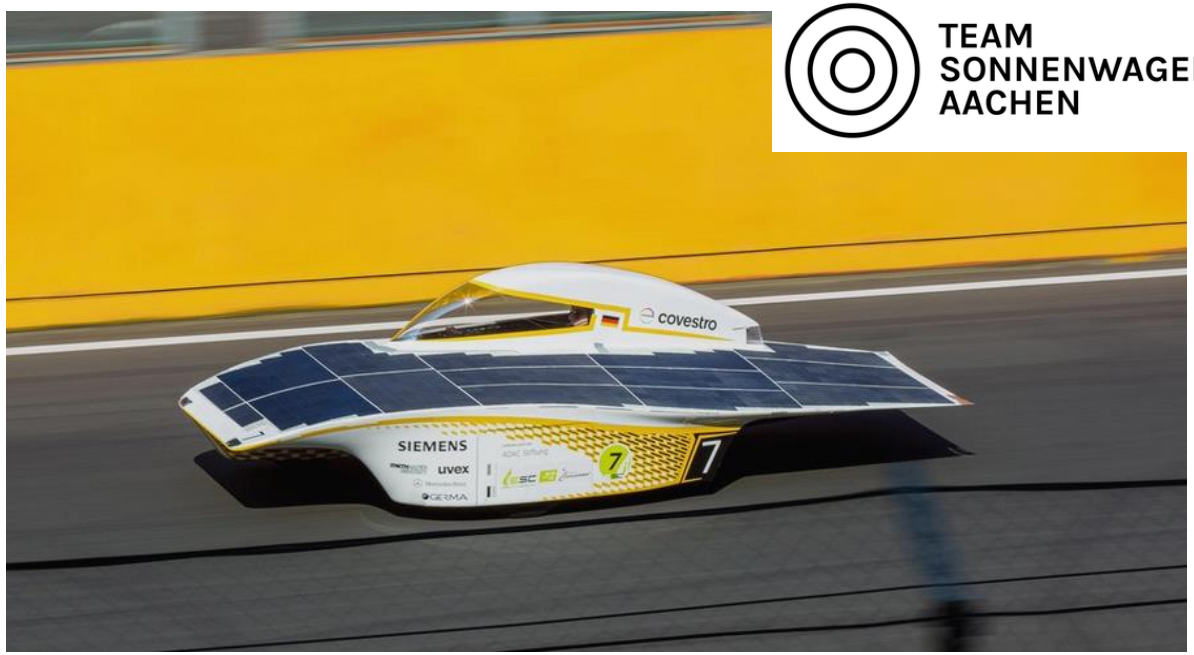
PV everywhere
Integrated PV

- Solar car roofs (Solar challenge)
- 3-10 km / day for EV (today)
- Technical Potential for VIPV in Germany:
  - 25.5 GWp and more (higher integration)



Wirth *et al.,* 36. PV-Symposium, 2021.

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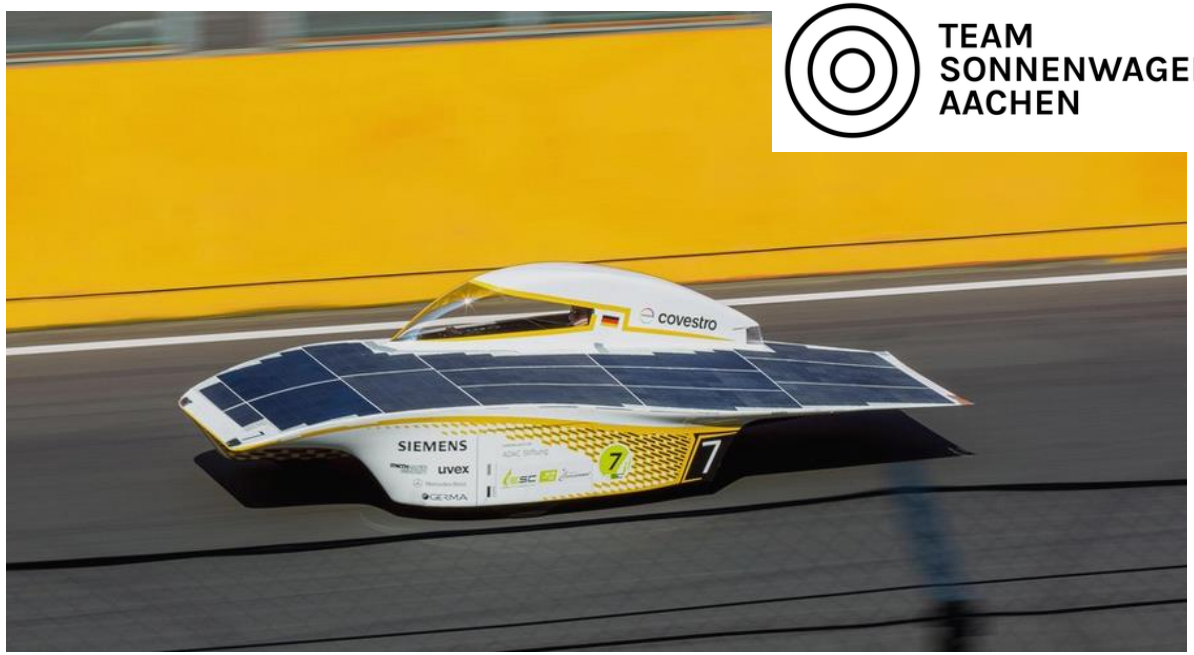
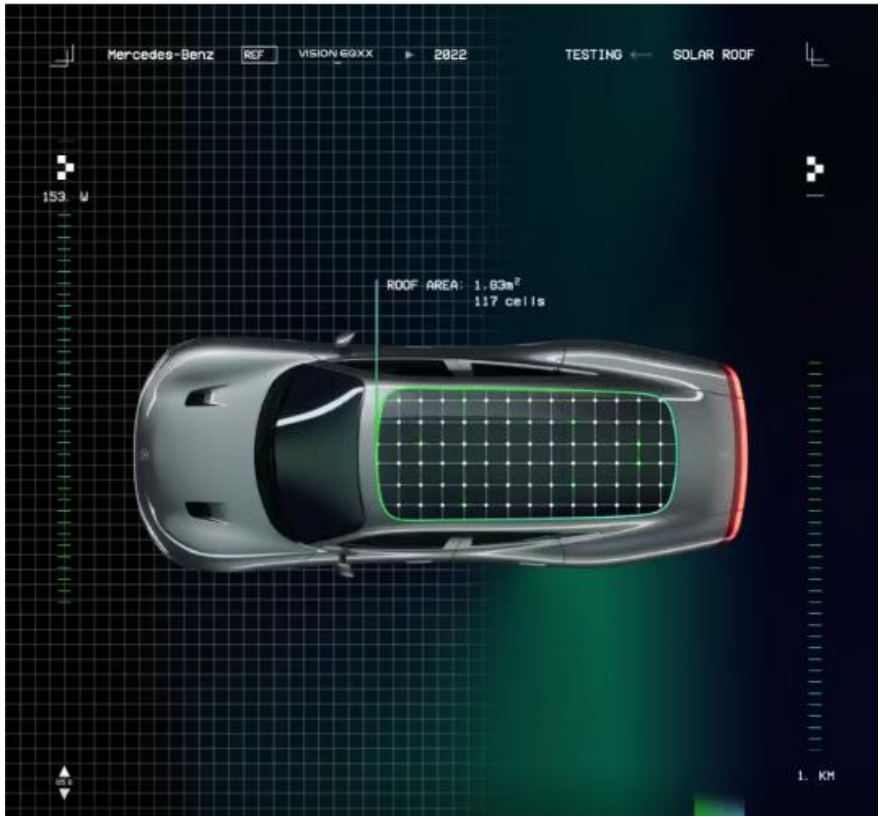


Ola Källenius • 3.+
Vorstandsvorsitzender von Mercedes-Benz
1 Monat • Bearbeitet •
+ Folgen

We are currently intensifying the real-world testing of our #VISIONEQXX to see what the most efficient Mercedes ever built - with a drag coefficient of just 0.17 - can really deliver on the road.

It uses #renewable #energy from the sun to go even further: 117 individual solar cells on the roof turn the vehicle into a solar power plant in its own right, feeding the battery with up to 25 kilometres of extra range.

Übersetzung anzeigen



Wirth *et al.*, 36. PV-Symposium, 2021.

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03

MWT solar cells for BC applications
PERC-based BC devices

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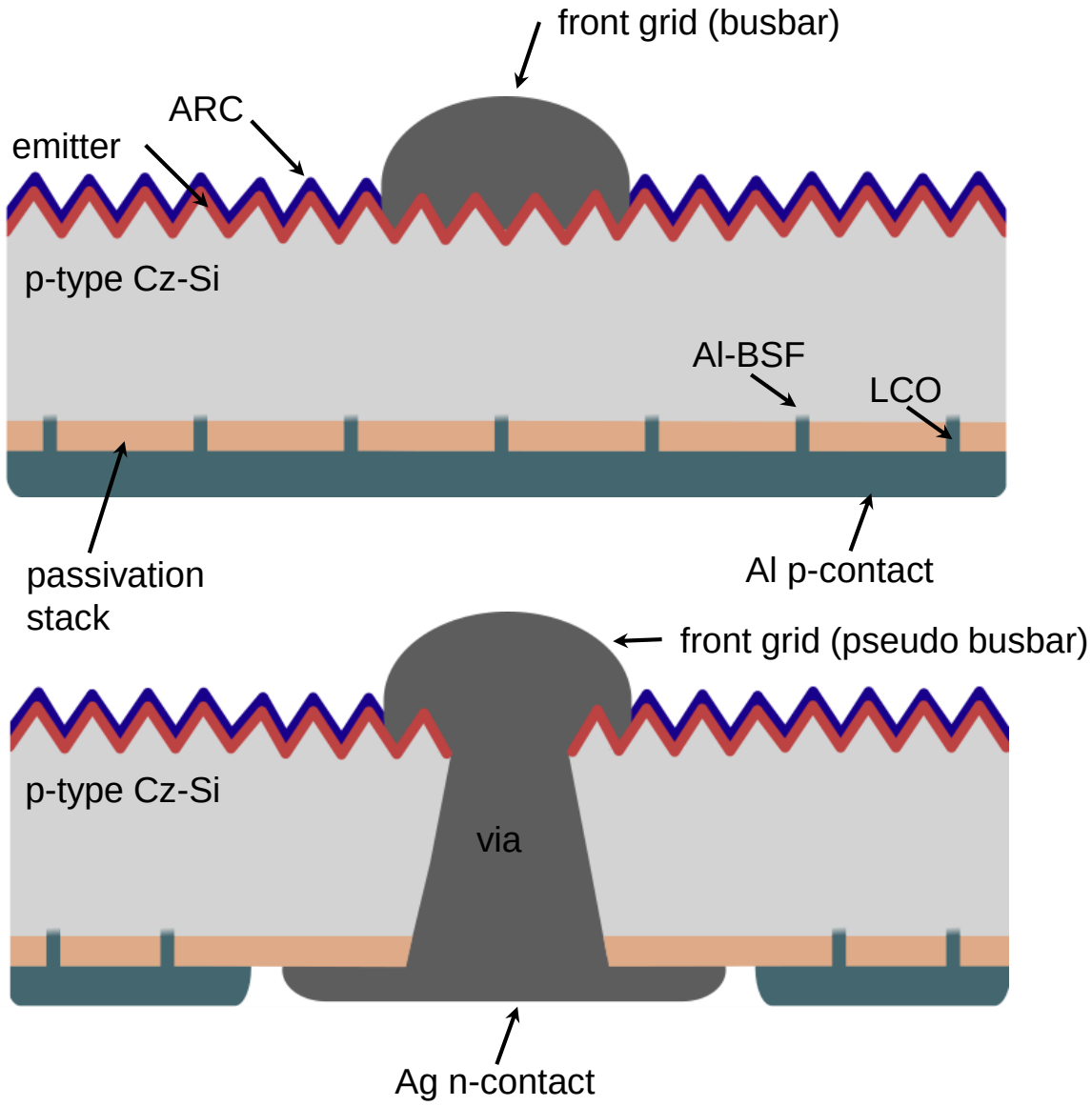
Metal Wrap Through Solar Cells
Based on PERC Front-End Processing

- Improved front side light absorption
- One sided interconnection, tighter spacing

- Fully compatible to standard PERC front-end
  - Using an industrial precursor

Area (cm²)	j_{SC} (mA/cm²)	V_{OC} (mV)	*FF* (%)	η (%)
244	40.2	674	79.2	21.4

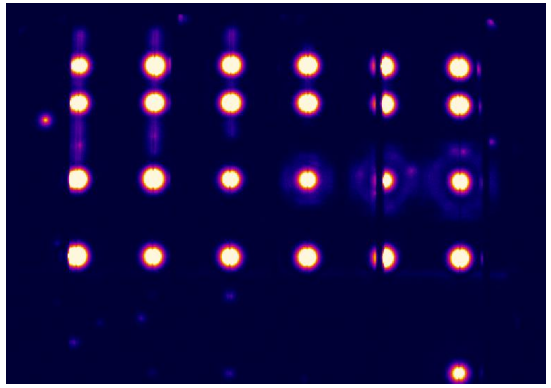
- Layout adaptable to applications (“all-purpose MWT”)
  - Adjustments only in back-end
  - Flexible product size, wafer based processing



Schweigstill *et al.,* EUPVSEC, 2021.

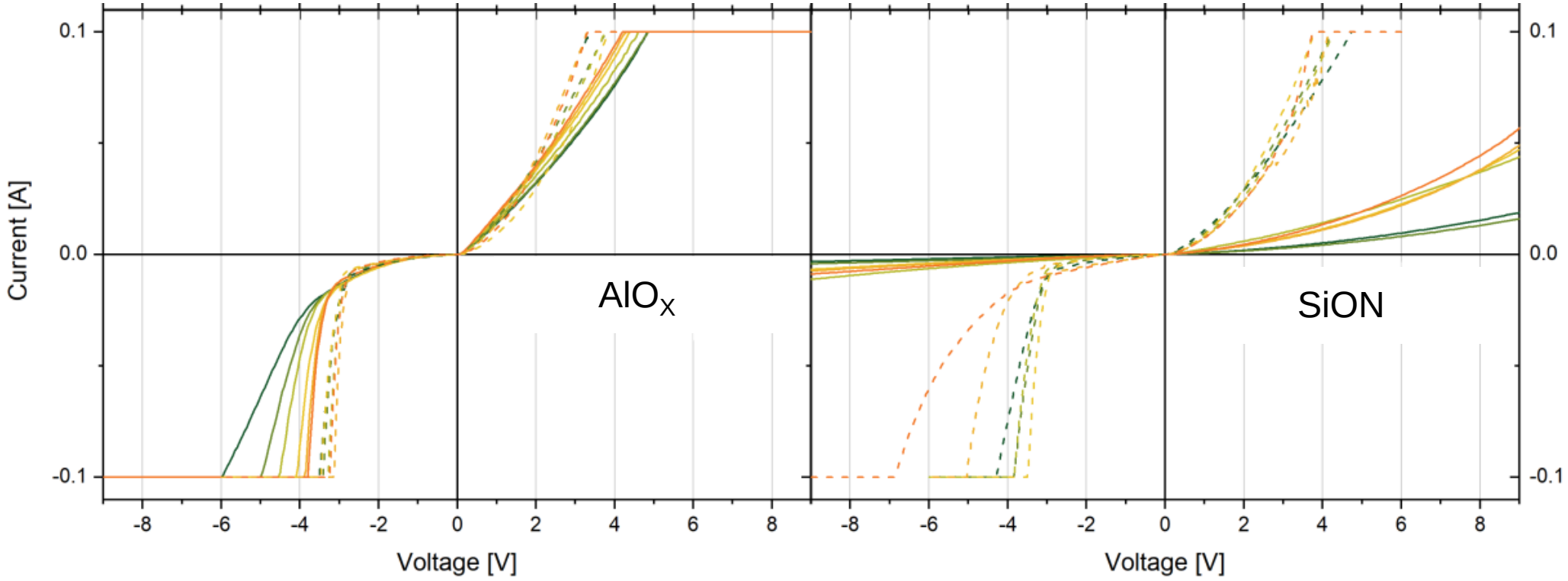
ARC: Anti-reflection coating
BSF: Back surface field
LCO: Local contact opening

Metal Wrap Through Solar Cells
Based on PERC Front-End Processing



- Soft breakdown in reverse bias with charged dielectric
  - Breakdown on n-contact pad

Solid line: with dielectric
Dashed line: with dielectric removed

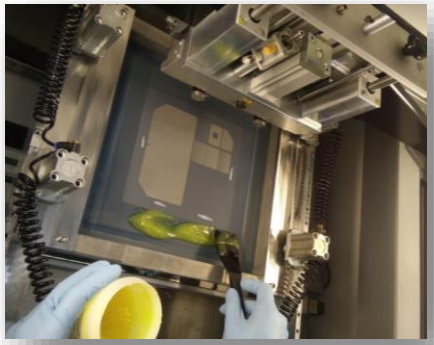


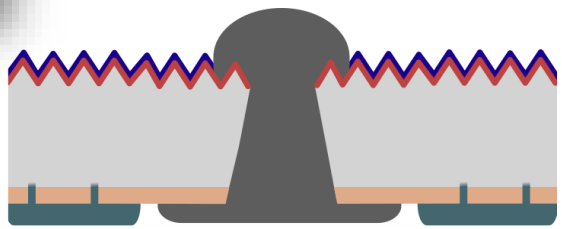
Schweigstill *et al.*, EUPVSEC, 2021.

Back-contact solar cells at Fraunhofer ISE

Summary

- Demonstrated a very lean process flow: „All screen-printed BCBJ“
  - Challenges remain in alignment accuracy
  - Optimization of processes to improve performance
  - Simulated potential of up to 23 % (without pass. contacts)
- Super soft wires for one-sided interconnection
  - Avoiding bow after soldering
- Back-contact a supreme choice for Integrated PV
  - Increased output on smaller areas (cell performance, spacing)
  - Very appealing aesthetics, combination with color coatings
- MWT process compatible to state-of-the-art PERC
  - Keep some advantages of BCBJ
  - Very lean process flow
  - Easily adjustable for different applications in back-end





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