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Passivated Edge Technology (PET): Edge Passivation for Industrial Solar Cell Applications

Elmar Lohmüller, Jonas D. Huyeng, Marc Hofmann, Puzant Baliozian#, Armin Richter, Alexander Göbel, Florian Clement, Ralf Preu

Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstraße 2, 79110 Freiburg, Germany
#now with VDMA Photovoltaic Equipment, Lyoner Str. 18, 60528 Frankfurt am Main, Germany

pv magazine Webinar
July 10, 2023
www.ise.fraunhofer.de

Fraunhofer Institute for Solar Energy Systems (ISE)

Freiburg im Breisgau, Germany

Fraunhofer ISE

- Founded in 1981
- Largest solar energy research institute in Europe
- About 1400 employees
- Budget 2022: € 107.0 million (20% industry)

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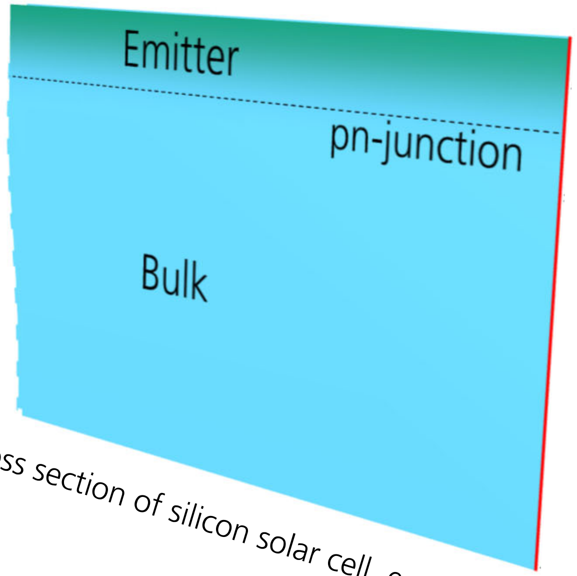
Motivation

What Is Edge Recombination?

Edge recombination differs by edge region[1]



Simplified cross section of silicon solar cell, e.g. PERC or TOPCon

[1] S. Glunz et al., 29th IEEE PVSC, 2002.

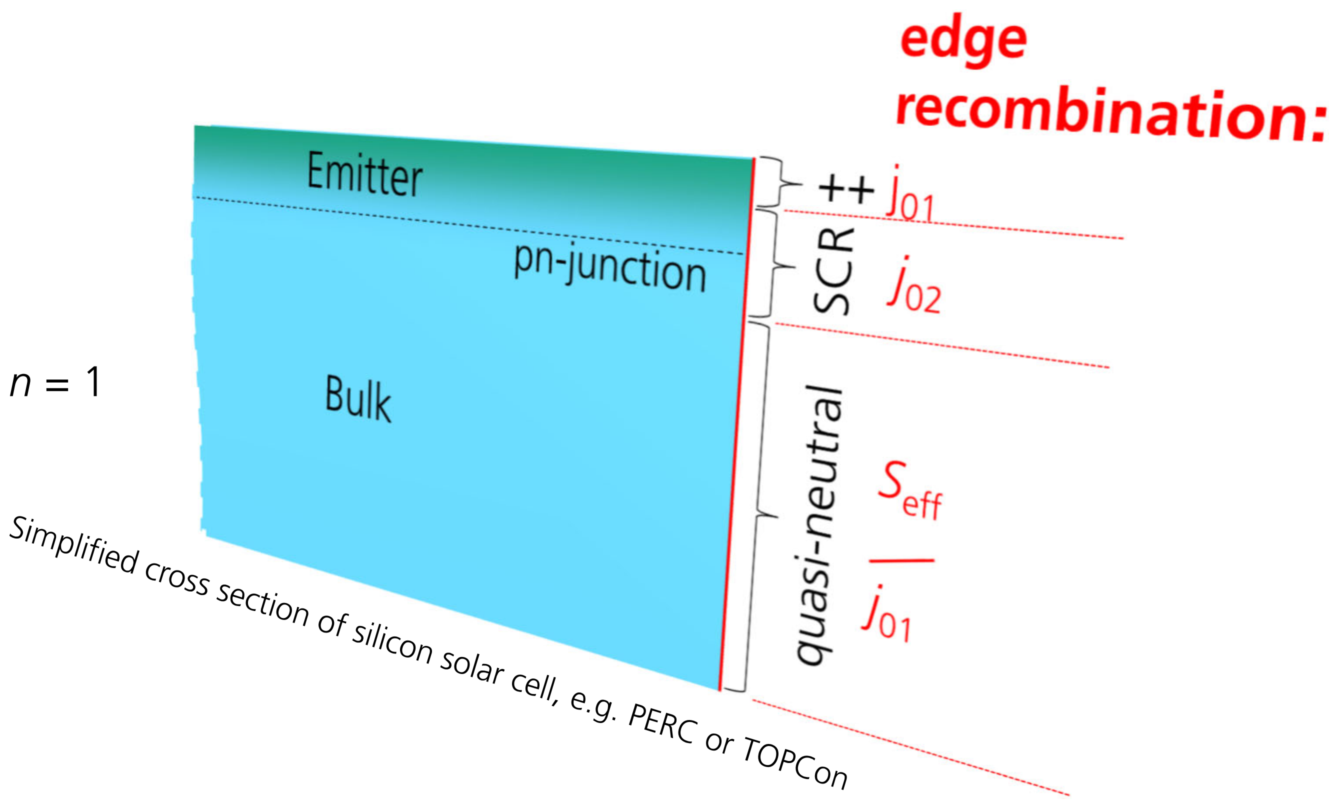
Motivation

What Is Edge Recombination?

Edge recombination differs by edge region[1]

Three regions

- Highly-doped **emitter** (++) surface
  - "Regular" surface recombination with ideality factor n = 1
- **Space charge region (SCR)** surface
  - "j_{02}"-recombination" with n = 2
- **Bulk** surface
  - "Regular" surface recombination with n = 1



j_{01}: dark saturation current density with idealitiy factor n = 1

j_{02}: dark saturation current density with idealitiy factor n = 2

S_{eff}: effective surface recombination velocity

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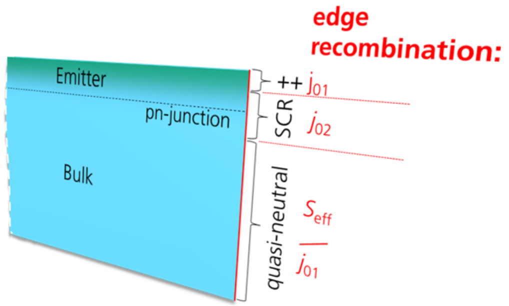
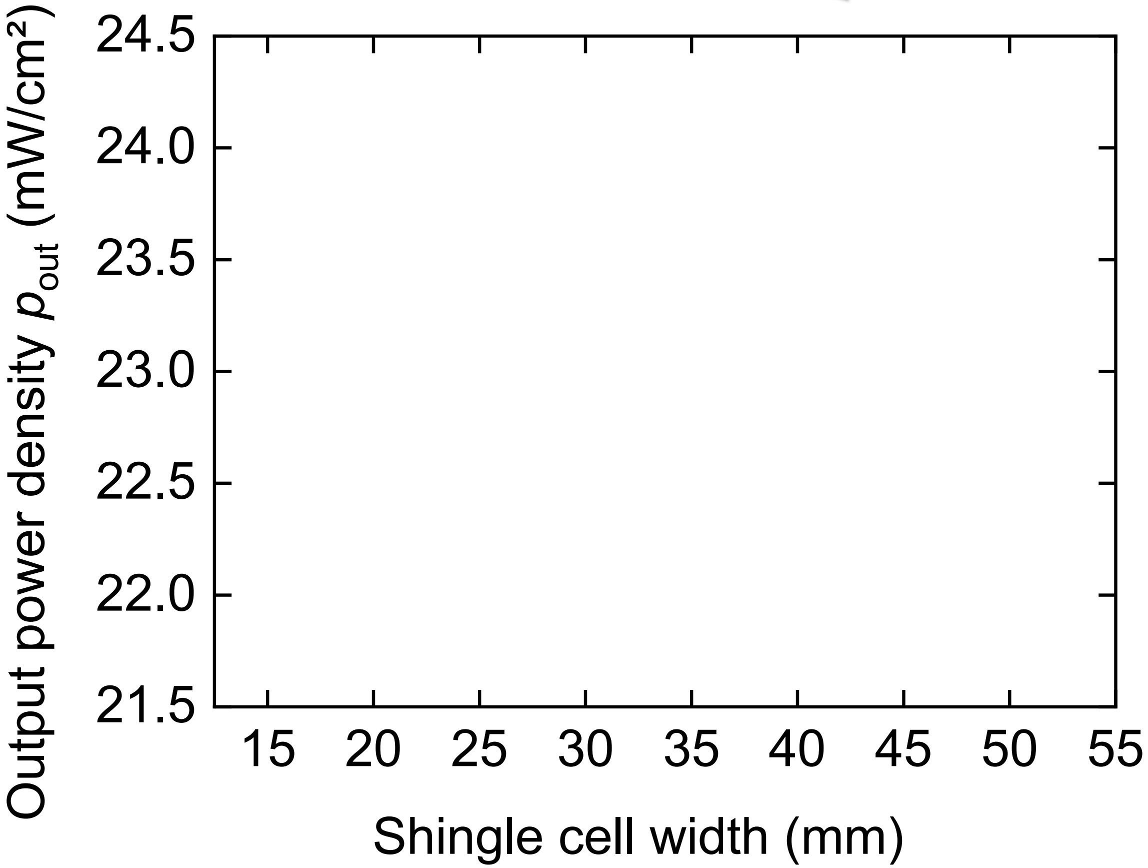
Motivation

Why Do We Need Edge Passivation?



Simulation results on bifacial PERC shingle solar cells[1]



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Motivation

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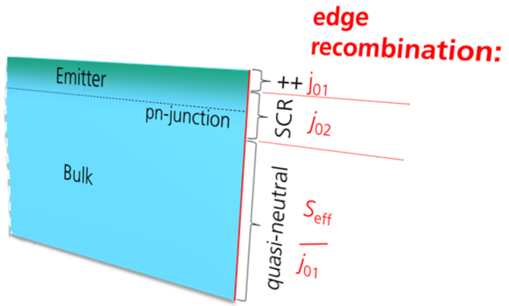
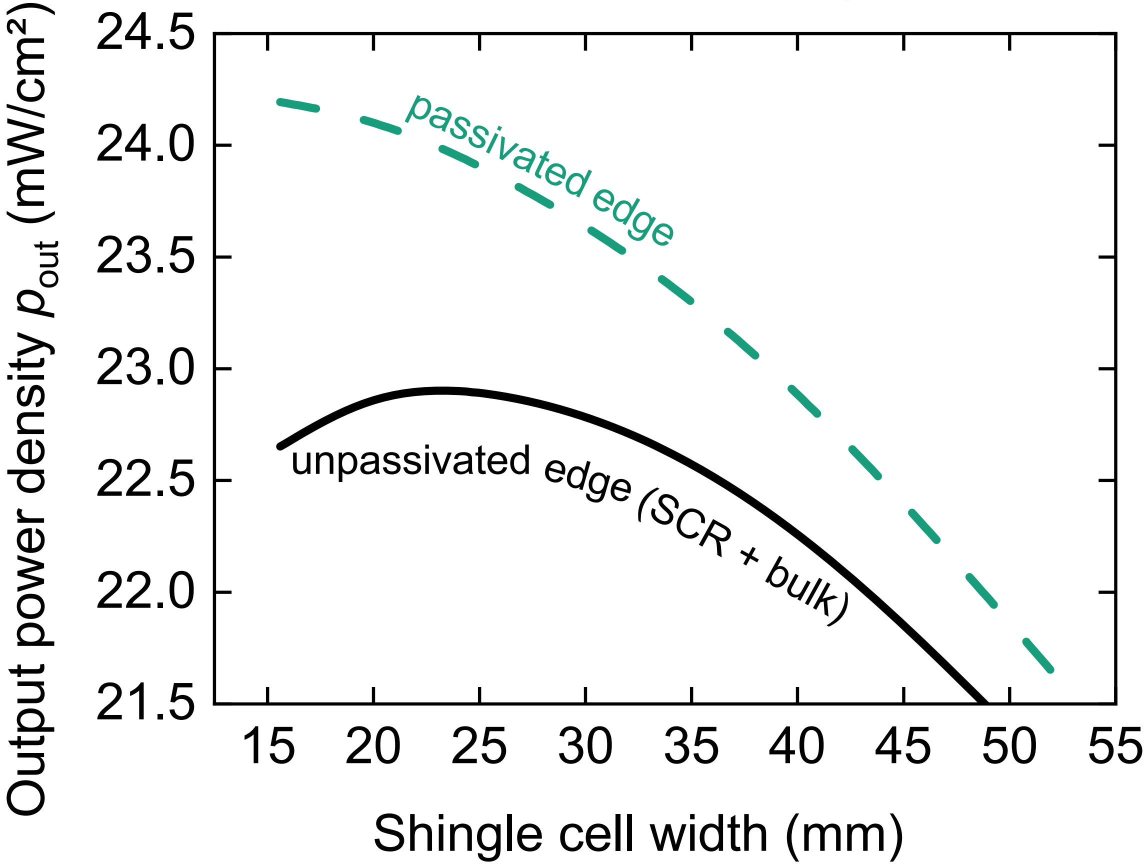
Simulation results on bifacial PERC shingle solar cells[1]

- Edge passivation boosts output power density / efficiency
  - The smaller the cell width is, the larger is the benefit
  - For 25 mm cell width ➔ 1 mW/cm² gain with edge passivation





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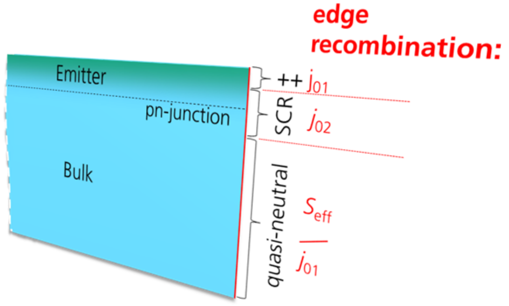

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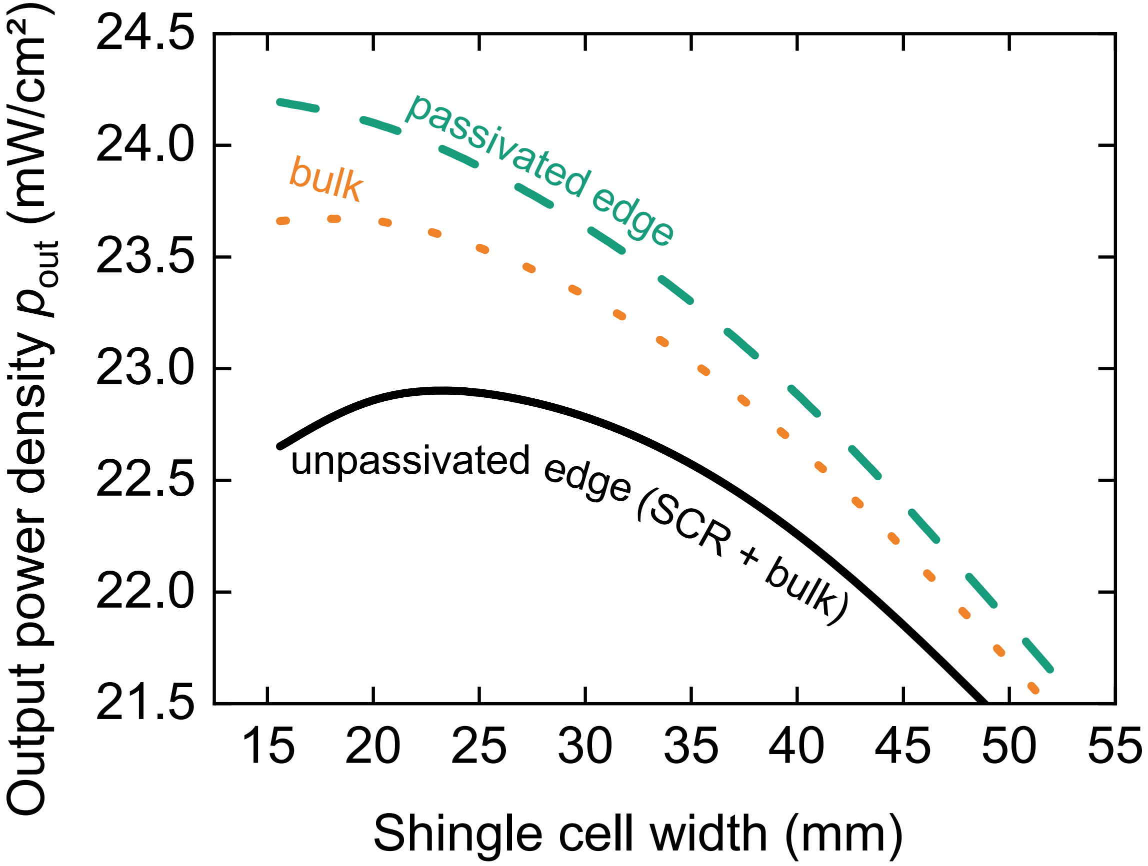

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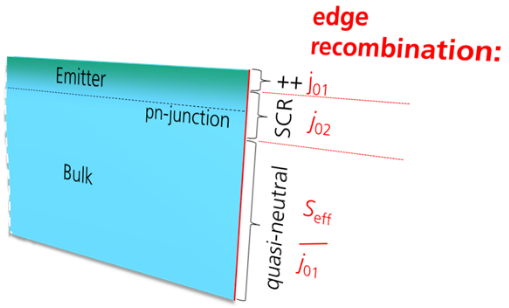

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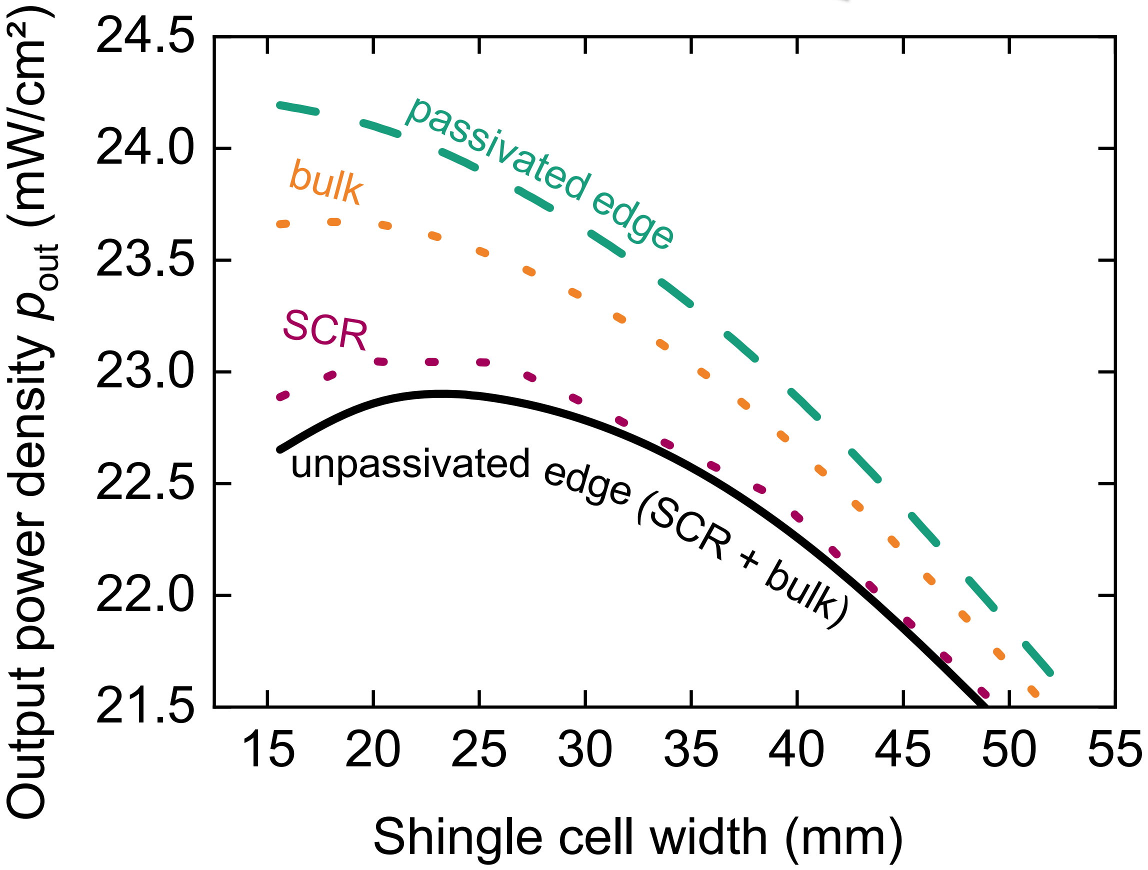
- Suppression of "regular" bulk recombination j_{01}
  - Small gain in open-circuit voltage V_{OC}
- Suppression of "j_{02}"-recombination at SCR
  - Significant gain in pseudo fill factor *pFF* (and thus in *FF*)



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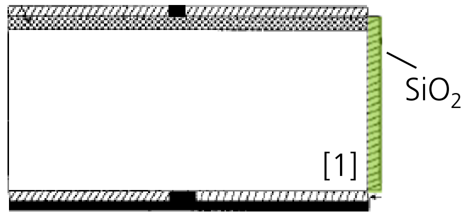
Edge Passivation
Technologies

- Native grown SiO_2 layer on cell edge[1]



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Edge Passivation

Technologies

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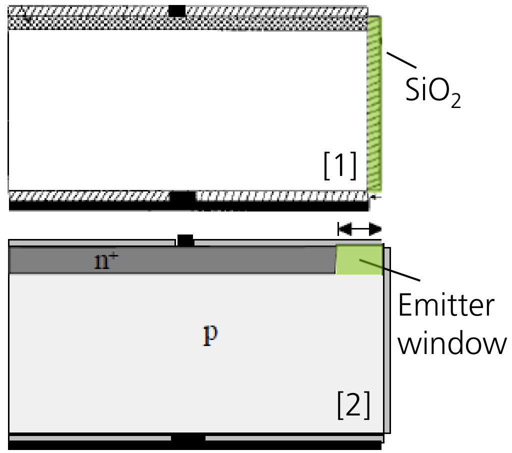
- Emitter window that keeps space charge region away from edge[2]



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Edge Passivation

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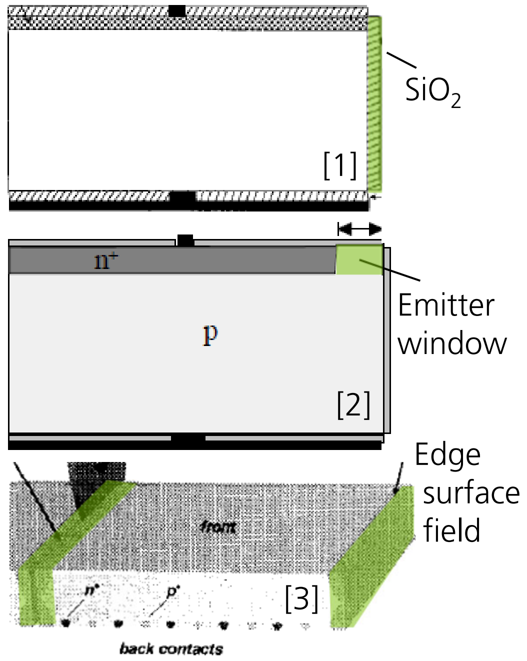

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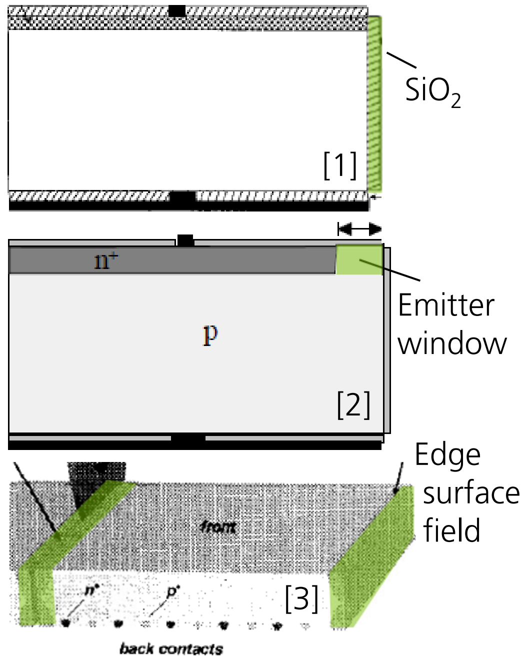

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[3] W. Mulligan et al., IEEE PVSC, 2000.
[4] D.D. Tune et al., EU-PVSEC, 2021.
[5] W. Li et al., Adv. Energy and Sustain. Res., 2022.

Edge Passivation

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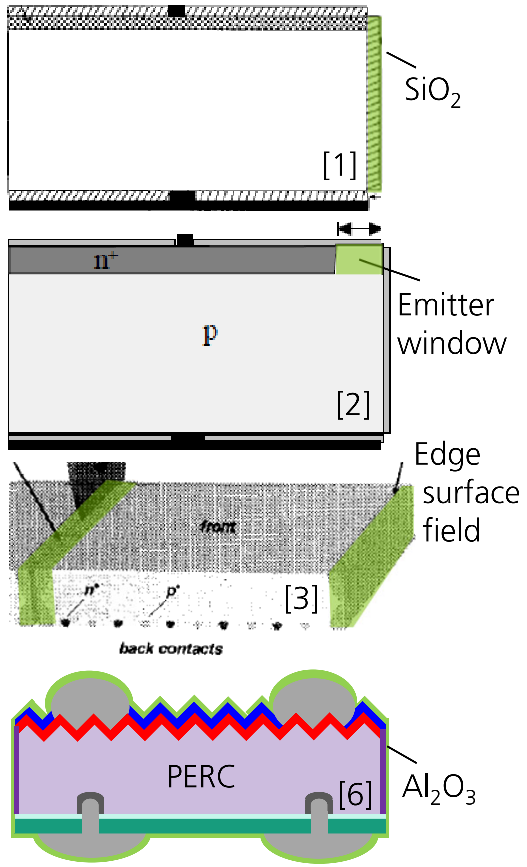
- Usage of organic solutions basing on Nafion[4,5]
- **Passivated edge technology (PET)**[6]
  - Introduced by Fraunhofer ISE in 2019
  - Deposition/formation of dielectric passivation layer on cell edge
  - Performed after cell cutting



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[6] P. Baliozian et al., IEEE J. Photovoltaics, 2020.

Fraunhofer ISE

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(10) DE 10 2018 123 485 B4 2021.04.08

(12) Patentschrift

(21) Aktenzeichen: **10 2018 123 485.6**
(22) Anmeldetag: **24.09.2018**
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(74) Vertreter:
Lemcke, Brommer & Partner, Patentanwälte Partnerschaft mbB, 76135 Karlsruhe, DE

(72) Erfinder:
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DE	10 2009 026 410	A1
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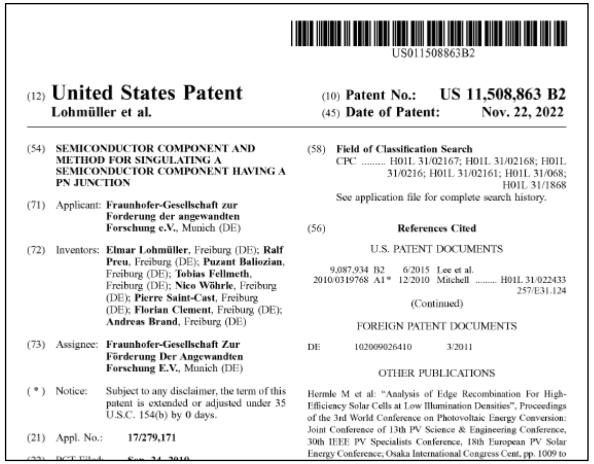

US011508863B2

(12) **United States Patent**
Lohmüller et al.

(10) **Patent No.: US 11,508,863 B2**
(45) **Date of Patent: Nov. 22, 2022**

(54) **SEMICONDUCTOR COMPONENT AND METHOD FOR SINGULATING A SEMICONDUCTOR COMPONENT HAVING A PN JUNCTION**

(71) Applicant: **Fraunhofer-Gesellschaft zur Forderung der angewandten Forschung e.V.**, Munich (DE)

(72) Inventors: **Elmar Lohmüller**, Freiburg (DE); **Ralf Preu**, Freiburg (DE); **Puzant Baliozian**, Freiburg (DE); **Tobias Fellmeth**, Freiburg (DE); **Nico Wöhrle**, Freiburg (DE); **Pierre Saint-Cast**, Freiburg (DE); **Florian Clement**, Freiburg (DE); **Andreas Brand**, Freiburg (DE)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/279,171**

(58) **Field of Classification Search**
CPC H01L 31/02167; H01L 31/02168; H01L 31/0216; H01L 31/02161; H01L 31/068; H01L 31/1868
See application file for complete search history.

(56) **References Cited**

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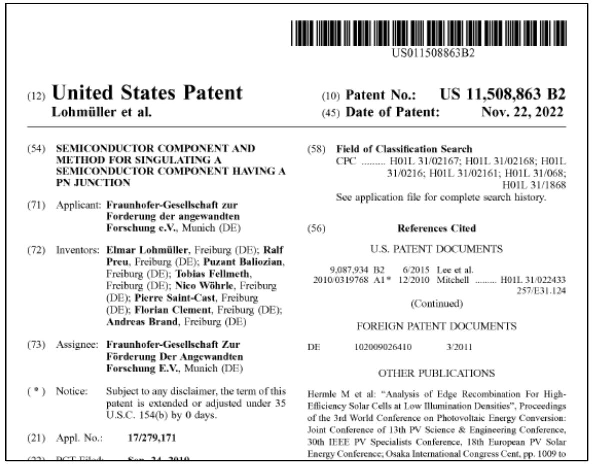

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  - First demonstration on tunnel-oxide passivated contact (**TOPCon**) shingle cells[4]
  - Transfer to high-throughput ALD tool[5] and demonstration on **TOPCon** shingle cells[6]

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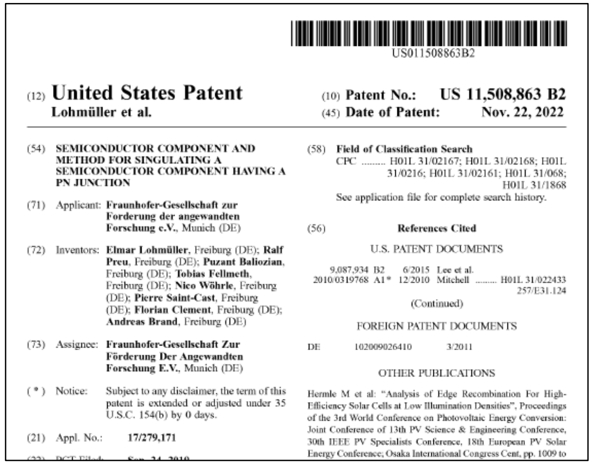

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(72) Inventors: **Elmar Lohmüller**, Freiburg (DE); **Ralf Preu**, Freiburg (DE); **Puzant Baliozian**, Freiburg (DE); **Tobias Fellmeth**, Freiburg (DE); **Nico Wöhrle**, Freiburg (DE); **Pierre Saint-Cast**, Freiburg (DE); **Florian Clement**, Freiburg (DE); **Andreas Brand**, Freiburg (DE)

(73) Assignee: **Fraunhofer-Gesellschaft Zur Förderung Der Angewandten Forschung E.V.**, Munich (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/279,171**

(58) **Field of Classification Search**
CPC H01L 31/02167; H01L 31/02168; H01L 31/0216; H01L 31/02161; H01L 31/068; H01L 31/1868
See application file for complete search history.

(56) **References Cited**

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2010/0319768 A1* 12/2010 Mitchell H01L 31/022433 257/E31.124

(Continued)

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[1] P. Baliozian et al., IEEE J. Photovolt., 2020.
[2] P. Baliozian et al., Photovoltaics Int., 2019.
[3] A. Münzer et al., IEEE J. Photovoltaics, 2021.
[4] E. Lohmüller et al., Progress Photov., 2023.
[5] M. Hofmann et al., Solar RRL, to be published.
[6] E. Lohmüller et al., Solmat, 2023.

Fraunhofer ISE

Passivated Edge Technology (PET)

Milestones

Fraunhofer ISE

- 2018: Patent application (already granted in Germany and USA)
- 2019: First publications with application to bifacial **PERC** shingle solar cells[1,2] using Al_2O_3 by atomic layer deposition (ALD)
- 2021: First demonstration on silicon heterojunction (**SHJ**) half solar cells[3]
- 2022/2023
  - First demonstration on tunnel-oxide passivated contact (**TOPCon**) shingle cells[4]
  - Transfer to high-throughput ALD tool[5] and demonstration on **TOPCon** shingle cells[6]

Others

- 2020 (CEA-INES): First demonstration on **SHJ** shingle cells[7]
- 2023 (Singulus): Generis PET tool[8]

PET approach is "**industry ready**" and compatible with **PERC, TOPCon,** and **SHJ** cells


(19) Deutsches Patent- und Markenamt

(10) DE 10 2018 123 485 B4 2021.04.08

(12) Patentschrift

(21) Aktenzeichen: 10 2018 123 485.6
(22) Anmeldetag: 24.09.2018
(43) Offenlegungstag: 26.03.2020
(45) Veröffentlichungstag der Patenterteilung: 08.04.2021

(51) Int Cl.: H01L 31/18 (2006.01)
H01L 31/0216 (2014.01)
H01L 23/29 (2006.01)
H01L 21/301 (2006.01)

Innerhalb von neun Monaten nach Veröffentlichung der Patenterteilung kann nach § 59 Patentgesetz gegen das Patent Einspruch erhoben werden. Der Einspruch ist schriftlich zu erklären und zu begründen. Innerhalb der Einspruchsfrist ist eine Einspruchsgebühr in Höhe von 200 Euro zu entrichten (§ 6 Patentkostengesetz in Verbindung mit der Anlage zu § 2 Abs. 1 Patentkostengesetz).

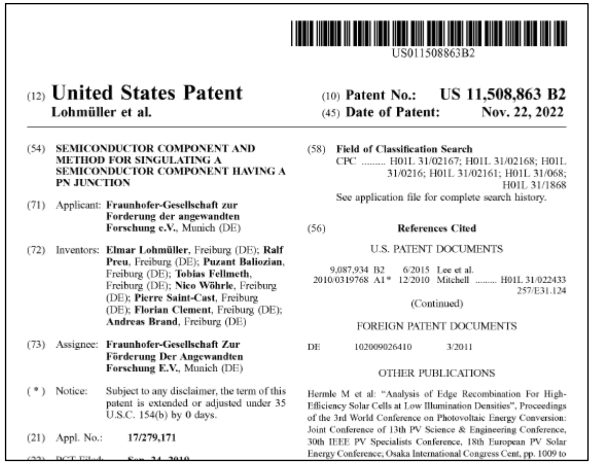
(73) Patentinhaber: Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., 80686 München, DE

(74) Vertreter: Lemcke, Brommer & Partner, Patentanwälte Partnerschaft mbB, 76135 Karlsruhe, DE

(72) Erfinder: Lohmüller, Elmar, Dr., 79110 Freiburg, DE; Preu, Ralf, Dr., 79110 Freiburg, DE; Baliozian, Puzant, Freiburg, DE; Wöhrle, Nico, Dr., 79110 Freiburg, DE; Saint-Cast, Pierre, 79110 Freiburg, DE; Clement, Florian, Dr., 79110 Freiburg, DE; Brand, Andreas, 79110 Freiburg, DE

(56) Ermittelter Stand der Technik:
DE 10 2009 026 410 A1
US 9 087 934 B2

SZE, S.M.: Physics of Semiconductor Devices.


US011508863B2

(12) United States Patent
Lohmüller et al.

(10) Patent No.: US 11,508,863 B2
(45) Date of Patent: Nov. 22, 2022

(54) SEMICONDUCTOR COMPONENT AND METHOD FOR SINGULATING A SEMICONDUCTOR COMPONENT HAVING A PN JUNCTION

(71) Applicant: Fraunhofer-Gesellschaft zur Forderung der angewandten Forschung e.V., Munich (DE)

(72) Inventors: Elmar Lohmüller, Freiburg (DE); Ralf Preu, Freiburg (DE); Puzant Baliozian, Freiburg (DE); Tobias Fellmeth, Freiburg (DE); Nico Wöhrle, Freiburg (DE); Pierre Saint-Cast, Freiburg (DE); Florian Clement, Freiburg (DE); Andreas Brand, Freiburg (DE)

(73) Assignee: Fraunhofer-Gesellschaft Zur Förderung Der Angewandten Forschung E.V., Munich (DE)

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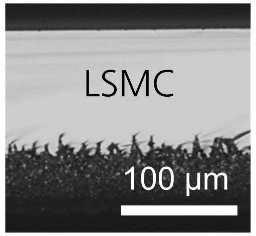
[3] A. Münzer et al., IEEE J. Photovoltaics, 2021.
[4] E. Lohmüller et al., Progress Photov., 2023.
[5] M. Hofmann et al., Solar RRL, to be published.
[6] E. Lohmüller et al., Solmat, 2023.
[7] S. Harrison et al., EU-PVSEC, 2020.
[8] Singulus, press release, 2023.

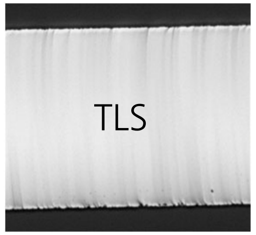
Fraunhofer ISE

Cell Cutting
Technologies

- „Conventional“
  - Laser scribe and mechanical cleaving (LSMC)[1]

- „Low-damage“
  - Thermal laser separation (TLS)[2]
  - Laser induced cutting (LIC)[3]
  - Laser direct cleaving (LDC)[4]
  - 45° rotated silicon brick and wafer fabrication[5]





TLS @ Fraunhofer ISE: microDICE (3D-Micromac)

[1] M. Oswald et al., EU-PVSEC, 2013.
[2] H.-U. Zuehlke et al., ISSM, 2008.
[3] S. Weinhold et al., LAMOM, 2014.
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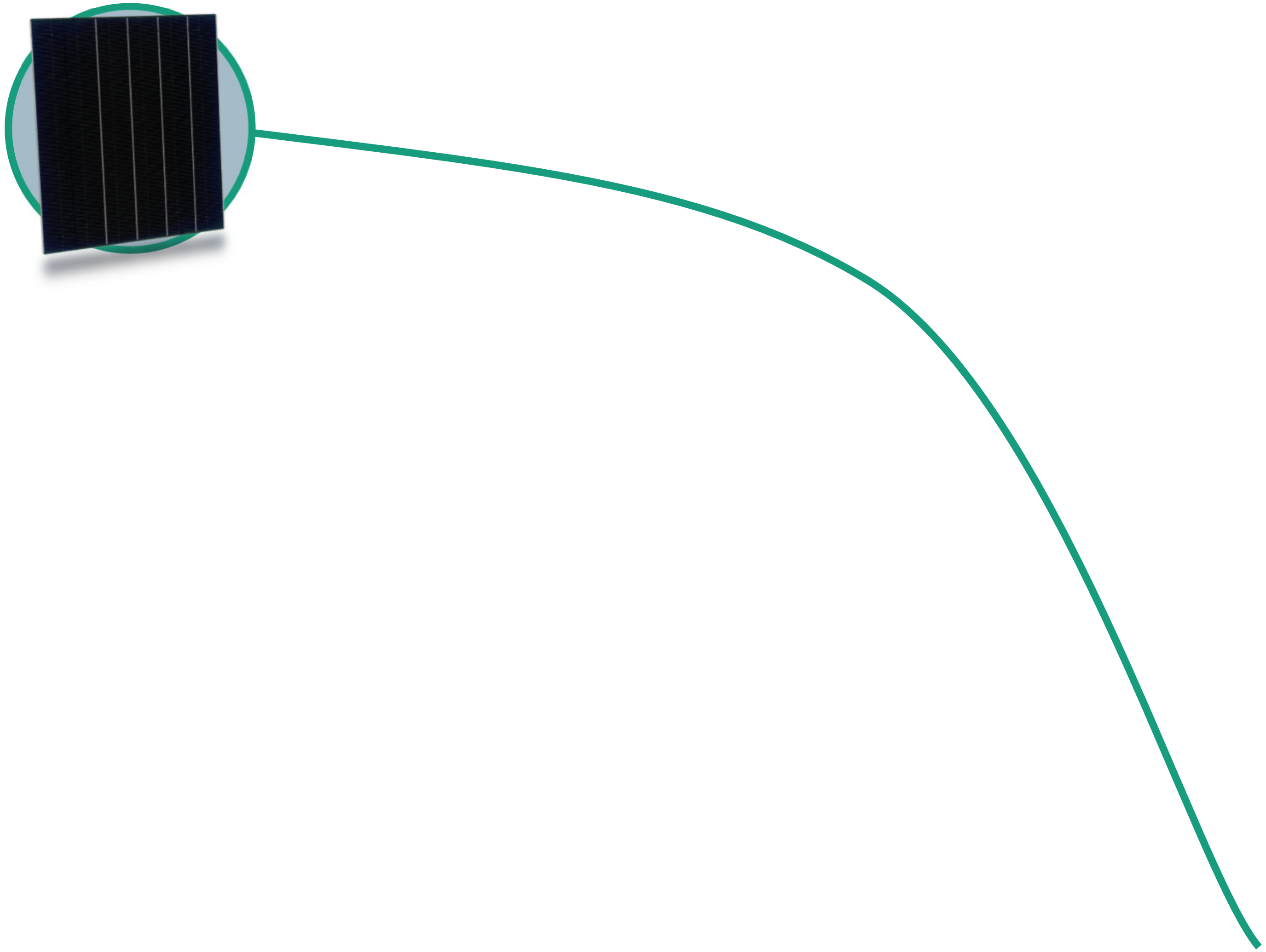
Fraunhofer ISE

Our Approach for Shingle Solar Cells

Low-Damage Cell Cutting and Edge Passivation by PET[1-3]

- Host solar cells with shingle layout



[1] P. Baliozian et al., IEEE J. Photovoltaics, 2020.
[2] E. Lohmüller et al., Prog. Photovolt.: Res. Appl., 2023
[3] E. Lohmüller et al., Solmat, 2023

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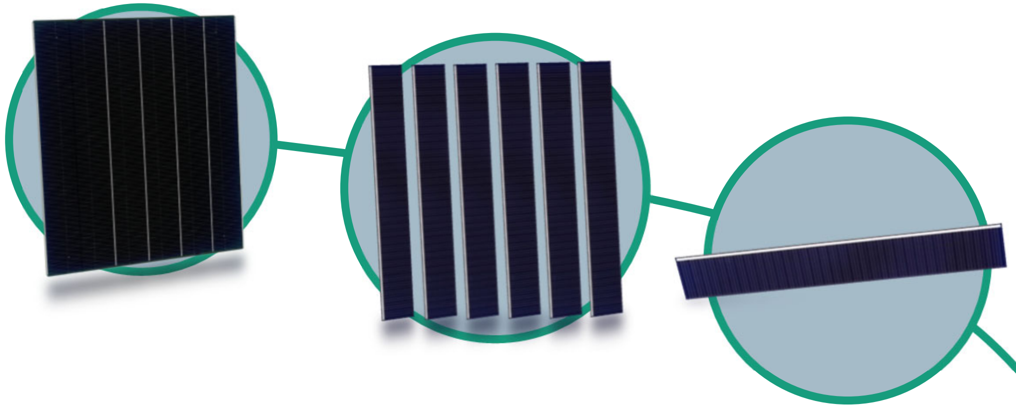
Our Approach for Shingle Solar Cells

Low-Damage Cell Cutting and Edge Passivation by PET[1-3]

- Host solar cells with shingle layout
- Separation into cell stripes
  - Increased perimeter-to-area ratio
  - Edge recombination due to cut edges[4-6]



[1] P. Baliozian et al., IEEE J. Photovoltaics, 2020.
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[3] E. Lohmüller et al., Solmat, 2023
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[5] J. Dicker, Phd thesis, Uni Konstanz, 2003.
[6] M. Hermle et al., WC-PVSC, 2003.

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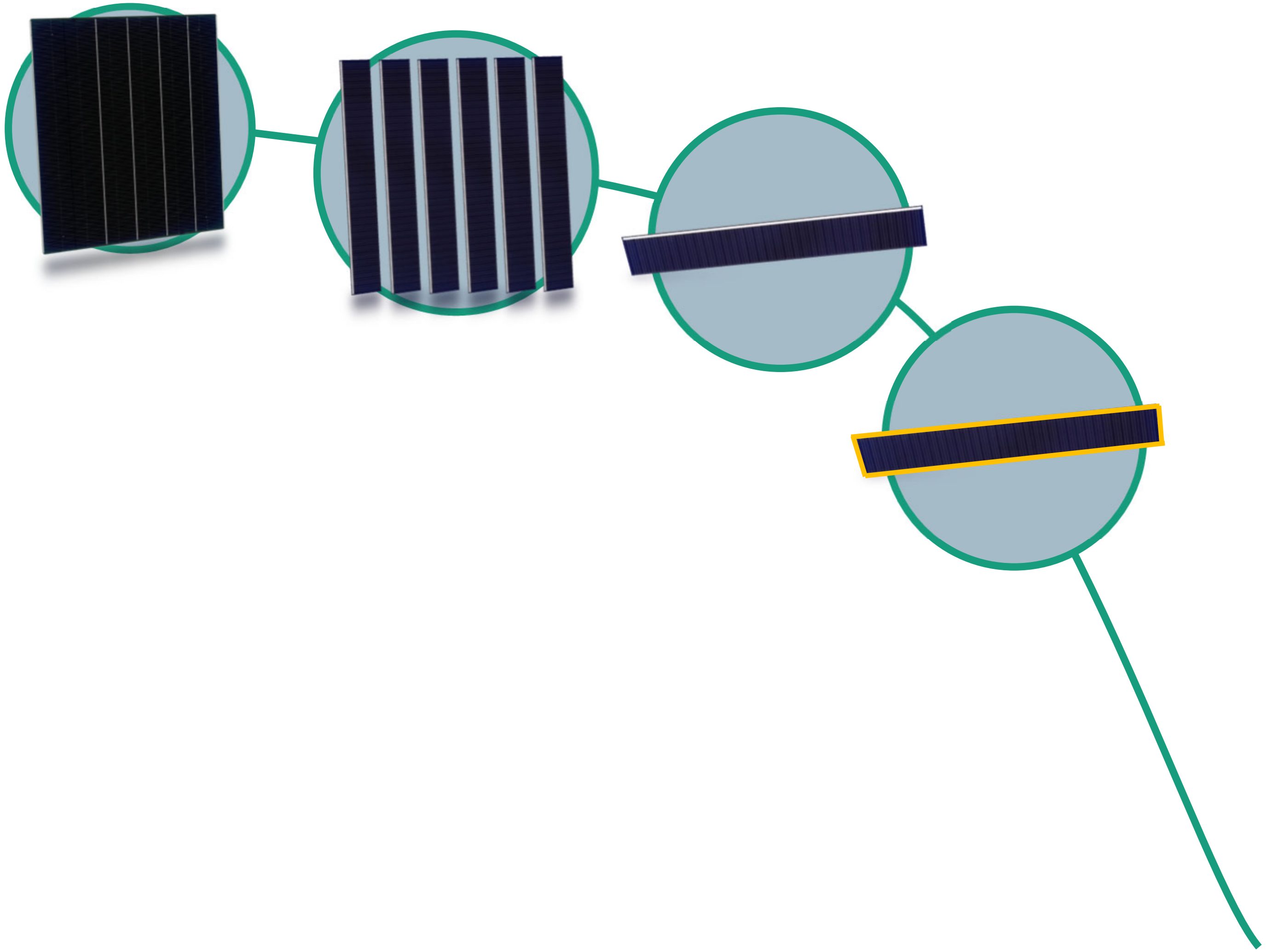
- Edge passivation by PET
  - ALD Al_2O_3
  - Annealing



[1] P. Baliozian et al., IEEE J. Photovoltaics, 2020.
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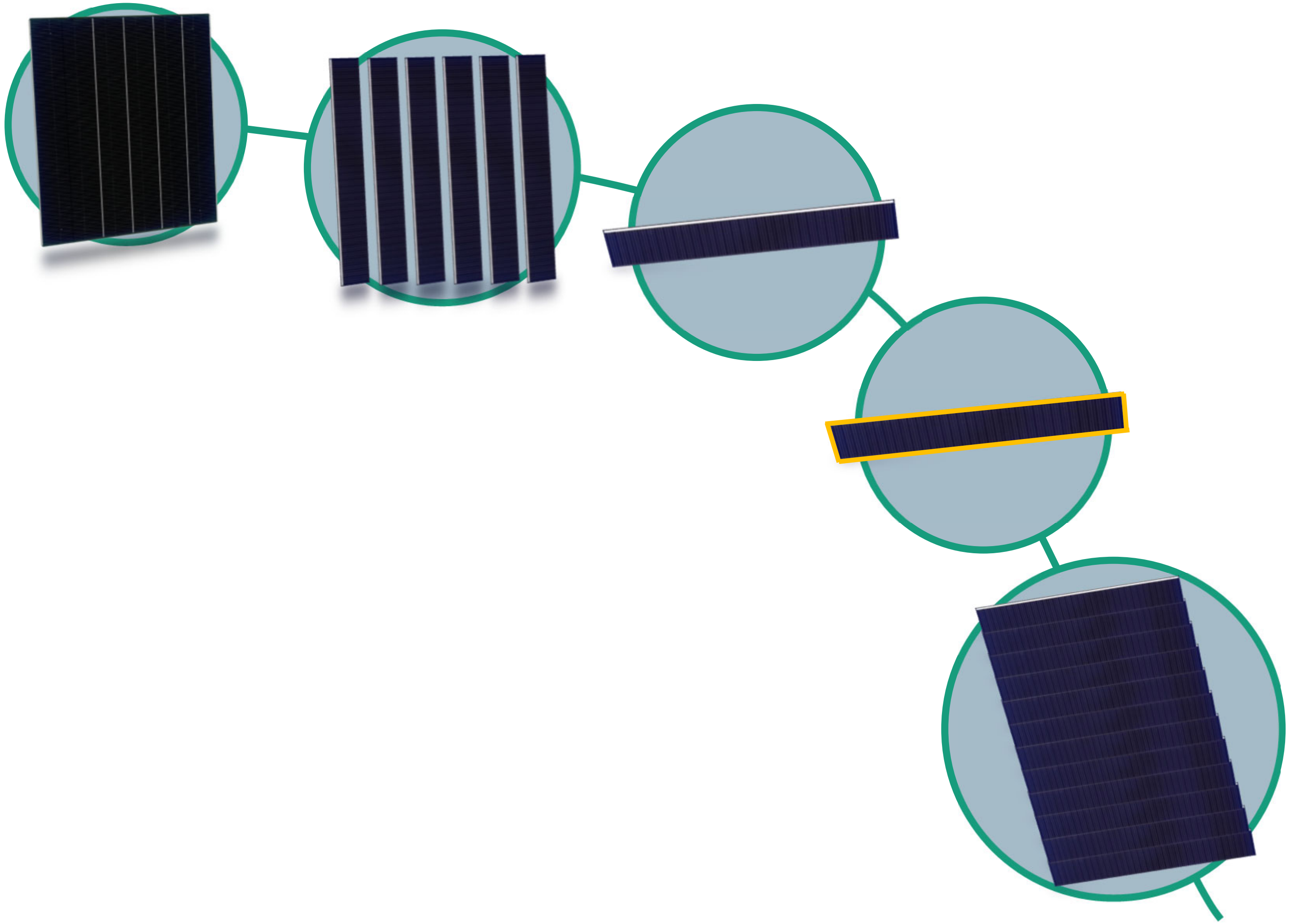
- Host solar cells with shingle layout
- Separation into cell stripes
  - Increased perimeter-to-area ratio
  - Edge recombination due to cut edges[4-6]
- Edge passivation by PET
  - ALD Al_2O_3
  - Annealing
- Shingling of cells into shingle strings[7] and …



[1] P. Baliozian et al., IEEE J. Photovoltaics, 2020.
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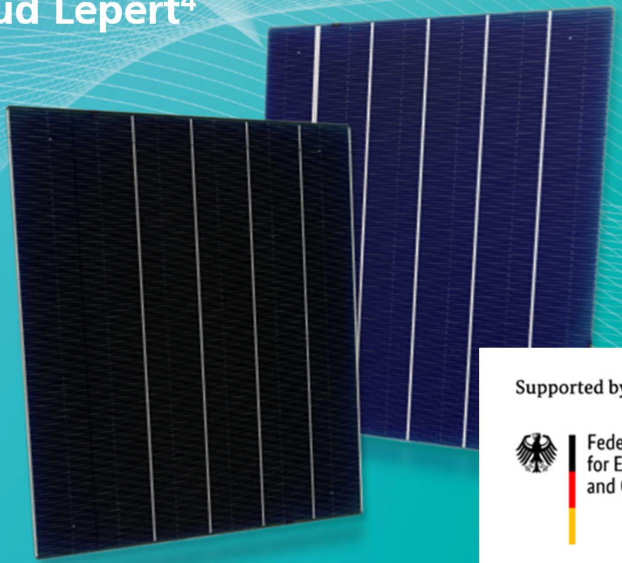
[5] J. Dicker, Phd thesis, Uni Konstanz, 2003.
[6] M. Hermle et al., WC-PVSC, 2003.
[7] T. Rößler et al., AIP Conf. Proc., 2022.

Fraunhofer ISE

Passivated Edge Technology (PET): TOPCon Shingle Solar Cells

Elmar Lohmüller[1], Puzant Baliozian[1,2], Marc Hofmann[1], Leon Gutmann[1], Leander Kniffki[1], Jonas D. Huyeng[1], Armin Richter[1], Vivek Beladiya[3], Jürgen Geng[3], Lili Wang[4], Ricky Dunbar[4], Arnaud Lepert[4]

[1]Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstraße 2, 79110 Freiburg, Germany
[2]now with VDMA Photovoltaic Equipment, Lyoner Str. 18, 60528 Frankfurt am Main, Germany
[3]Plasma Electronic GmbH, Otto-Lilienthal-Straße 2, 79395 Neuenburg, Germany
[4]The Solaria Corporation, 45700 Northport Loop E, Fremont, CA 94538, USA



More information on this, see

E. Lohmüller et al., „Thermal laser separation and high-throughput layer deposition for edge passivation for TOPCon shingle solar cells“, Sol. Energy Mater. Sol. Cells 258, 112419, DOI: 10.1016/j.solmat.2023.112419.

Fraunhofer ISE

SOLARIA

PLASMA ELECTRONIC CHANGING SURFACES

Supported by:

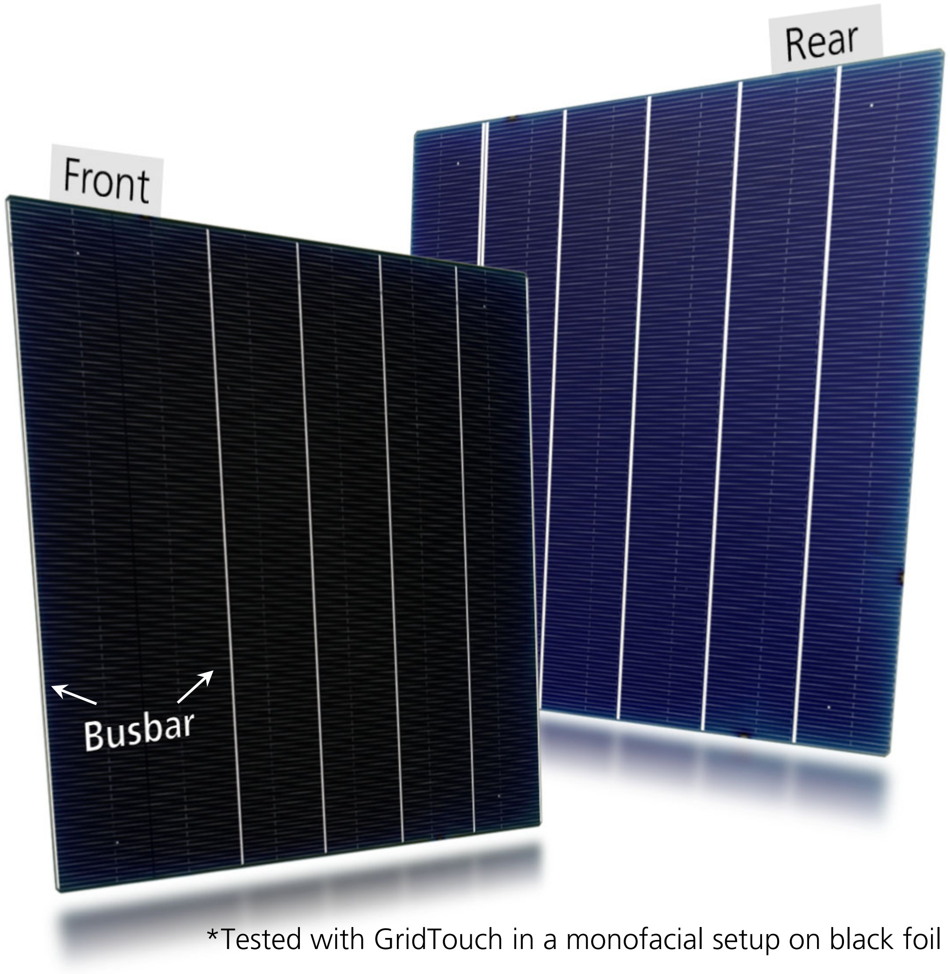
Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Approach

TOPCon Host Cells

- Industrial TOPCon host solar cells
  - Bifacial six-shingle metallization design
  - Full-square format
    - 158.75 mm edge length
    - Shingle cell width: 26.46 mm
  - Mean energy conversion efficiency of 22.0%*



*Tested with GridTouch in a monofacial setup on black foil

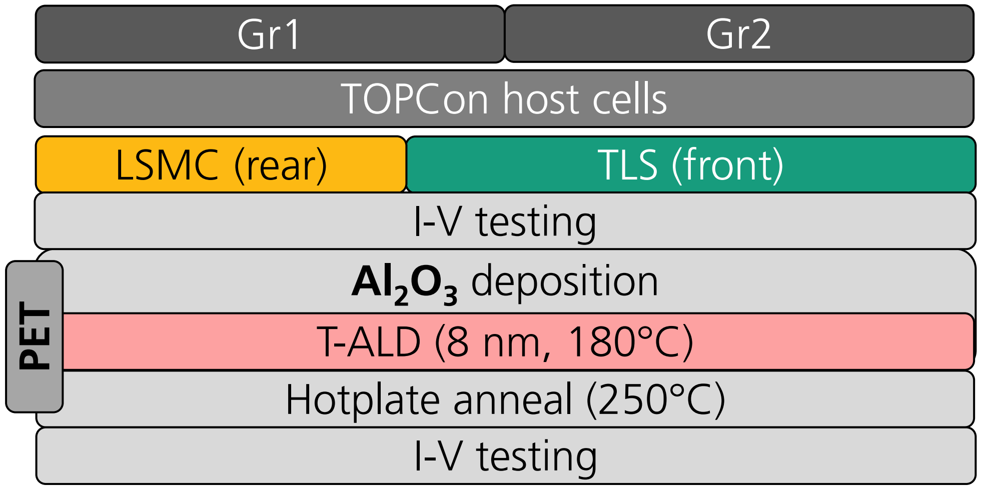
Experimental

Schematic Process Sequence

Comparison between

- **Gr1 vs Gr2**
  - LSMC
  - TLS

  Lab-scale thermal ALD (T-ALD) Al_2O_3



Experimental

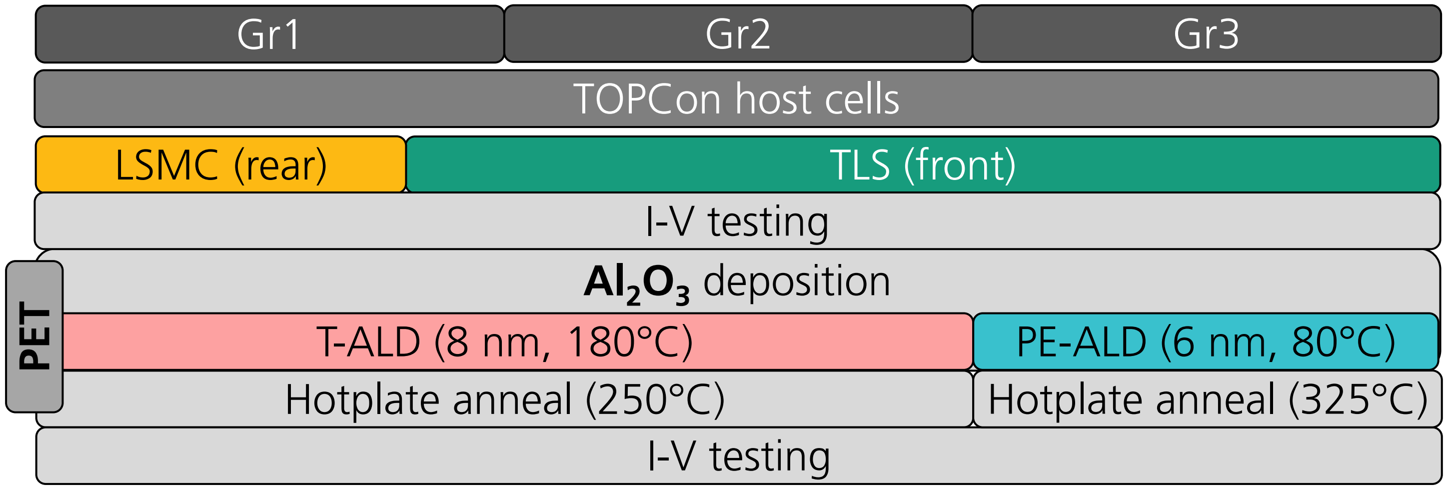
Schematic Process Sequence

Comparison between

- **Gr1 vs Gr2**
  - LSMC
  - TLS

  Lab-scale thermal ALD (T-ALD) Al_2O_3

- **Gr3**
  - Transfer to high-throughput plasma-enhanced ALD (PE-ALD) Al_2O_3



High-Throughput Al_2O_3 Layer Deposition
Processing with Stacked Shingle Cells

High-throughput PE-ALD Al_2O_3

- Shingle stacks

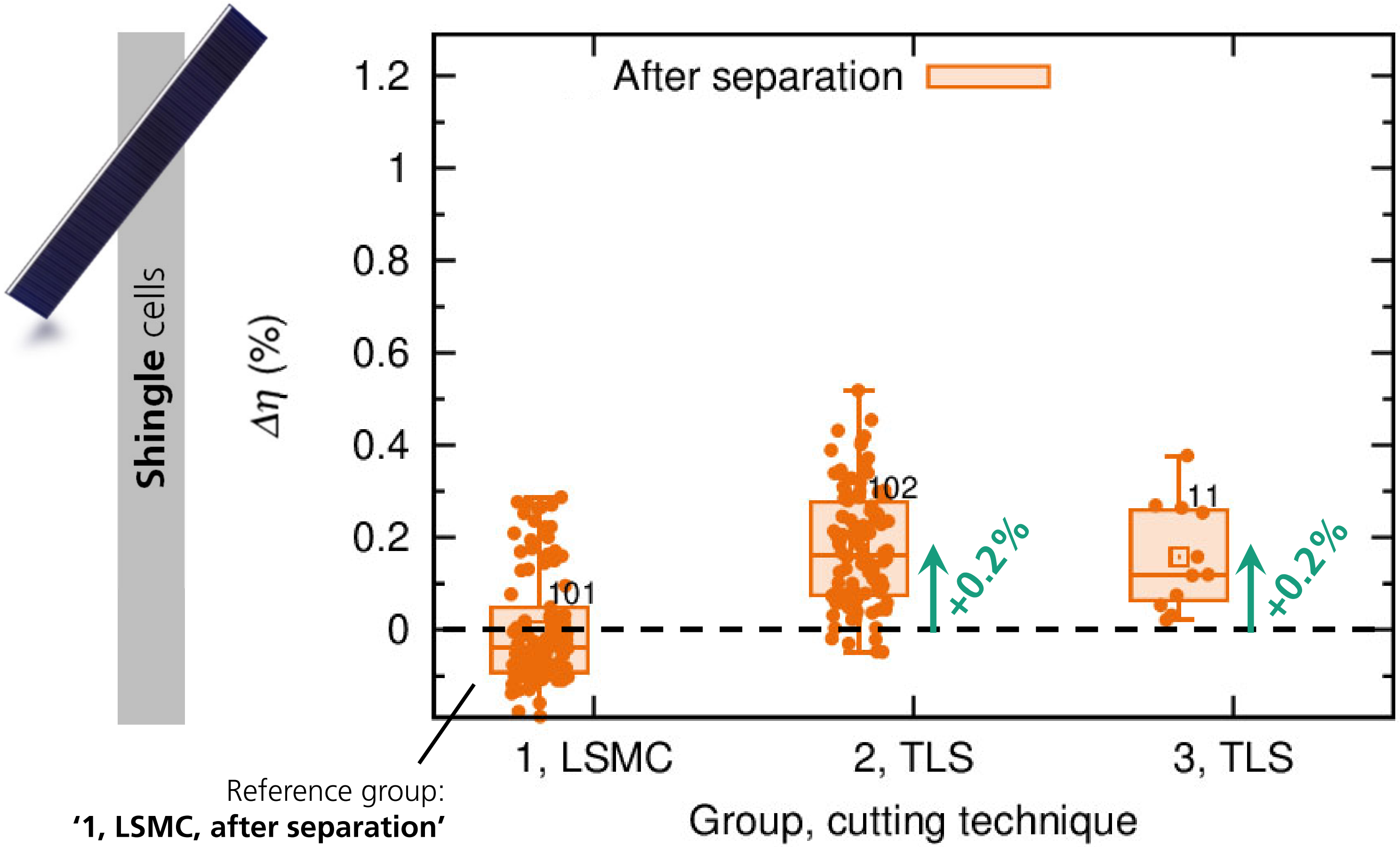
- Current run duration: 1 hour
- Capactity: 60.750 shingle cells per run
  ➔ 0.5 GW_p /year

- Run duration of around 15 min possible by hardware and process optimization
  ➔ 2 GW_p /year

Results

Comparison Laser Cutting Technology

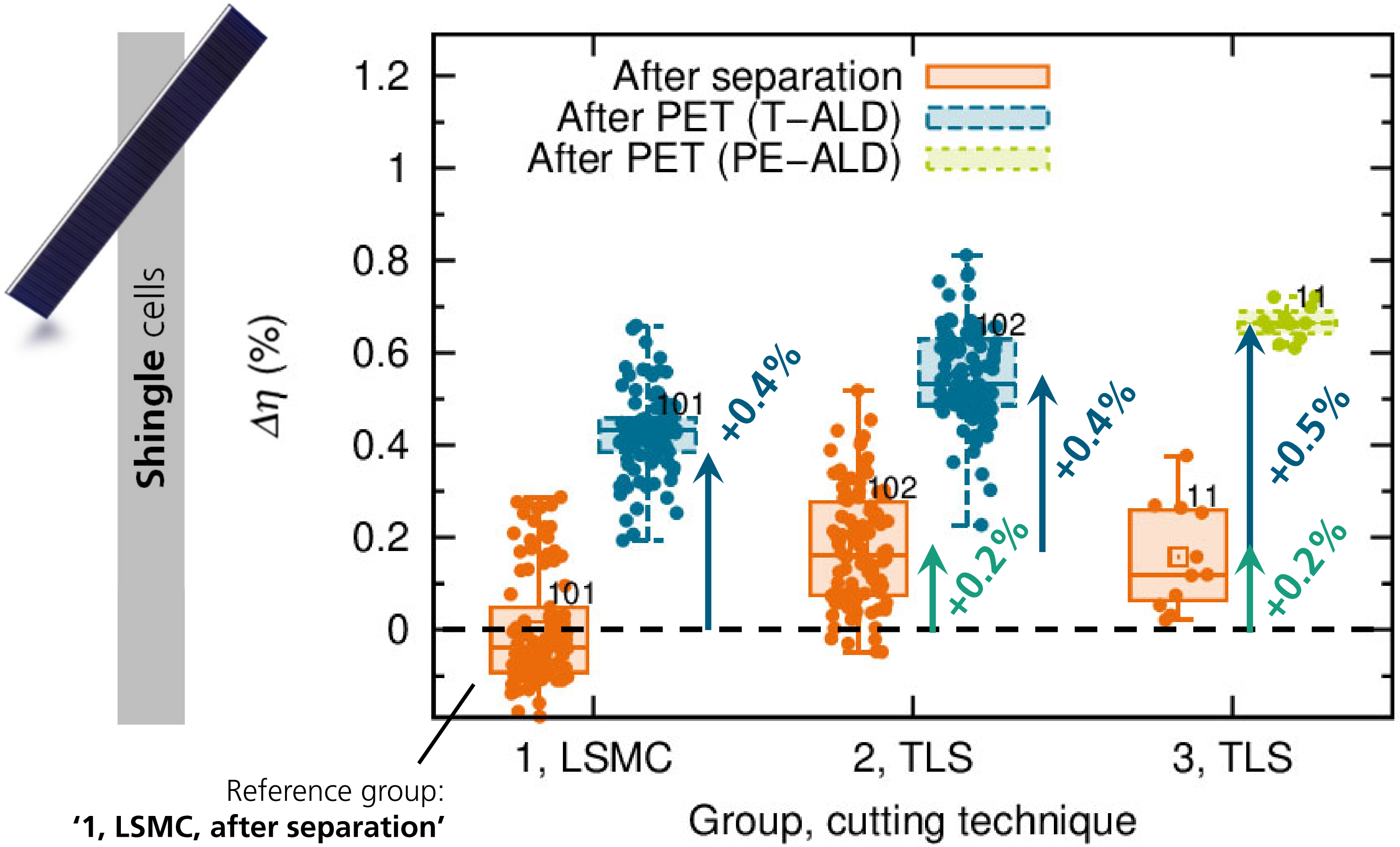
- TLS in Gr2/3 yields $\Delta\eta$ = **+0.2%**$_{\mathbf{abs}}$ more efficient shingle cells



Results

Comparison ALD of Al_2O_3 Passivation Layer

- TLS in Gr2/3 yields $\Delta\eta$ = **+0.2%$_{abs}$** more efficient shingle cells
- PET yields
  - $\Delta\eta$ = **+0.4%$_{abs}$** for LSMC and TLS
  - $\Delta\eta$ = **+0.5%$_{abs}$** for PE-ALD
- **TLS + PET:**
  Up to $\Delta\eta$ = **+0.7%$_{abs}$** compared to shingle cells without edge passivation cut by LSMC



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Comparison ALD of Al_2O_3 Passivation Layer

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- PET yields
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- **TLS + PET:**
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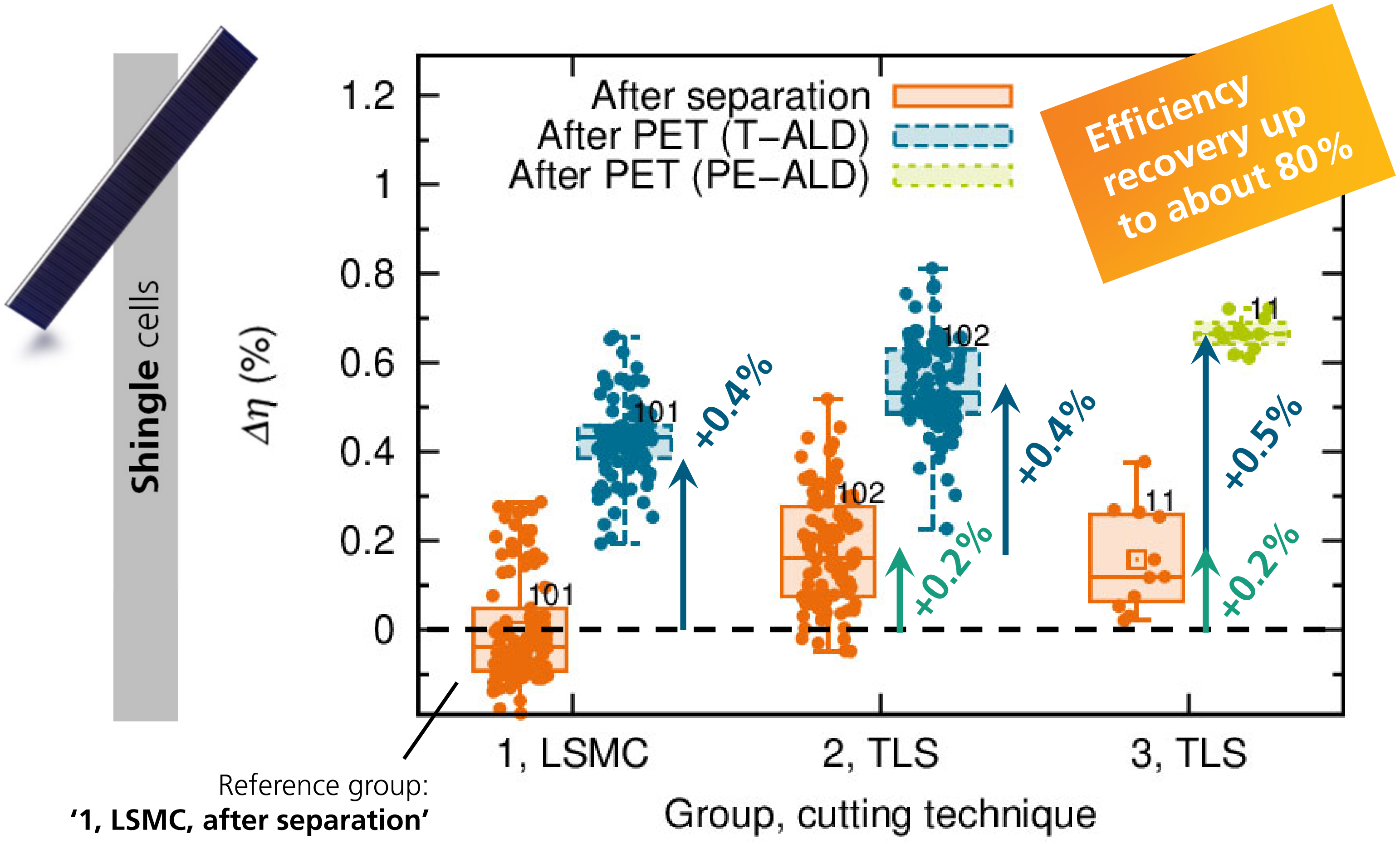


Reference group:
'1, LSMC, after separation'

Summary

Thermal laser separation (TLS) into shingle cell

+0.2%$_{abs}$ compared to conventional cutting

Edge passivation by passivated edge technology (PET)*

+0.5%$_{abs}$

Efficiency recovery up to about 80%

TLS + PET: +0.7%$_{abs}$

*patented by Fraunhofer ISE

Low-damage cutting and **high-throughput Al_2O_3 deposition** is very promising for **industrialization** of the **PET**

SOLARIA PLASMA ELECTRONIC CHANGING SURFACES Fraunhofer ISE

Thank You for Your Attention!

Contact

Dr.-Ing. Elmar Lohmüller
PV Production Technology
elmar.lohmueller@ise.fraunhofer.de

Fraunhofer ISE
Heidenhofstraße 2
79110 Freiburg
Germany
www.ise.fraunhofer.de

Fraunhofer ISE

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

The activities have been financially supported by the German Federal Ministry for Economic Affairs and Climate Action within the research projects "PV-BAT400" (grant number 0324145) and "GutenMorgen" (03EE1101A).

High quality cell cutting with Thermal Laser Separation

PV Magazine Webinar, 10 July, 2023

3D MICROMAC

3D-Micromac – The Specialist in Laser Micromachining

Key Facts

» Founded in **2002**
» 180 employees
» Based in **Chemnitz, Germany**
» Branch offices in US and Taiwan

Services

» **Feasibility studies & process development** in-house
» Production of limited lots and ramp-up production
» **Worldwide** sales & service network

Machine Base

> 600 installations worldwide
> 50 systems in semi industry
> 150 systems in glass/display
> 30 systems in microdiagnostics
> 110 systems in photovoltaics
> 30 systems in roll-to-roll production

Target Markets & Products

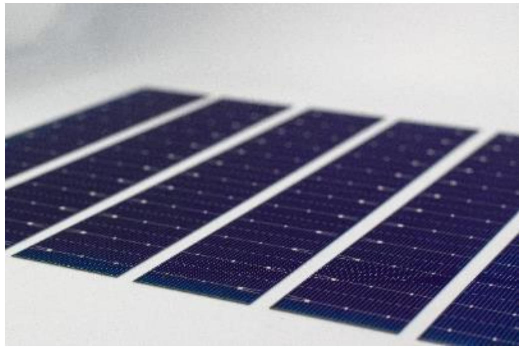
» Semiconductor

» Glass & Display

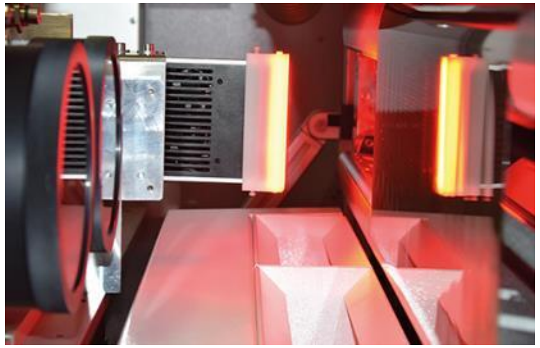
» Microdiagnostic

» Photovoltaic

Laser Technology for Photovoltaics



TLS-cut shingled-cells



Laser structuring of flexible TFPV

- **microCELL™ MCS** and **microCELL™ TLS**:
  Enabling best-in-class throughput & unmatched edge quality in solar cell cutting
  - Patented TLS technology
  - For half- and shingled PV cells
  - Free-form cuts possible

- **microFLEX™ PV:** Laser structuring of flexible and organic thin-film solar cells in P1, P2, P3, and P4/PT

Content

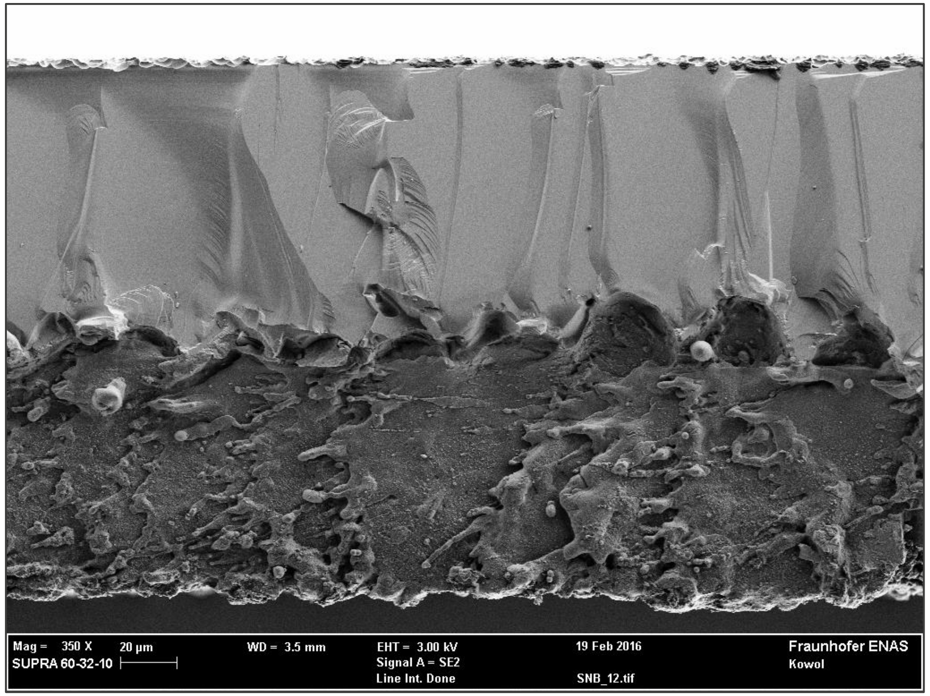
1. Motivation
2. Thermal Laser Separation explained
3. Advantages for cell and module manufacturing
4. Economic Impact
5. Summary

Motivation

Standard industry process:

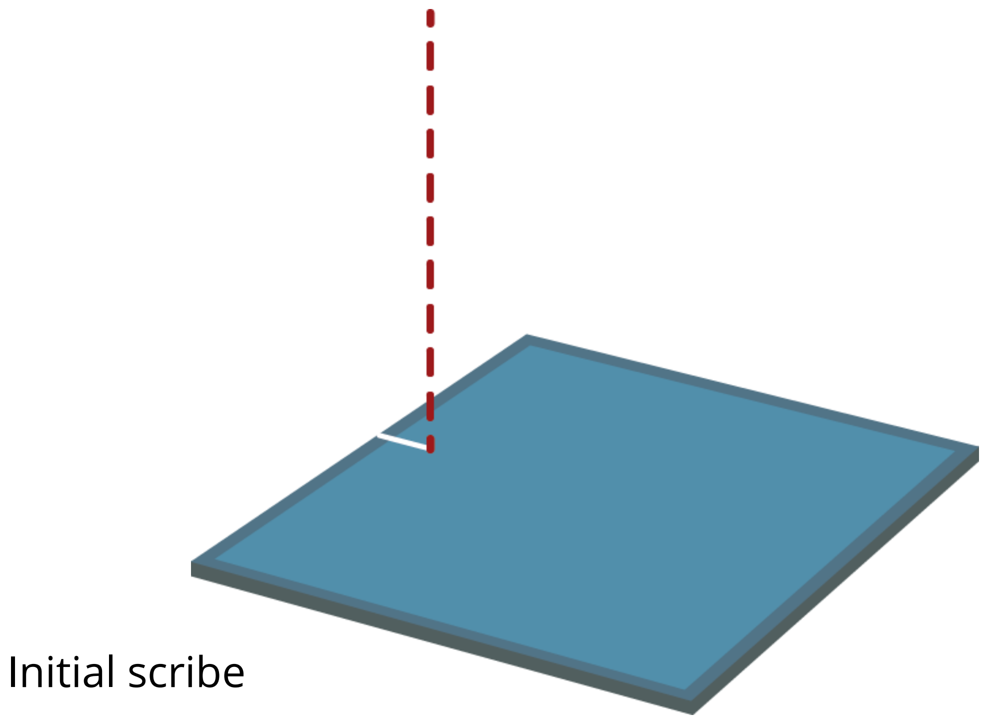
- Laser ablation "scribe and break"
  - Trench 40 – 60 % of the cell's thickness
  - Subsequent mechanical breaking

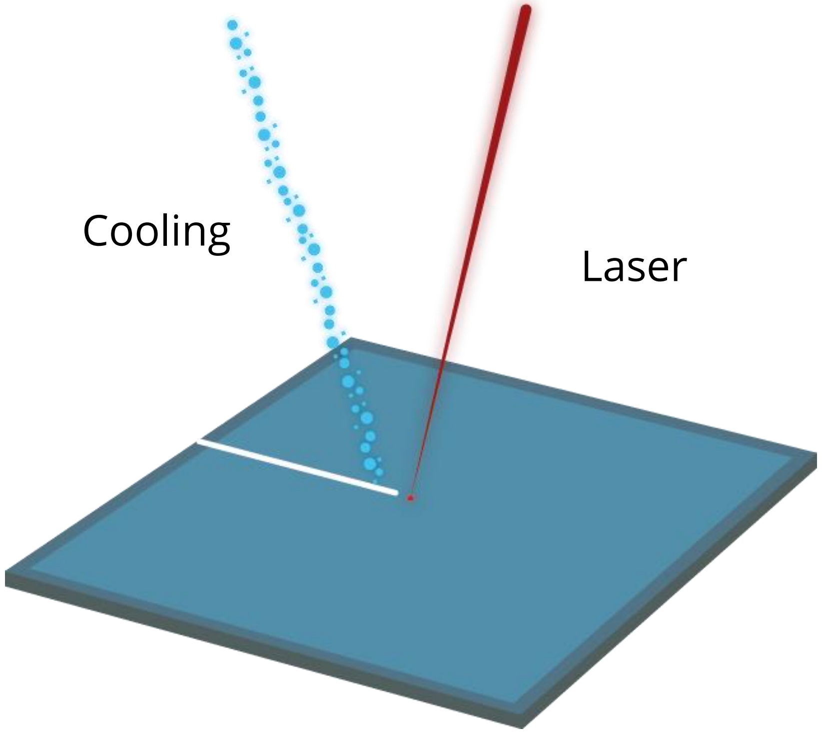
- Limitations in:
  - Throughput
  - Process quality
  - Particle generation
  - Electrical and mechanical performance



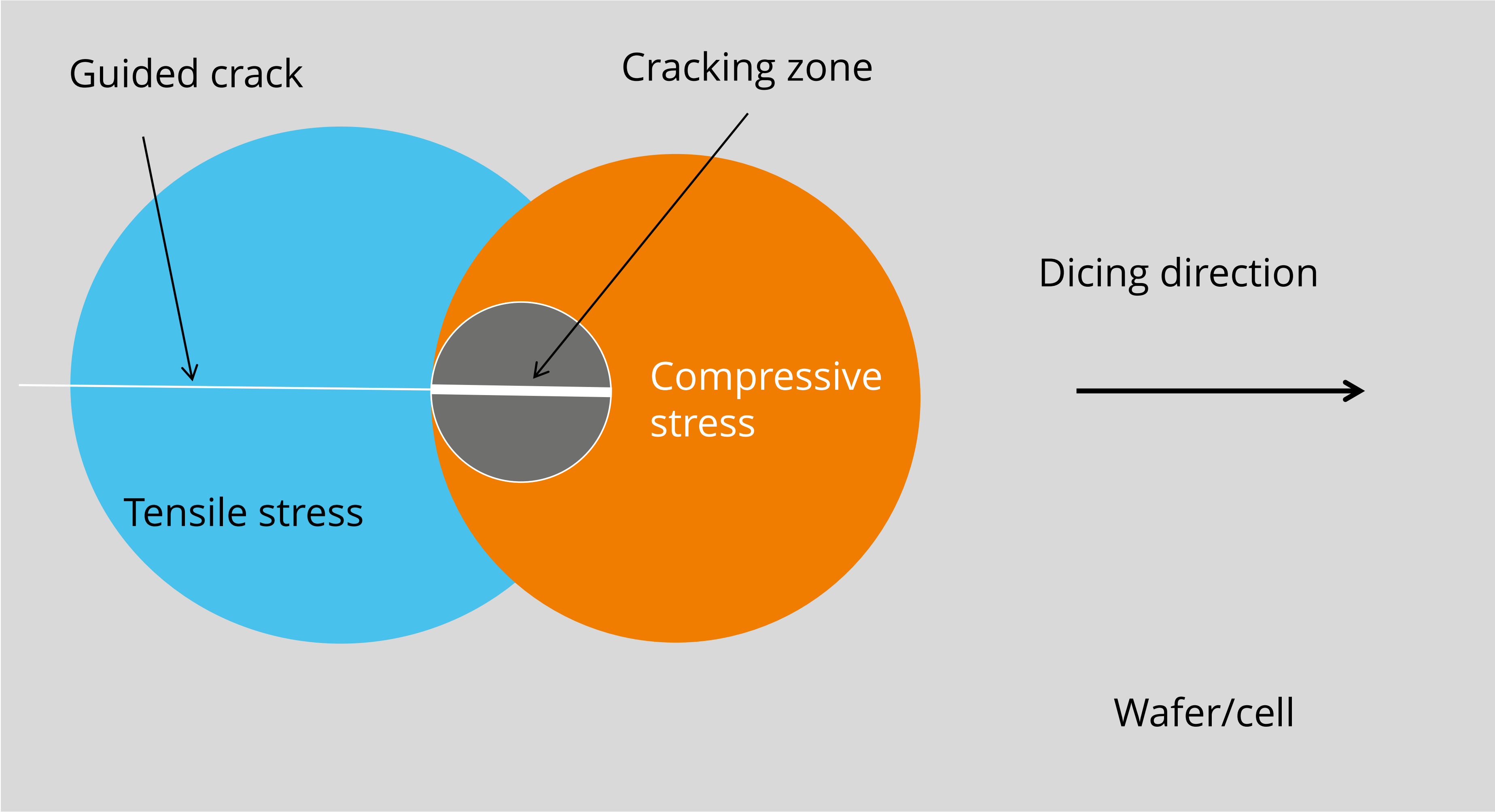
Thermal Laser Separation (TLS)

- Starting point (and optional straightness) defined by scribe
- TLS is a cleaving process, initiated by heat and cooling

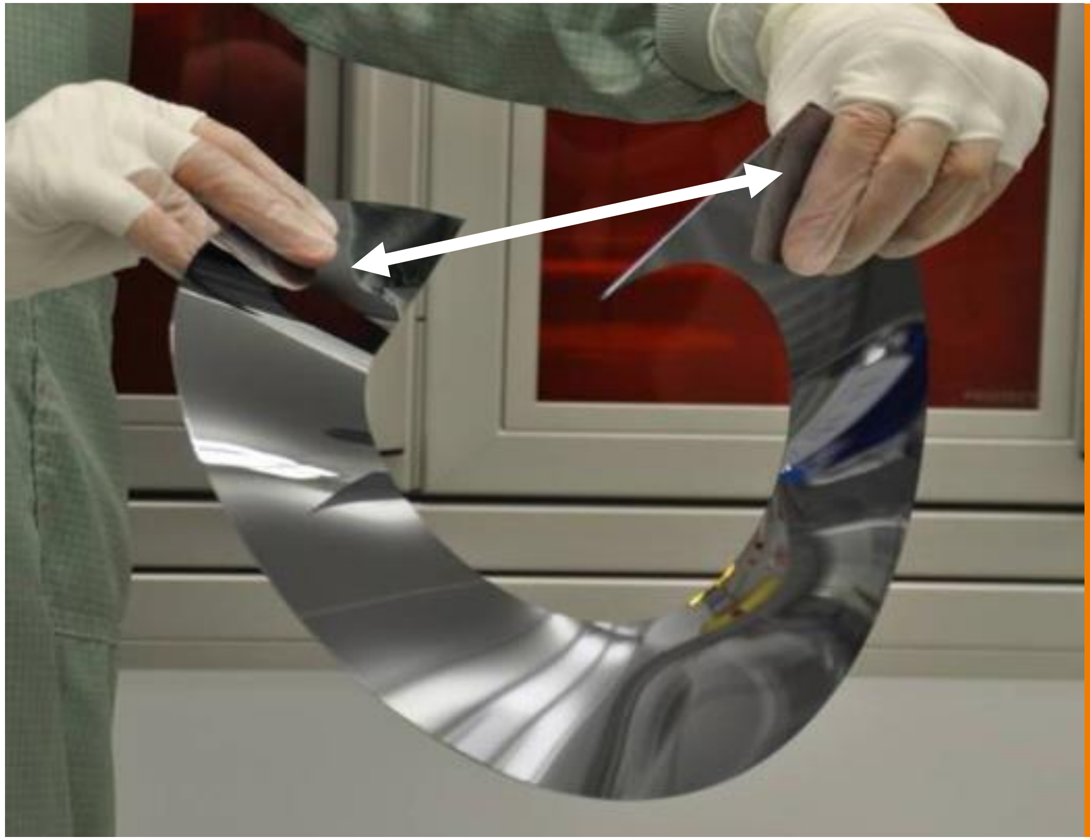




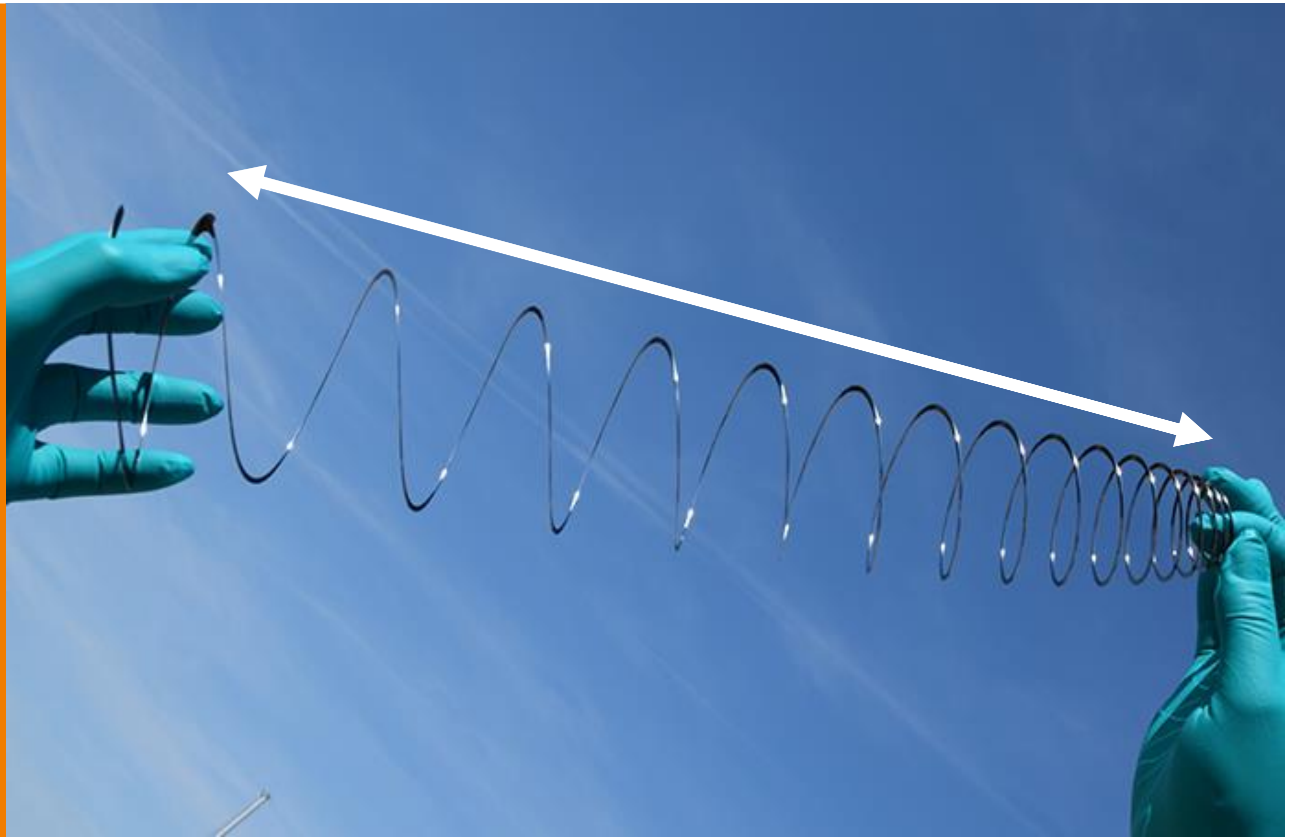
TLS-Cutting Technology



Main Properties of TLS-Dicing®



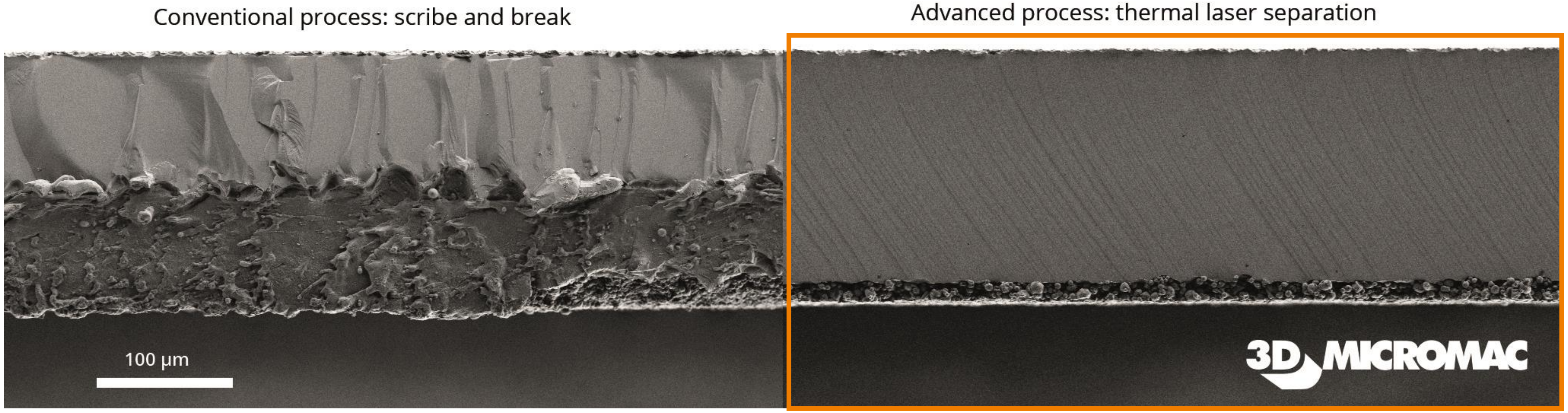
Resizing of Si (ø 300 to 200 mm, Si 775 µm), Courtesy of Fraunhofer Gesellschaft



Spiral of Si (ca. 400 µm thick) after TLS-cleave and I-Scribe

TLS-Cutting vs. Scribe and Break – Results Breaking Edge

Cross sectional view on solar cell after cutting



→ Extensive chipping
→ Very rough structure

→ Very smooth structure
→ No chipping visible
→ perfect surface for re-passivation approaches

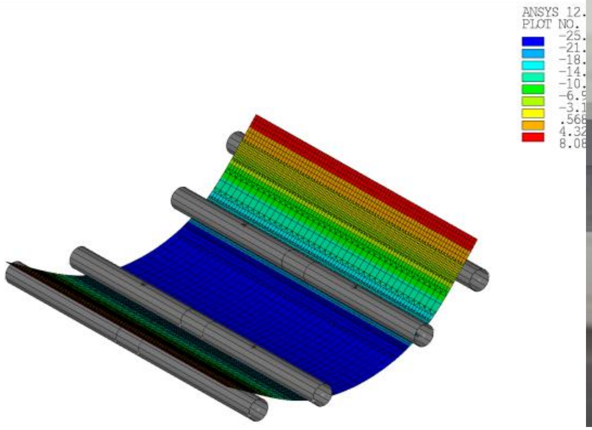
TLS-Cutting – Mechanical Performance

Goal

- Compare mechanical strength of a full-cell cut by TLS and scribe and break

Measurement Method

- Measuring the mechanical strength by using the 4-point bending test
- Tests done by Fraunhofer Institute



FE-Model 4-point-Bending

4-point-bending (mc-Si Wafer)

Results
Mechanical Strength

Cell vs Module

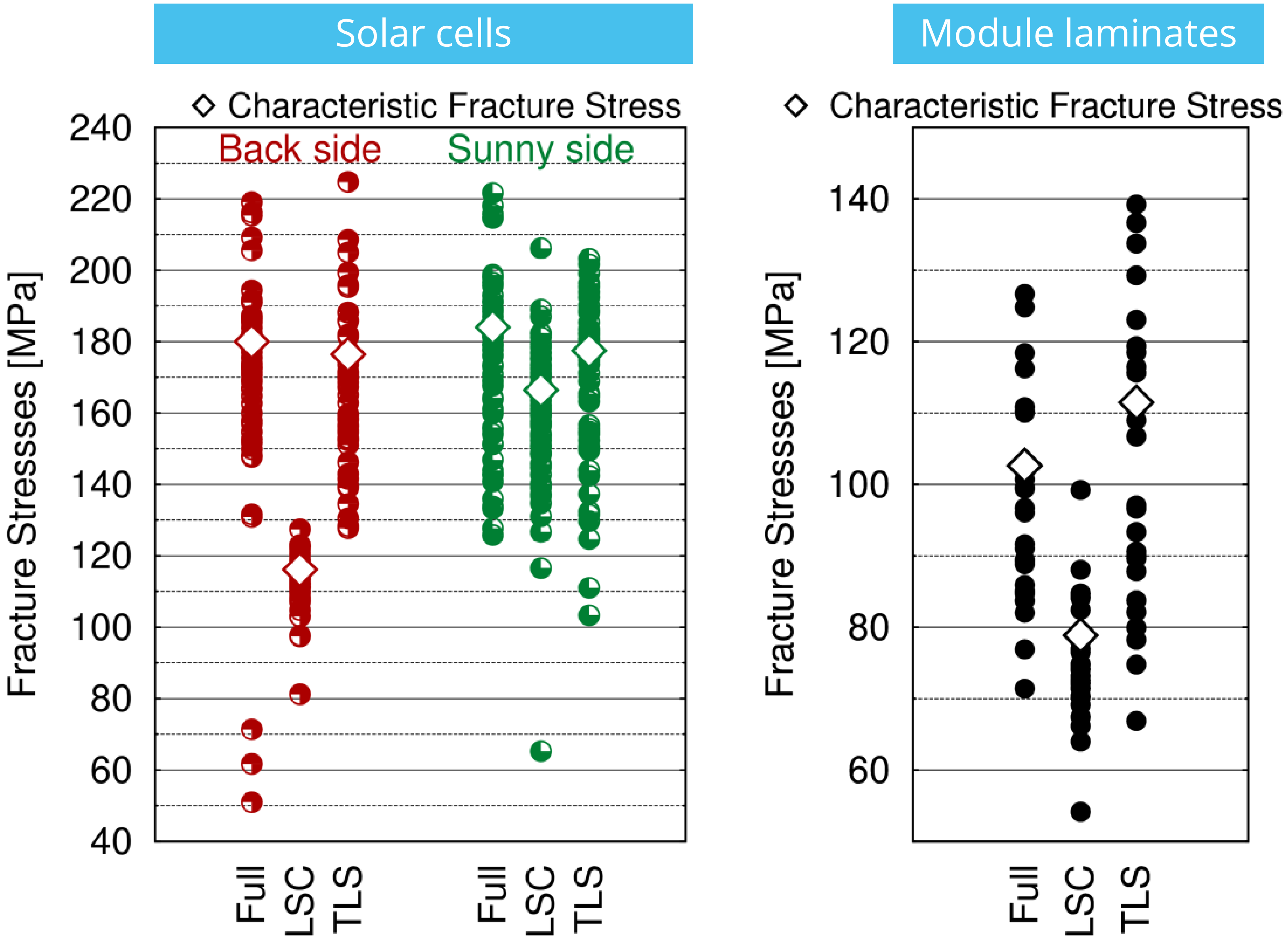
Laser Scribe and Cleaving (**LSC**)

Mechanical strength:
cell (-35%)
module (-23%)

Thermal Laser Separation (**TLS**)

No damage visible on cells and modules

→ Cell and module results in good agreement



→ Courtesy Fraunhofer CSP

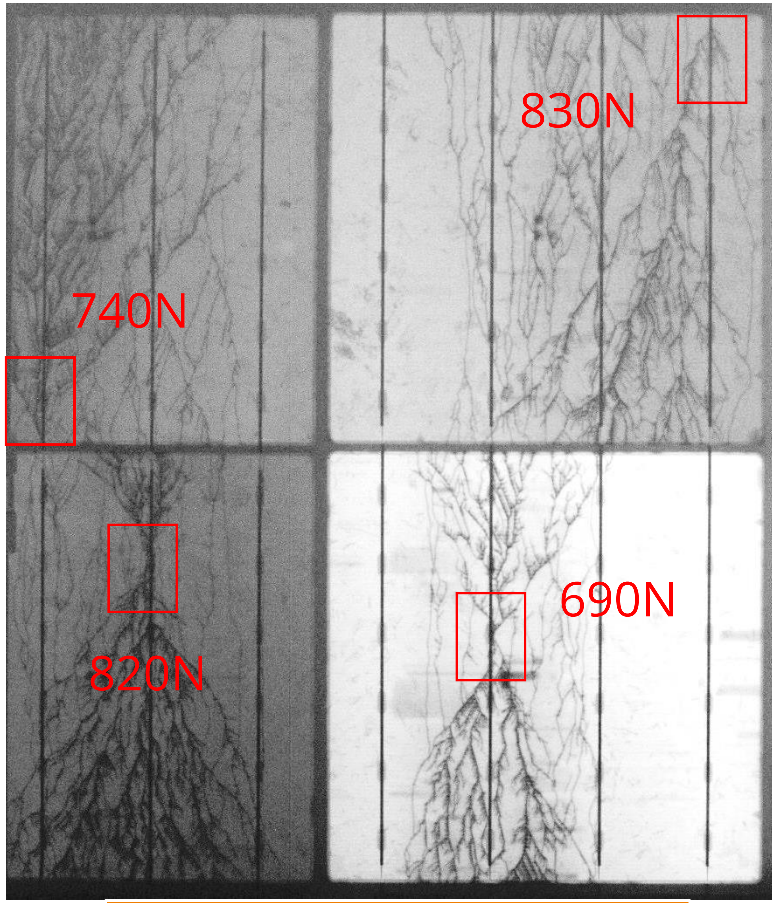
Comparison of Fracture Origin

EL images from module laminate test

Fracture Origin: □ Surface ▽ Edge

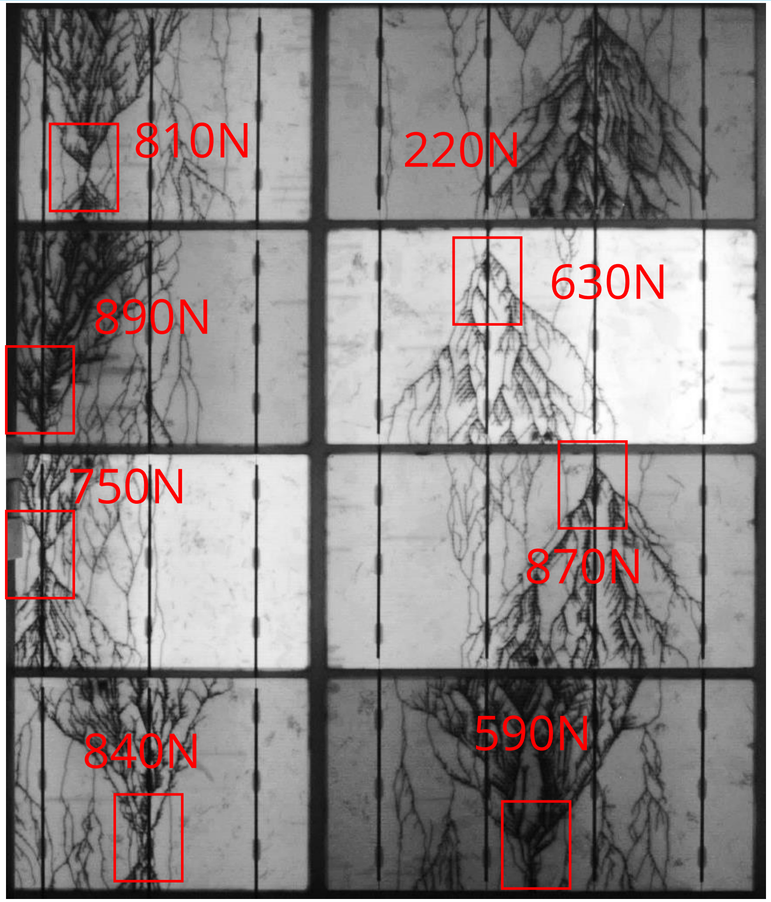
EL pictures after testing | brightness and contrast adjusted

Full Cells (reference)



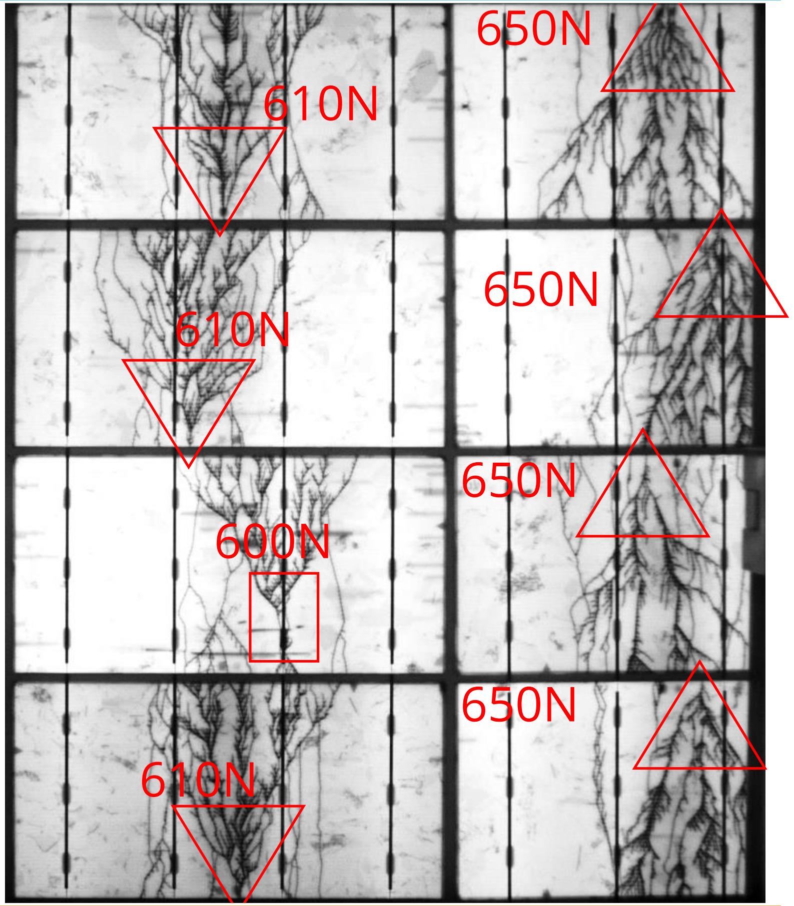
surface defects → pads

Thermal Laser Separation (**TLS**)



surface defects → pads

Laser Scribe and Cleaving (**LSC**)



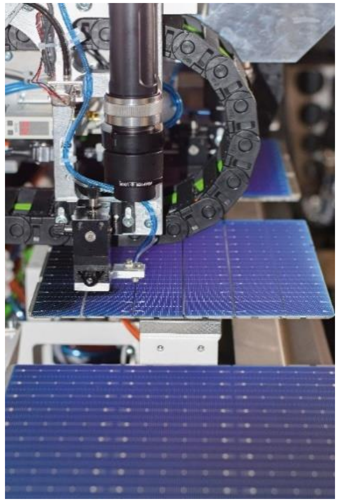
mostly edge defects → cutting process

→ Courtesy Fraunhofer CSP

TLS and Economic Benefit for Module Manufacturing

Cell cutting with Thermal Laser Separation

- Additional module power output
- High mechanical strength
- Ability to passivate cutting edge
- High throughput Shingle cell cutting



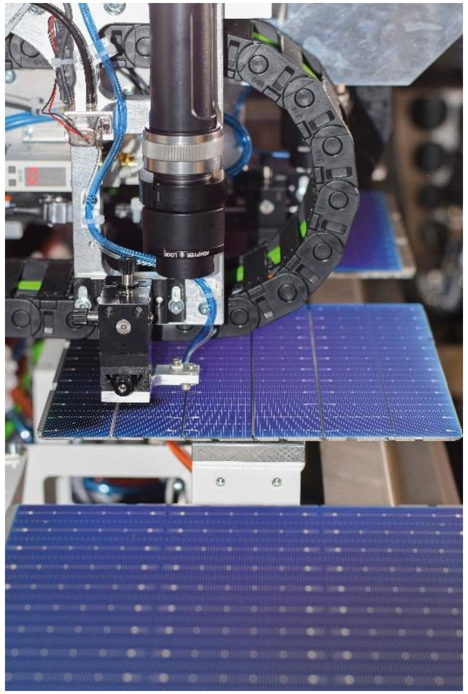
Enabling best-in-class throughput & unmatched edge quality in solar cell cutting

- Patented TLS technology
- For half- and shingled PV cells
- Free-form cutting

microCELL MCS – Next Generation Cell Cutting

- Worldwide install base > 15 GW
- Format and pattern adjustments via flexible chuck design
- up to five process positions: exchangeable, retrofitable, expandable
  → fully flexible from 1/2 cells to 1/6 cell stripes
- Wafer recognition by camera
- Scanner-based initial scribe
- Cleave: adjustable on motorizes stages

- > 6,000 wph for 1/2 to 1/6 cut cells
- Contactless and ablation-free cutting
- Improved module performance/less power degradation



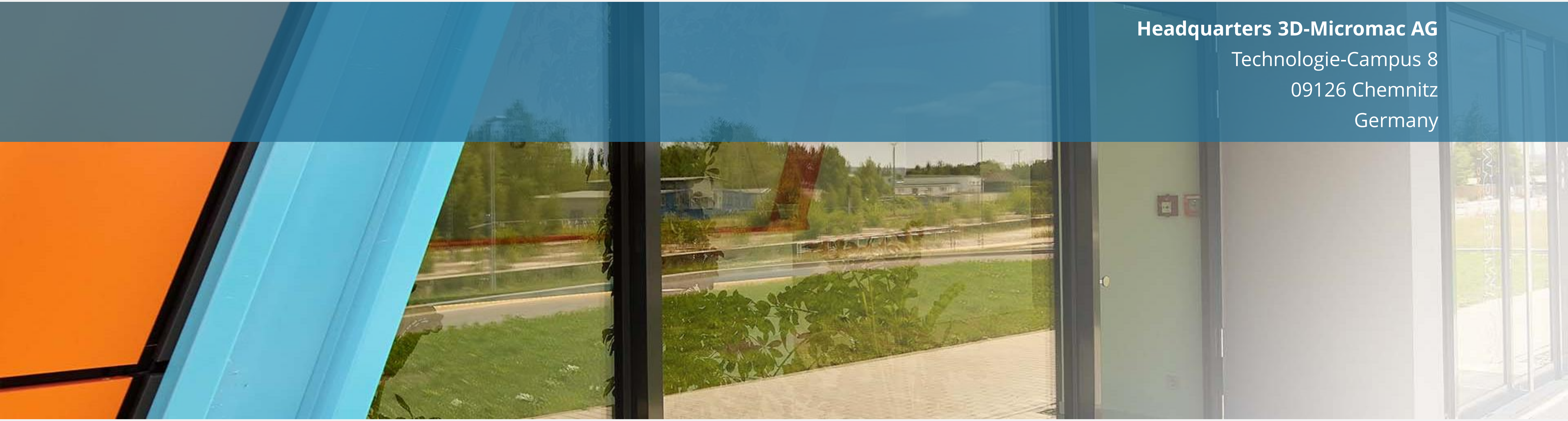
TLS-Cutting provides excellent cleaving results in combination with higher yield and throughput.

Thank you for your attention!

Thomas Kießling
sales@3d-micromac.com
+49 371 40043 222

Financial support from the European Union's Horizon2020 Programme for research, technological development and demonstration (Grant Agreement no. 857793) is acknowledged.

+49 371 400 43 0 *info@3d-micromac.com* *www.3d-micromac.com*



Headquarters 3D-Micromac AG
Technologie-Campus 8
09126 Chemnitz
Germany

GENERIS PET
Industrialized High Throughput Solution for Passivated Edge Technology

July 10th, 2023

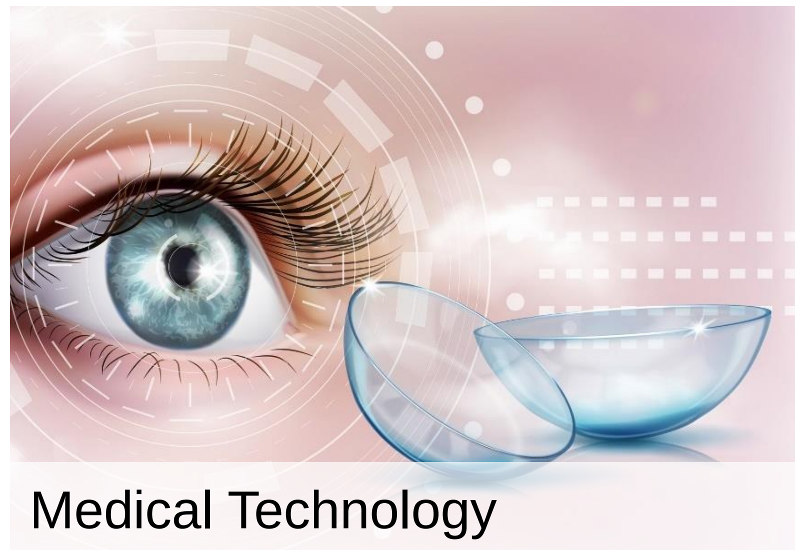
SINGULUS

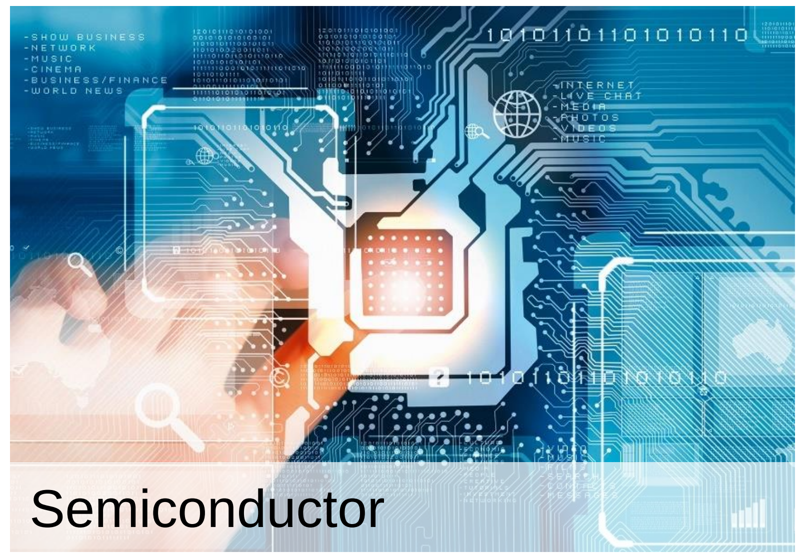
Outline

- Introduction SINGULUS TECHNOLOGIES AG
- GENERIS PET for Edge Passivation
- Summary
- Contact

Introduction SINGULUS TECHNOLOGIES AG

SINGULUS Technologies AG - Substantial Technologies for different Business Markets





- Established: 1995 (Buyout at Merger Balzers/Leybold)
- Employees: 354

- Research & Development
- Consulting
- Engineering & Design
- Production
- Project Management
- Installation/Commissioning
- Service/Maintenance
- Training

SINGULUS

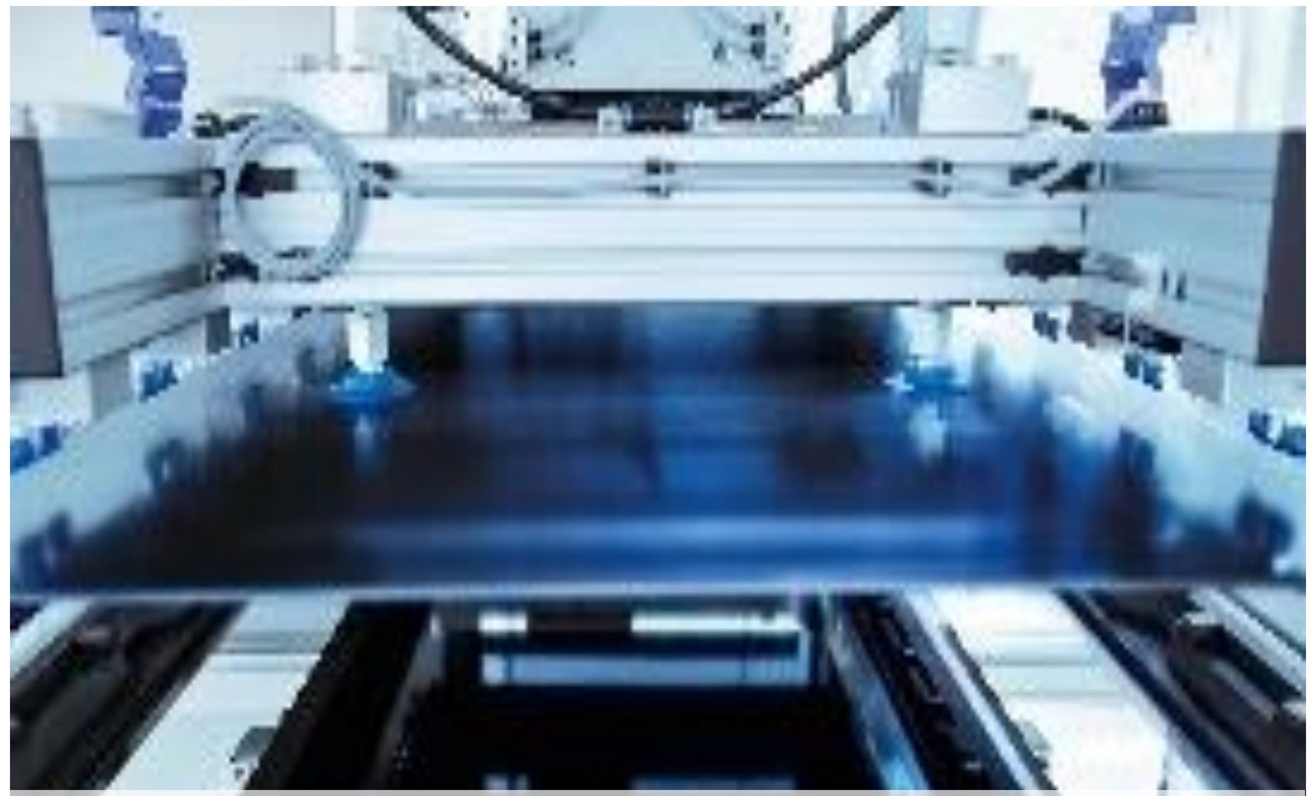
Introduction SINGULUS TECHNOLOGIES AG

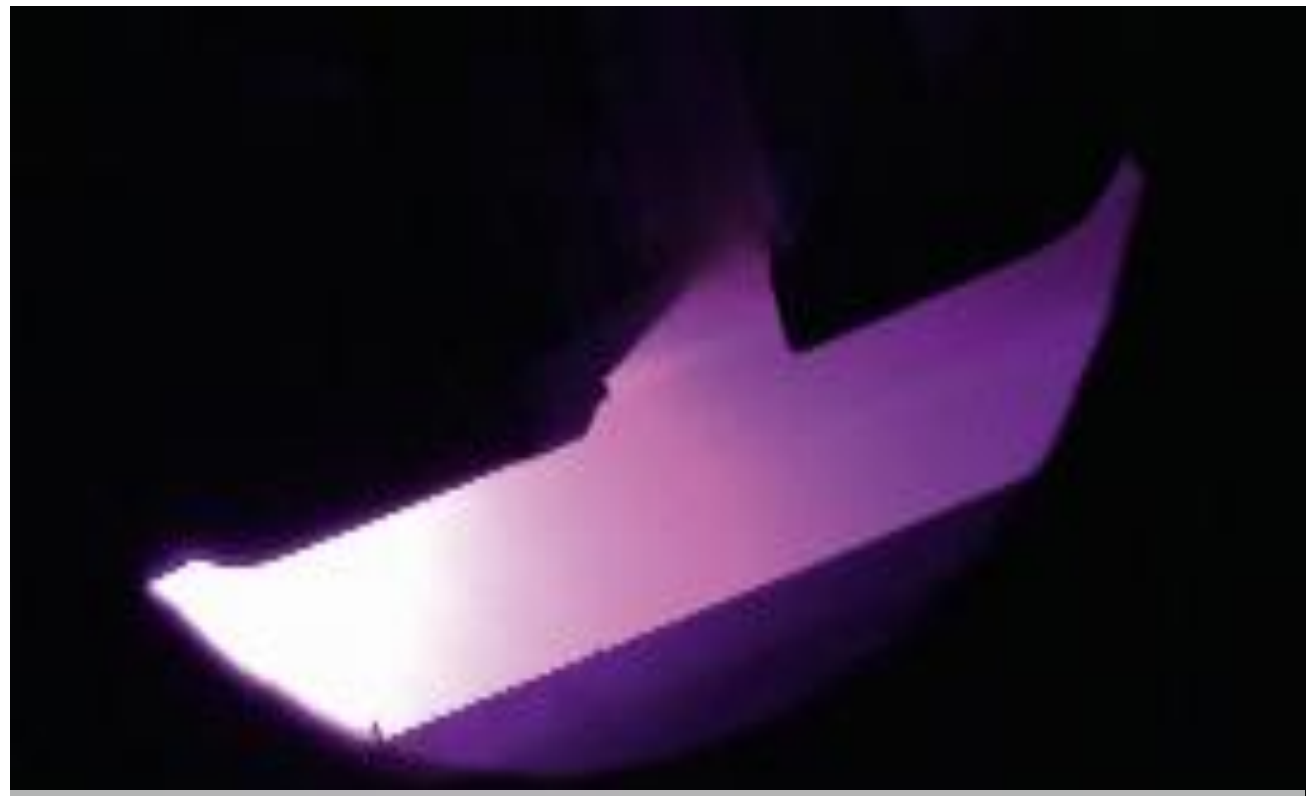
Innovative Application and Equipment for efficient and resource saving production processes

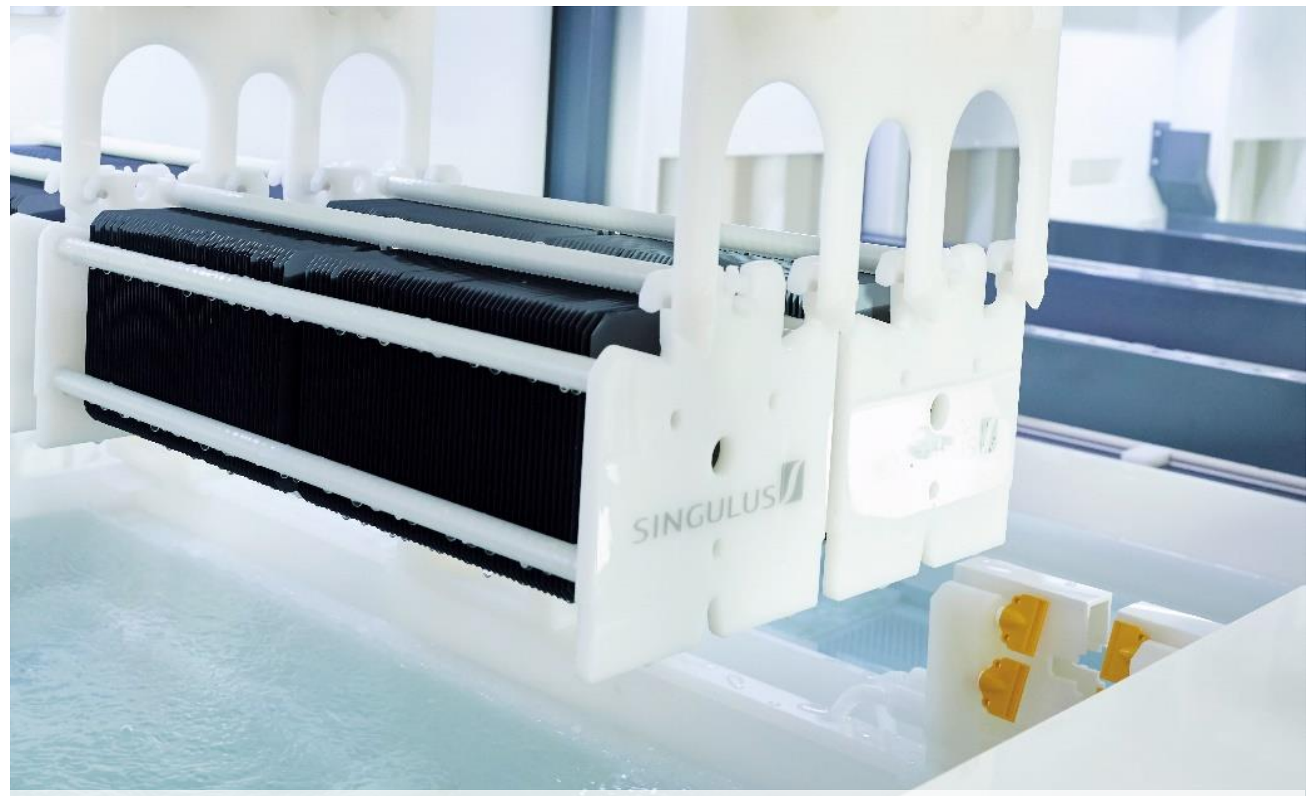

PVD


PECVD

Evaporation


RTP/CSS


Plasma Etching



Wet Chemical Treatment

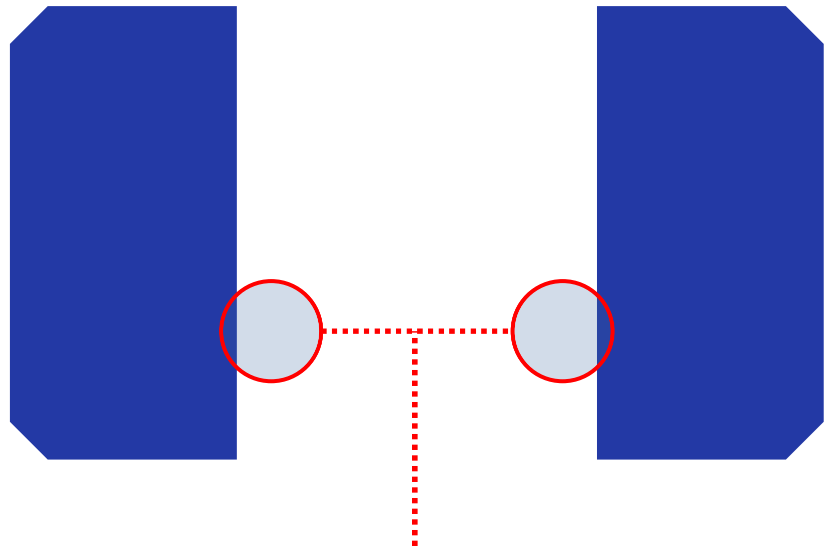
GENERIS PET for Edge Passivation

Improvement of Module Efficiency by Edge Passivation

Standard (Full) Cell → **Half Cut Cell**

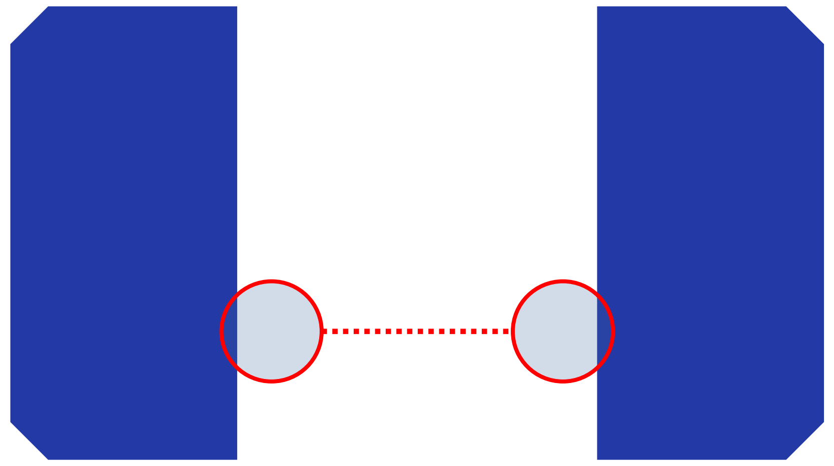
Cell cut after finished cell fabrication

- Less automatization/wafer handling during cell processing
- lowering breakage rate (only full wafer handling)



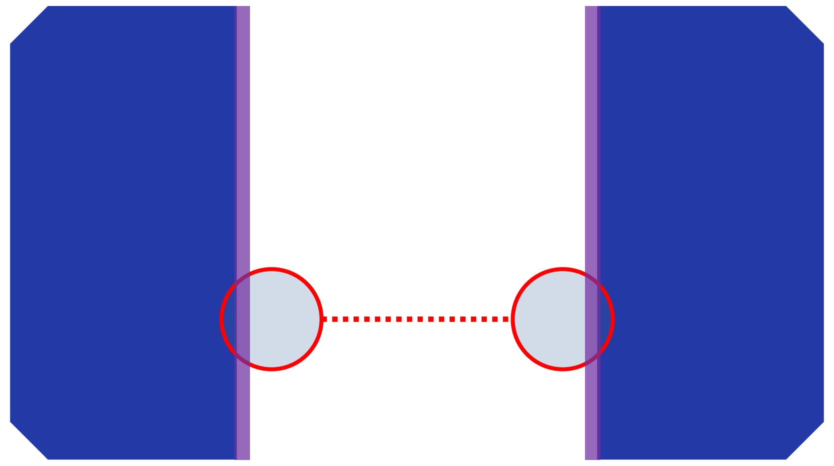
Unpassivated cut edges
Unpassivated wafer edges lead to efficiency loss

Half Cut Cell **w/o PET** → Half Cut Cell **with PET**



GENERIS PET: Deposition of edge cover layers after cell cut

- **Efficiency gain** up to 1.0 % for cut cell with PET vs. cut cell without PET
- Increased efficiency on module level



GENERIS PET for Edge Passivation

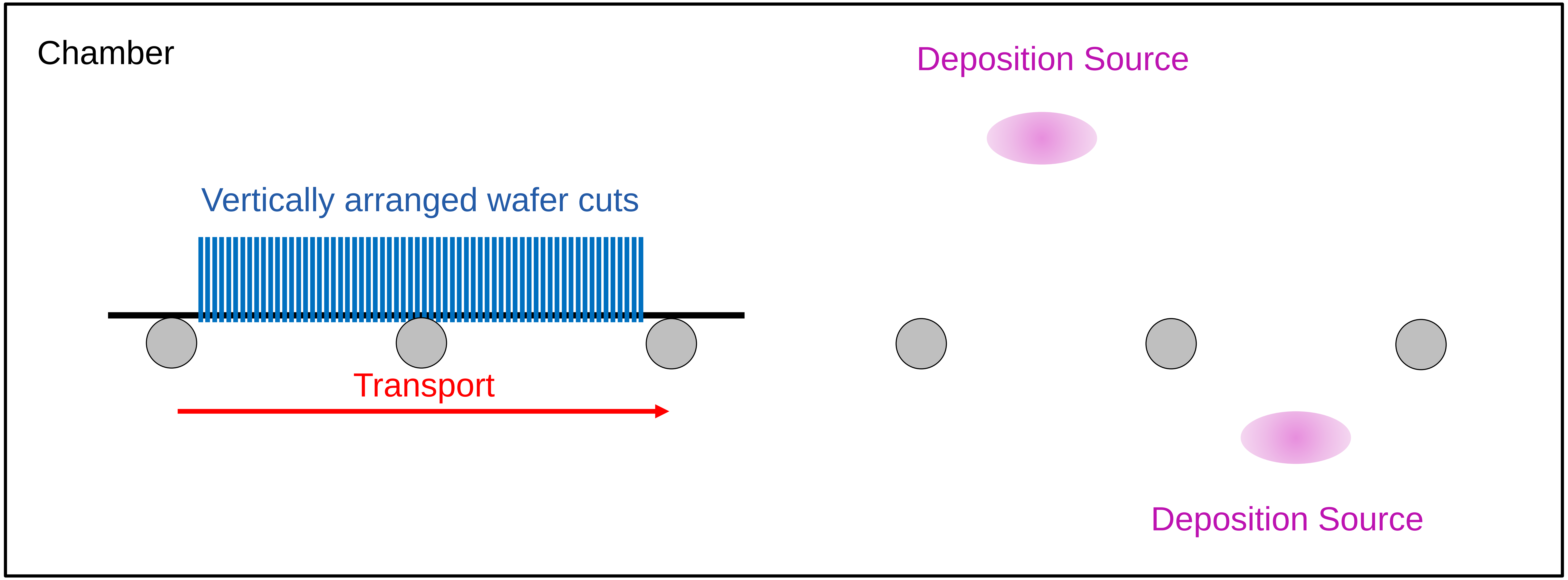
GENERIS PET Tool

Features

- **Industrialized High Volume Inline solution for deposition of edge cover layers** for passivated edge technology (PET)
- **Excellent passivation properties** of edge cover layers enabling
  - Compensation of recombination losses caused by cell cutting
  - Increased cell/module efficiency
- **Unique carrier design** for processing of all wafer and cut formats (Halfcut, Multi-cut, Shingle cells) and simultaneous passivation of all cut edges
- Available as standard and advanced version depending on throughput requirements
- Retrofittable to existing fabs due to stand-alone machine design
- **Fully automated** carrier loading and unloading

GENERIS PET for Edge Passivation

Concept of Deposition



Inline deposition of edge cover layers on vertically arranged wafer cuts (Halfcut, Multi-cut, Shingle cells)

GENERIS PET for Edge Passivation

Throughput GENERIS PET Tool (Standard)

Cut Format	1/2 cut	1/4 cut	1/6 cut	1/8 cut
Wafer cuts per carrier	4800			
Machine cycle time	20 minutes			
Annual substrate throughput total (net)	~ 114 Mio.			
P net for annual throughput for G12	~ 600 MW	~ 300 MW	~ 200 MW	~ 150 MW

Throughput GENERIS PET Tool (Advanced)

Cut Format	1/2 cut	1/4 cut	1/6 cut	1/8 cut
Wafer cuts per carrier	7200			
Machine cycle time	6 minutes			
Annual substrate throughput total (net)	~ 562 Mio.			
P net for annual throughput for G12	~ 3000 MW	~ 1500 MW	~ 1000 MW	~ 750 MW

GENERIS PET for Edge Passivation

GENERIS PET Tool for Halfcut – Comparison Cost of Ownership

GENERIS PET Tool (Standard)

Cut Format	1/2 cut
Annual substrate throughput total (net)	~ 114 Mio.
P net for annual throughput for G12	~ 600 MW

GENERIS PET Tool (Advanced)

Cut Format	1/2 cut
Annual substrate throughput total (net)	~ 562 Mio.
P net for annual throughput for G12	~ 3000 MW

CoO GENERIS PET (Standard)

- Total **cost per substrate** for PET:

  ~ 0,01 €/substrate

- Total **cost per additional Wp** with PET:

  ~ 0,077 €/Wp

CoO GENERIS PET (Advanced)

- Total **cost per substrate** for PET:

  ~ 0,002 €/substrate

- Total **cost per additional Wp** with PET:

  ~ 0,015 €/Wp

GENERIS PET for Edge Passivation

Summary

- **Industrialized high throughput solution** for passivated edge technology
- **Excellent passivation layer properties** for increased efficiency on cell/module level
- **Unique carrier design** compatible for processing of all wafer and cut formats (Halfcut, Multi-cut, Shingle cells)
- **Retrofittable to existing fabs** due to stand-alone machine design
- **Low CoO and machine payback time**

Contact

Contact

Jan Krausmann

Product Manager

jan.krausmann@singulus.de

Contact

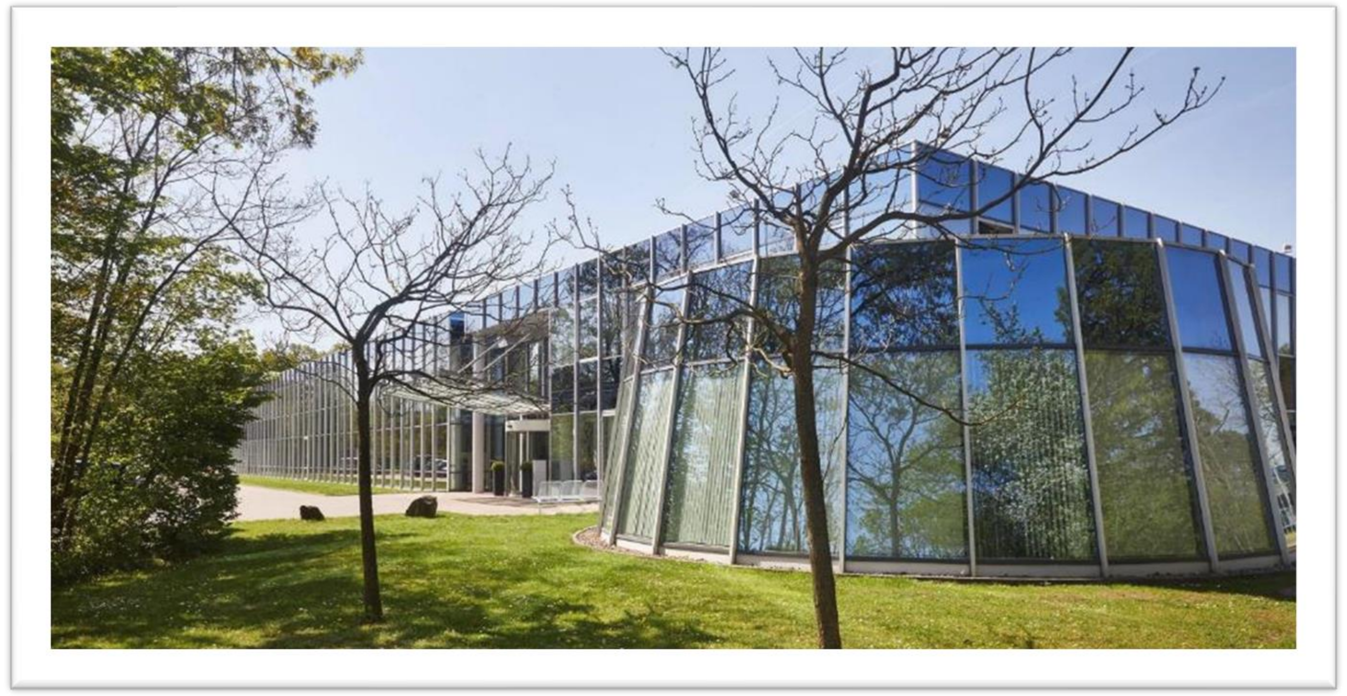
SINGULUS TECHNOLOGIES AG
Hanauer Landstrasse 103
D-63796 Kahl/Main

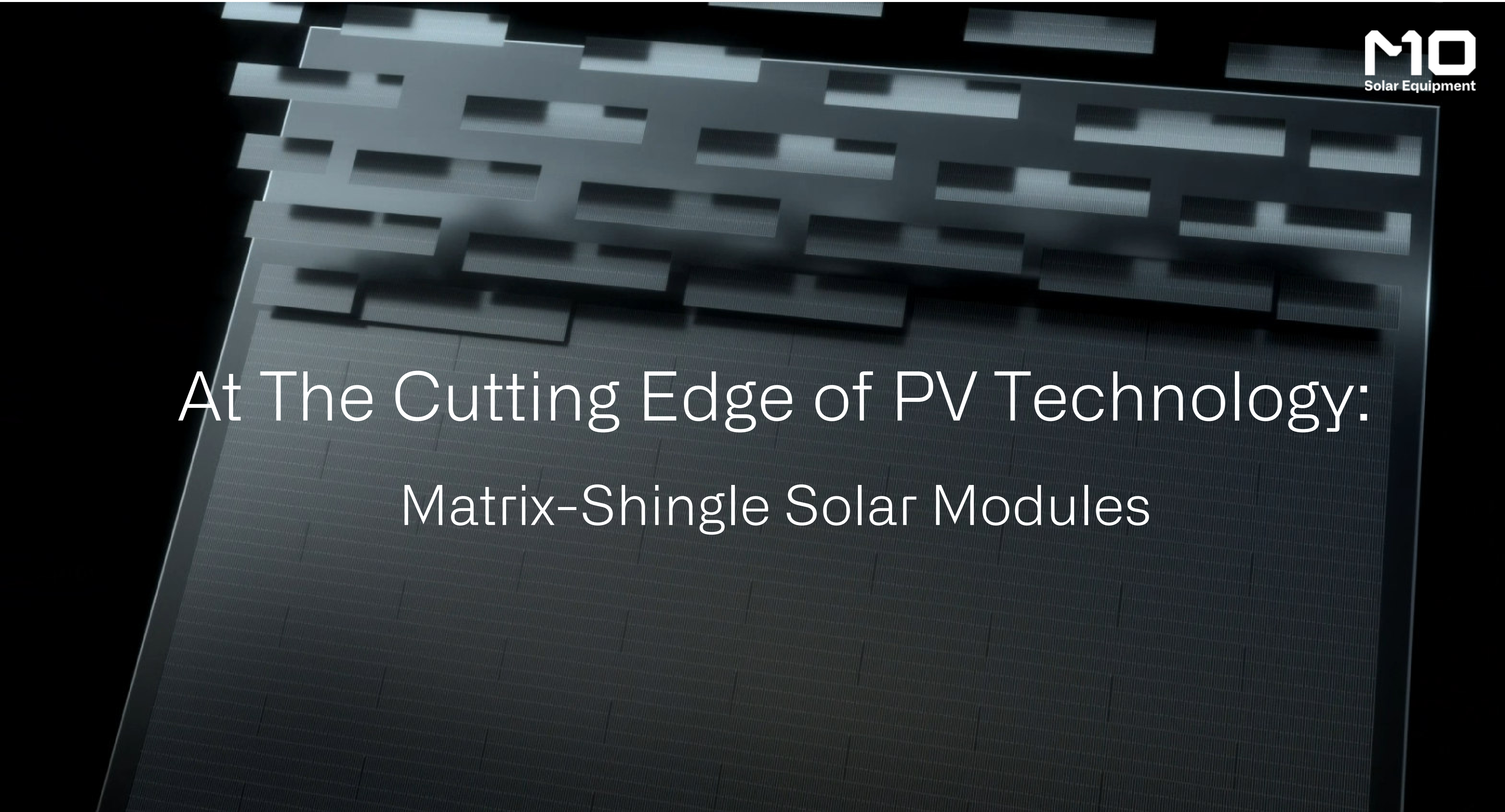
Dr.-Ing. Stefan Rinck, President and CEO
Stefan.Rinck@singulus.de

Markus Ehret, CFO
Markus.Ehret@singulus.de

Forward-Looking Statements

This presentation contains forward-looking statements based on current expectations, assumptions and forecasts of the executive board and on currently available information. Various known and unknown risks, unpredictable developments, changes in the economic and political environment and other presently not yet identifiable effects could result in the fact that the actual future results, financial situation or the outlook for the company differ from the estimates given here. We are not obligated to update the forward-looking statements made in this presentation unless there is a legal obligation.





At The Cutting Edge of PV Technology:

Matrix-Shingle Solar Modules

M10
Solar Equipment

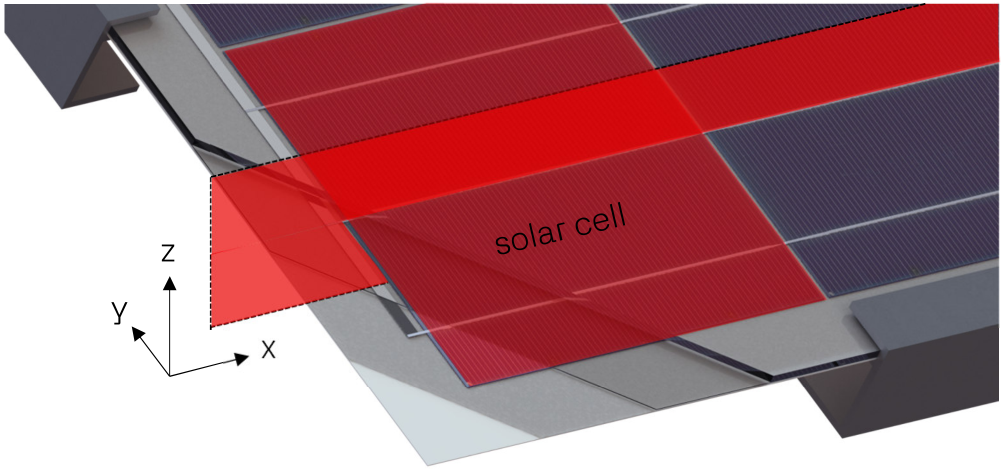
Module Manufacturing Process

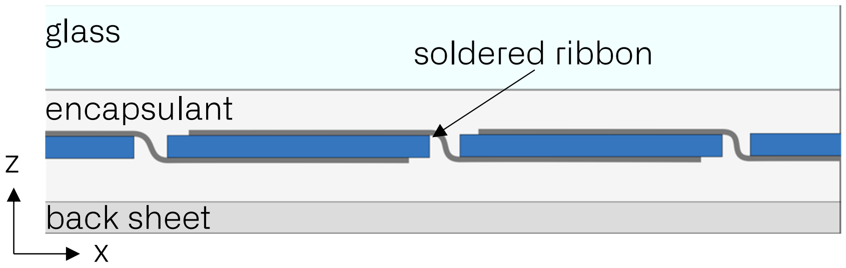
Solar Equipment

Solar cell manufacturing → Cutting 3D Micromac → Edge passivation Singulus → **Interconnection** M10 Solar Equipment → **Cross Connection / Bussing** M10 Solar Equipment → Lamination

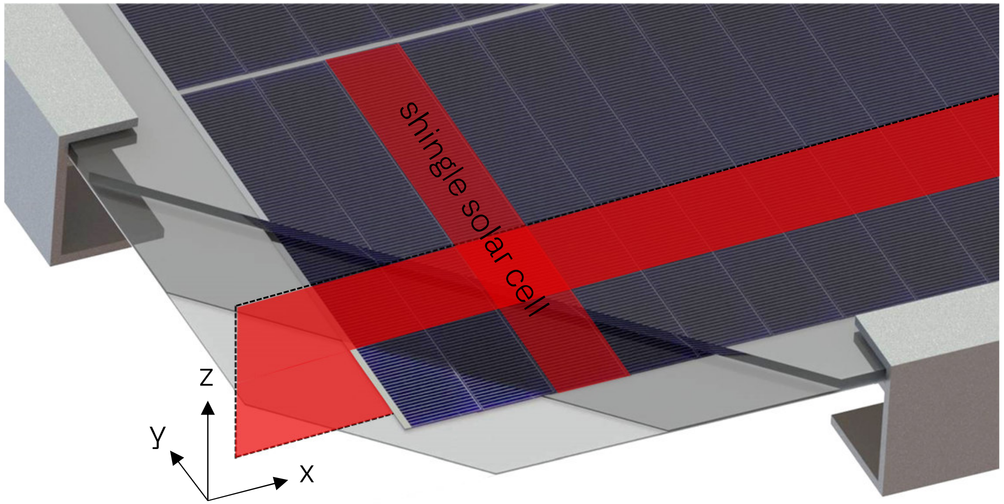
Solar Modules with Shingled Solar Cell Interconnection

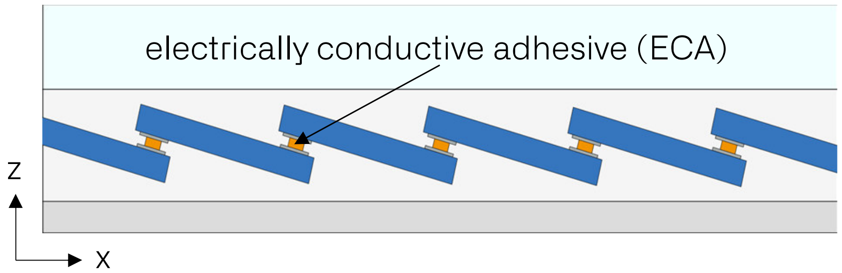
Ribbon / wire interconnection





Shingle solar cell interconnection [1]





Matrix-Shingle Interconnection

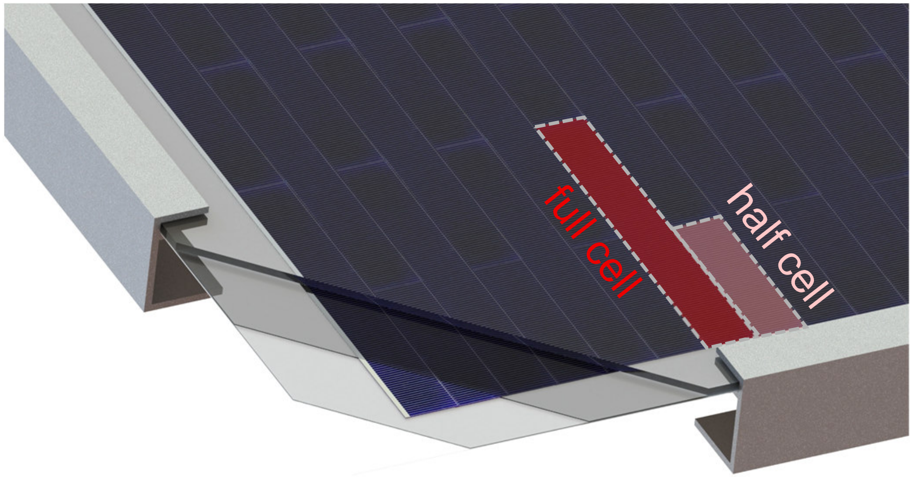
M10 Solar Equipment

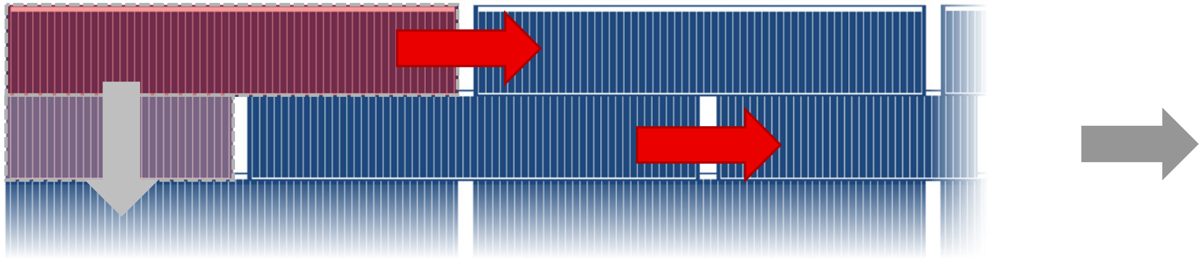
Matrix-shingle module layout

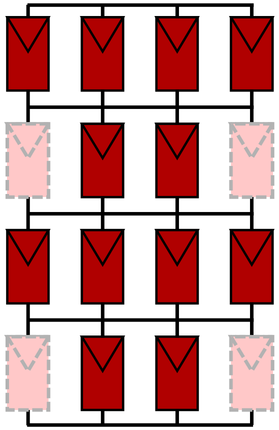
- Introducing: half-cut shingle solar cells
- Creation of masonry-like structure

- Parallel Interconnection of solar cells in one row
- Serial interconnection of rows forming the module

➔ Intrinsic serial-parallel interconnection of solar cells



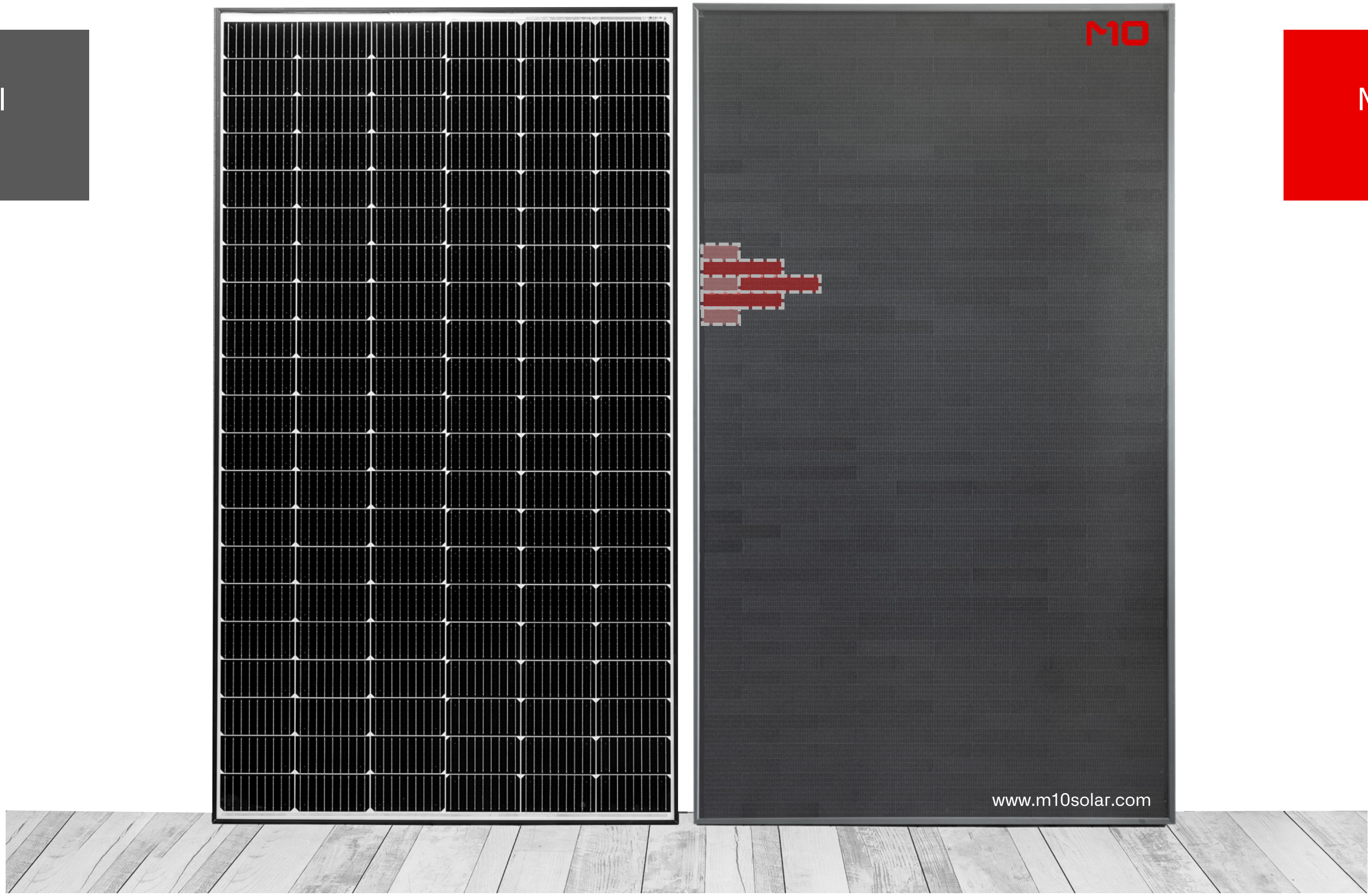




elektrical layout:
matrix of solar cells

Revolut[10]nary Module Aesthetics

SoA half-cell module



Matrix-shingle module

Revolut[10]nary Module Aesthetics

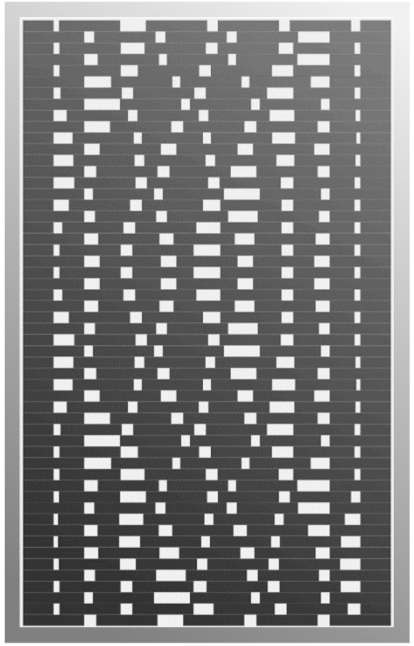
Highly aesthetic solar modules

- Creating surfaces without obvious „PV-optic“
- Working with cell distances to create patterns

Add color

- Colored back sheets
- Combination with MorphoColor® on front glass
  - Developed by Fraunhofer ISE
  - Highly intensive and homogenous color
  - Optical transmission losses <10 %

Plain matrix-shingle

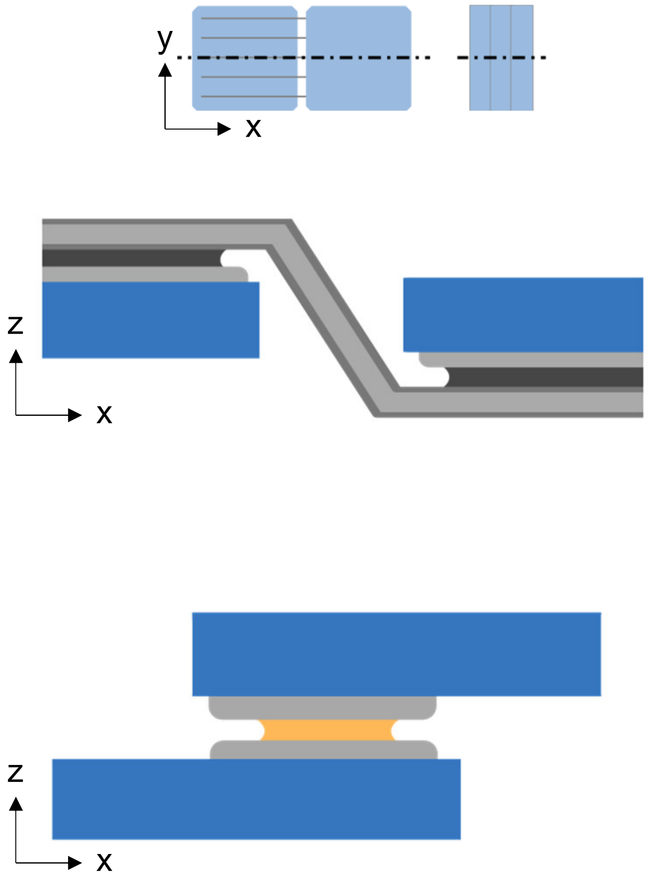


Patterned layout with (colored) back sheet

+ MorphoColor®

Revolut[10]nary Efficiency

Solar Equipment

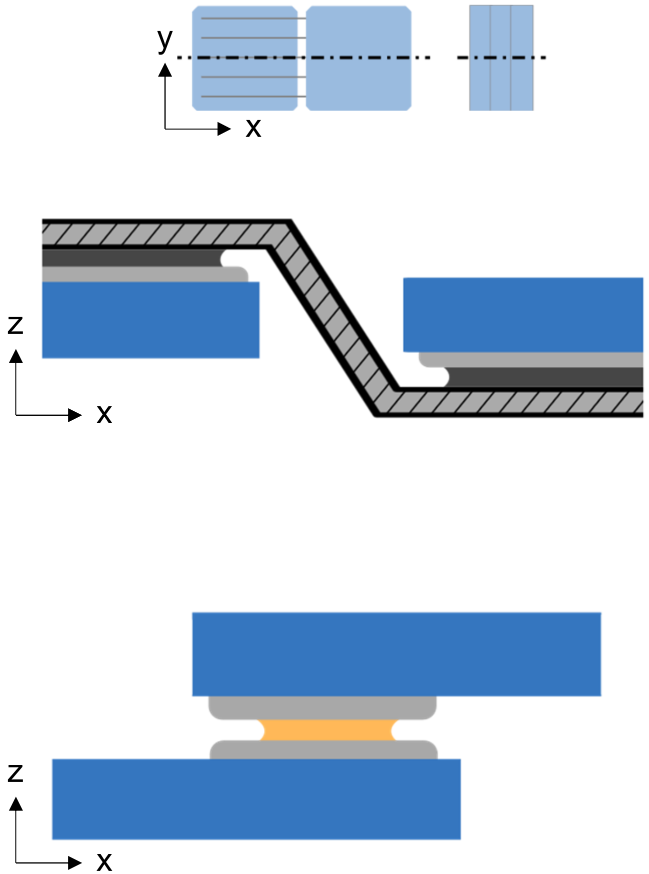


sketches not to scale

Revolut[10]nary Efficiency

M10 Solar Equipment

1. Electrical Advantages
   - No Ribbons
   - Reduced ohmic losses in module

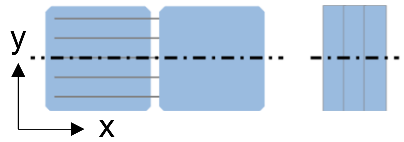


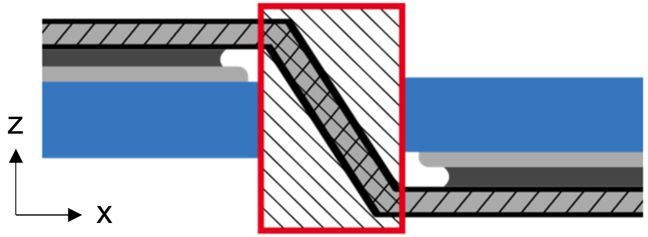
sketches not to scale

Revolut[10]nary Efficiency

1. Electrical Advantages
    - No Ribbons
    - Reduced ohmic losses in module

2. Geometrical Advantages
    - Reduction of inactive cell gaps
    - Higher packing densities of solar cells





sketches not to scale

Evolut[10]n Revolut[10]nary Efficiency

Solar Equipment

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   - No Ribbons
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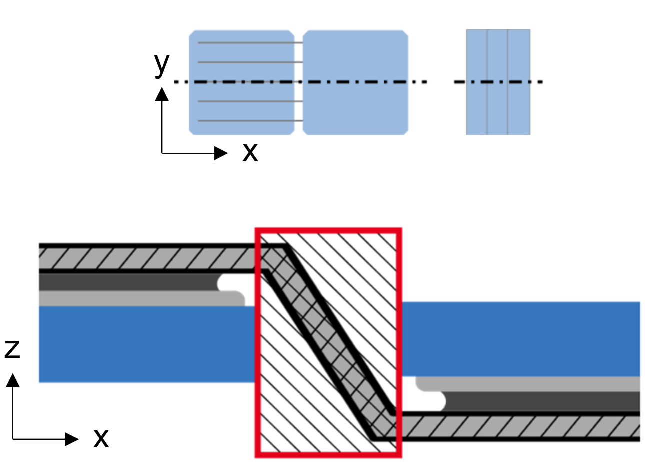
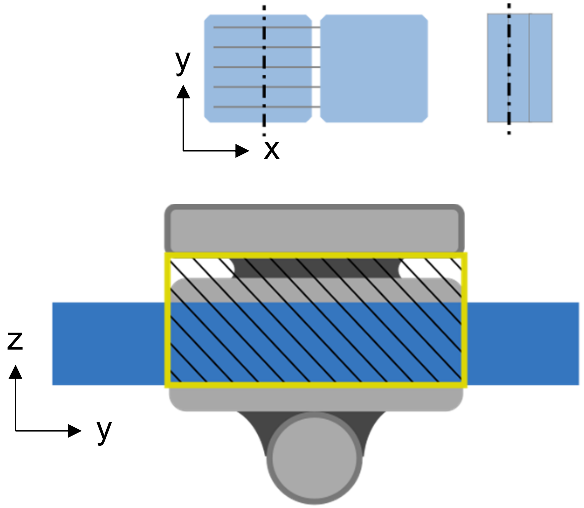
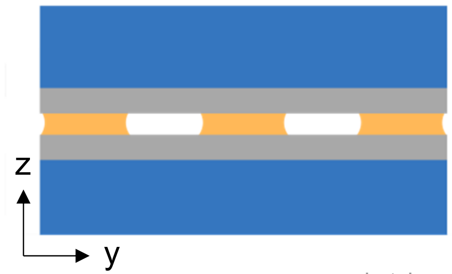




2. Geometrical Advantages
   - Reduction of inactive cell gaps
   - Higher packing densities of solar cells

3. Optical Advantages
   - „No“ shading from busbar metallization
   - No shading from ribbons



sketches not to scale

Evolut[10]n | Revolut[10]nary Efficiency

1. Electrical Advantages
    - No Ribbons
    - Reduced ohmic losses in module

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    - Higher packing densities of solar cells

3. Optical Advantages
    - „No“ shading from busbar metallization
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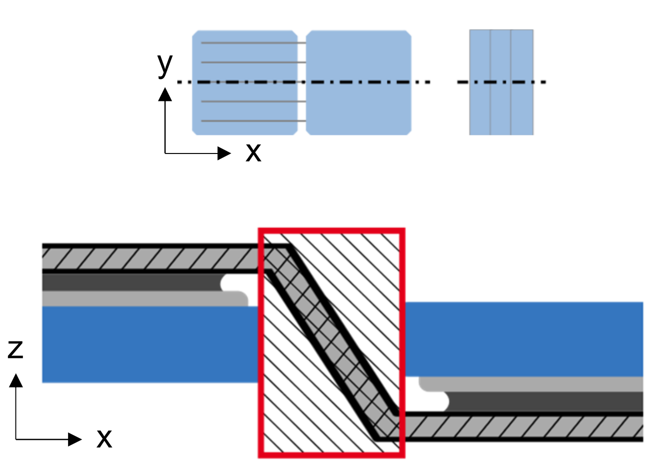
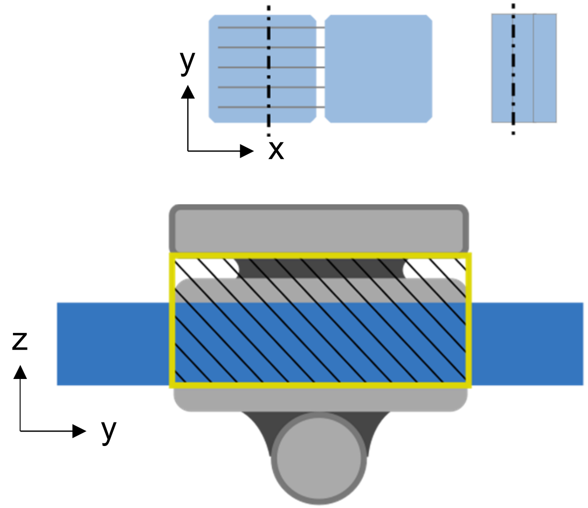
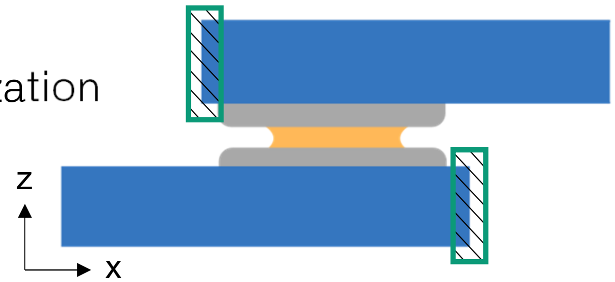
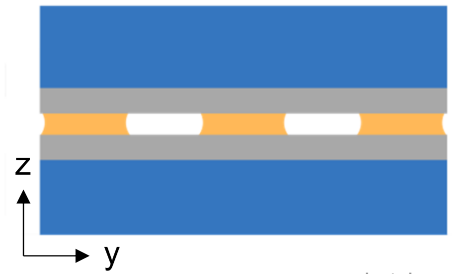
4. PET





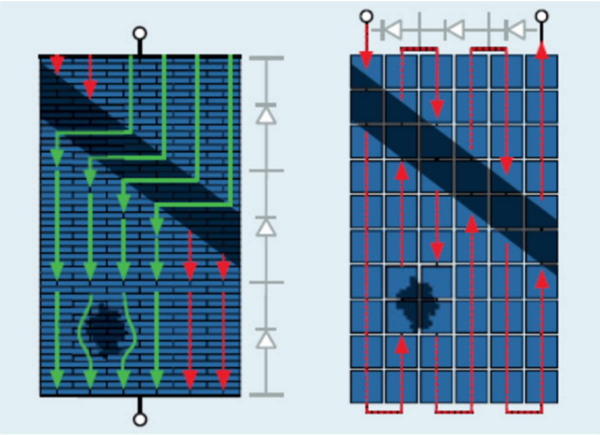




sketches not to scale

Revolut[10]nary Partial Shading Behavior

M10 Solar Equipment

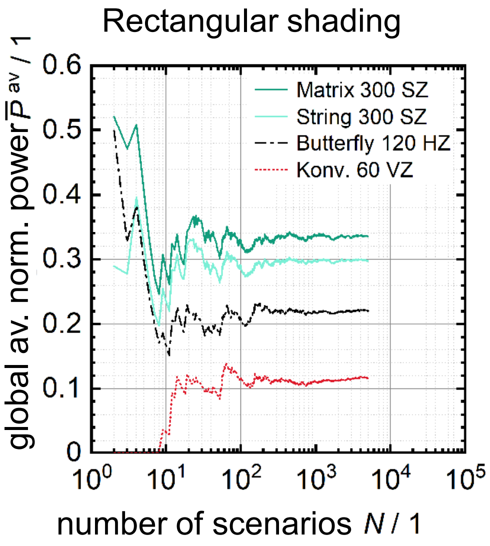


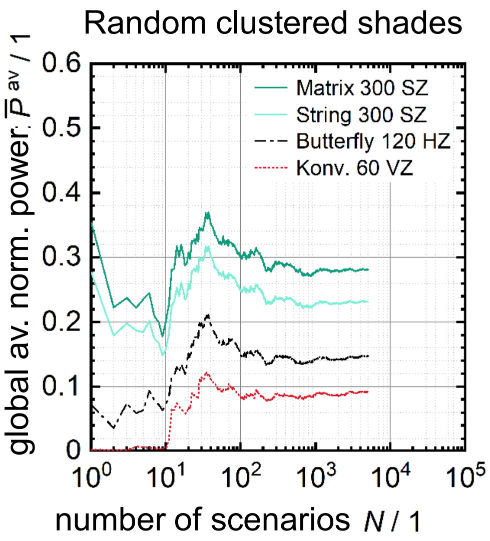
Significant increased shading resilience[1,2,3]

- Parallel interconnections
- Lateral currents
- Fill factor effect

Comprehensive Monte Carlo simulations

- Rectangular shades
- Random clustered shades
- Comparison of
  - Matrix-shingle module, 300 shingle cells
  - String-shingle module, 300 shingle cells
  - Butterfly module, 120 half-cells
  - Commercial 60 full cell module





Matrix-Shingle Modules

–

Highly
aesthetic, efficient* and shading resilient
Solar Modules

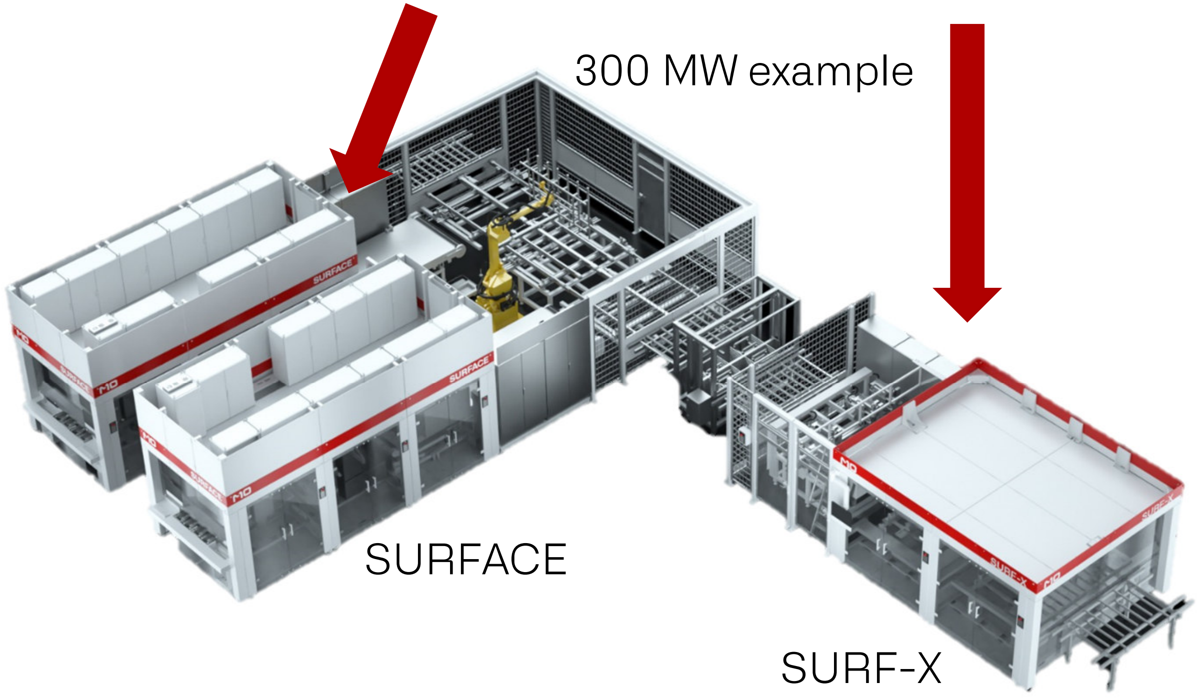
Preferred Application:

xIPV

*especially when combined with PET

Evolut[10]n Module Manufacturing Process

Solar cell manufacturing → Cutting 3D Micromac → Edge passivation Singulus → **Interconnection** M10 Solar Equipment → **Cross Connection / Bussing** M10 Solar Equipment → Lamination



Module Manufacturing Process

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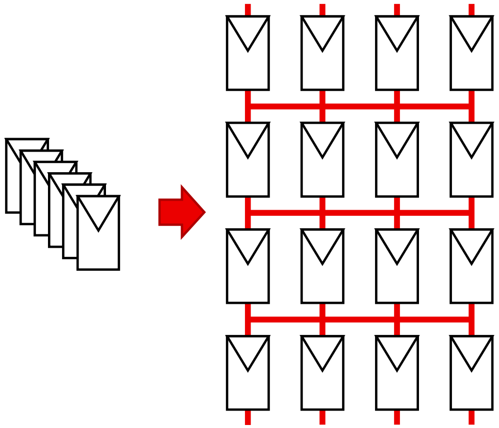

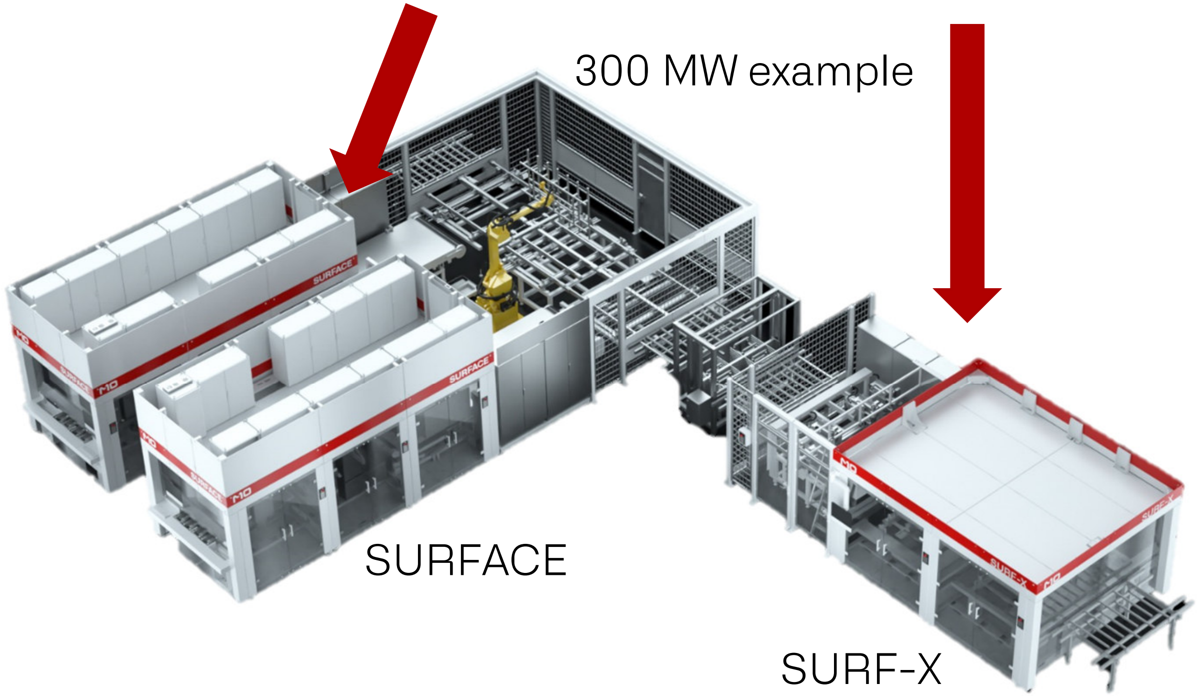

Evolut[10]n Module Manufacturing Process

Solar Equipment

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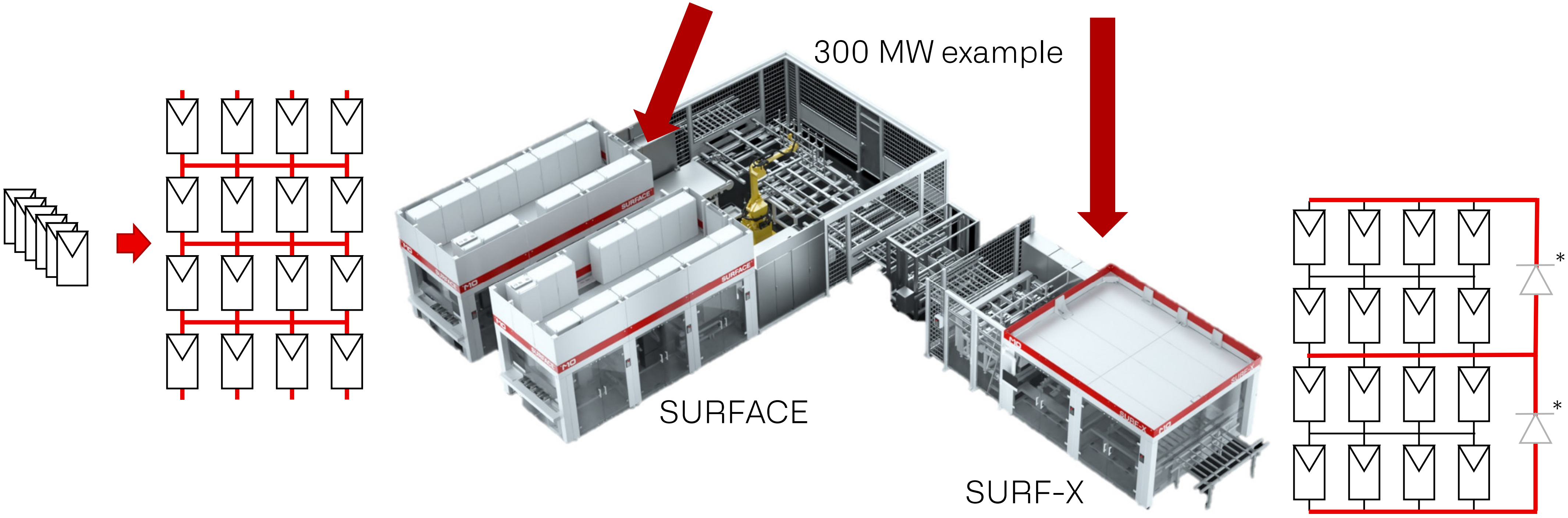


*bypass diodes integration after lamination in junction box

Evolut[10]n

M10 Solar Equipment

- Highly performing
- Compact Design
- Much more than just technically up to date
- Amazing output

no ribbon coil change required
→ [10]% increased uptime

inter solar award 2022 WINNER

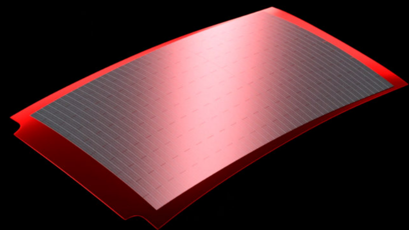
GERMAN INNOVATION AWARD '22 WINNER

Material	Process	Cost	Service-friendly
All solar cell formats: M0 to M12+	consistent production ⇨ 12'000 cells/h	Less Manpower	Artificial Intelligence
All types of cells like HJT, Perovskite, Tandem, TopCon,	Flexibility in changeover	Less material consumption	European Service Network
bifacial ready!	Lead-free process	Less cleaning & maintenance	
no ribbon, no flux			

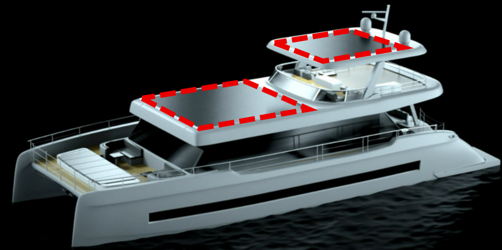
Evolut[10]n

Full Product Flexibility

One Host Wafer – Infinite Possibilities



Vehicle integrated PV

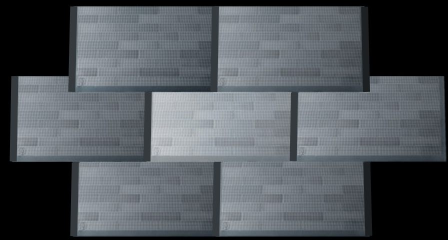


Off-grid solutions

passivated edge
shingle solar cells

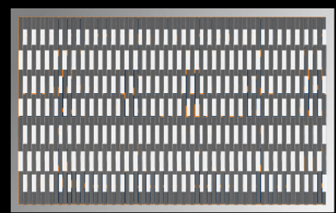
Interconnected
solar cells
ready for

Facade modules - flexible formats



Roof tiles

Configure your product,
not your tools!



Agri Photovoltaics

Thank you for your kind attention!

M10 Industries AG

Munzinger Str. 10
79111 Freiburg im Breisgau
G E R M A N Y
Web: www.m10solar.com

Speaker: Nils Klasen

Tel.: +49 761 7675 414
Email: nils.klasen@m10solar.com

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Q&A

10 July 2023

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4:00 pm – 5:00 pm | CEST, Berlin
10:00 am – 11:00 am | EDT, New York City

Mark Hutchins
Editor
pv magazine

Elmar Lohmüller
Product Manager
Fraunhofer ISE

Thomas Kießling
Sales Manager
3D-Micromac

Jan Krausmann
Product Manager
Singulus Technologies

Nils Klasen
Technology & Sales Manager
M10

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Coming up next...

Thursday, 13 July 2023
4:00 pm – 4:00 pm CEST, Berlin, Paris, Madrid
10:00 am – 11:00 am EDT, New York City

Tuesday, 25 July 2023
10:00 am – 11:00 am PDT, Los Angeles
1:00 pm – 2:00 pm EDT, New York City

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