

R&D Project NextTec – Next Generation High Throughput Production Processes & Inline Characterization for Si Solar Cells



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ASYS: Matthias Drews; **RCT Solutions:** Wolfgang Jooss;
ISC Konstanz: Elina Schmid; **HTWK:** Stephan Schoenfelder; **Fraunhofer CSP:** Ringo Koepge

8th WCPEC

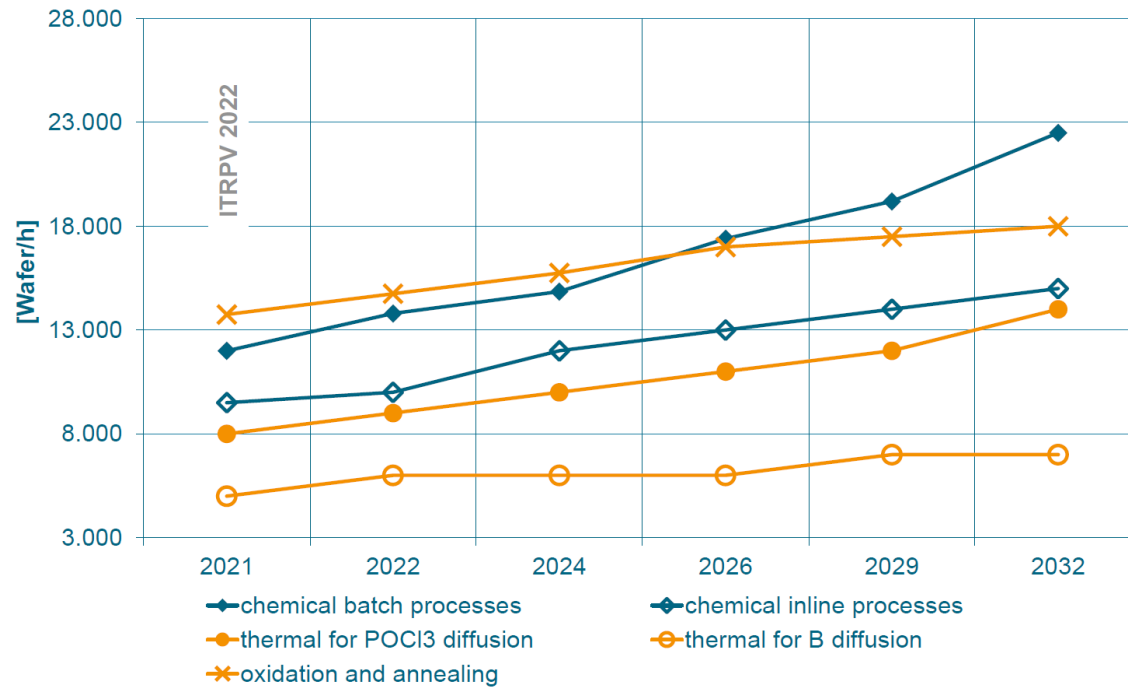
Milano, 29.09.2022

www.ise.fraunhofer.de

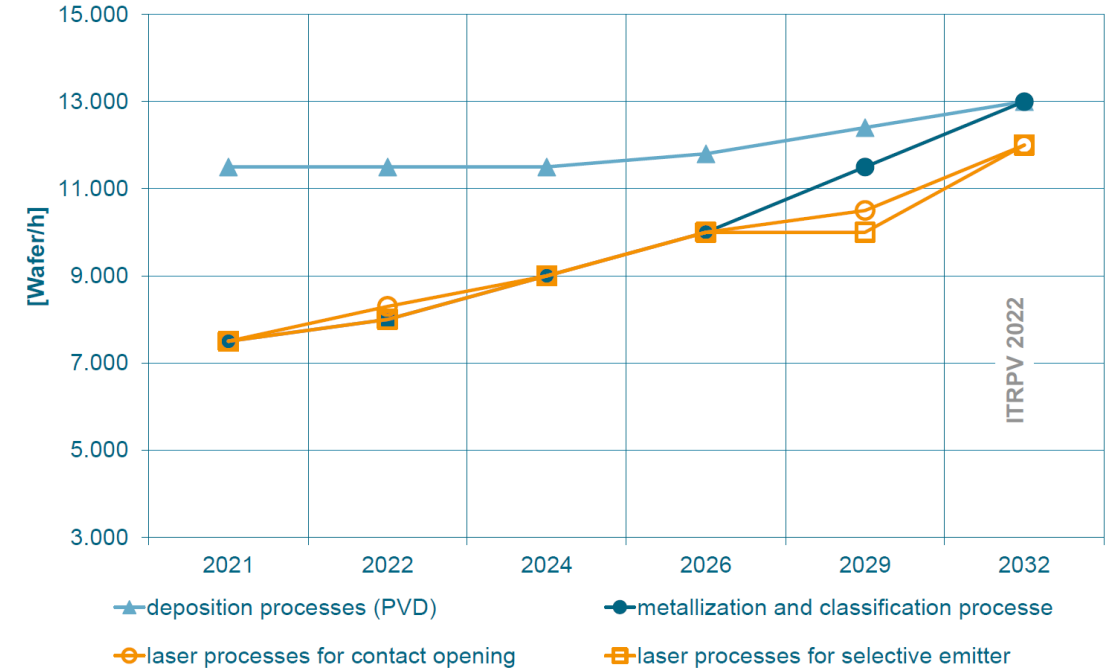
NextTec Project

Motivation – ITRPV Roadmap 2022 [1]

Progressive Scenario, new tools for wafer sizes M10 (182.0 x 182.0 mm²)



Progressive Scenario, new tools for wafer sizes M10 (182.0 x 182.0 mm²)



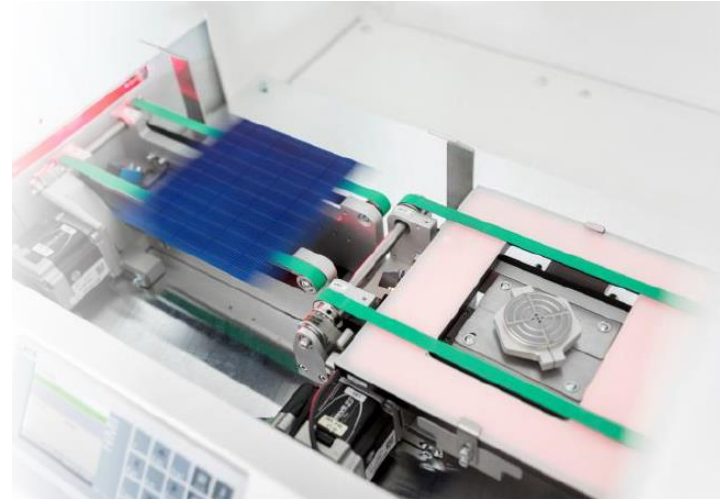
➤ ITRPV: Increase in throughput rates by approx. factor 2 estimated in the next ten years

[1] VDMA, ITRPV, 2022

NextTec Project

Short Project Description

- R&D project NextTec
- German consortium of equipment and metrology manufacturers as well as R&D institutes
- Funded by the German government
- Running Time: 01.05.2019 – 31.10.2022



Supported by:



Federal Ministry
for Economic Affairs
and Climate Action

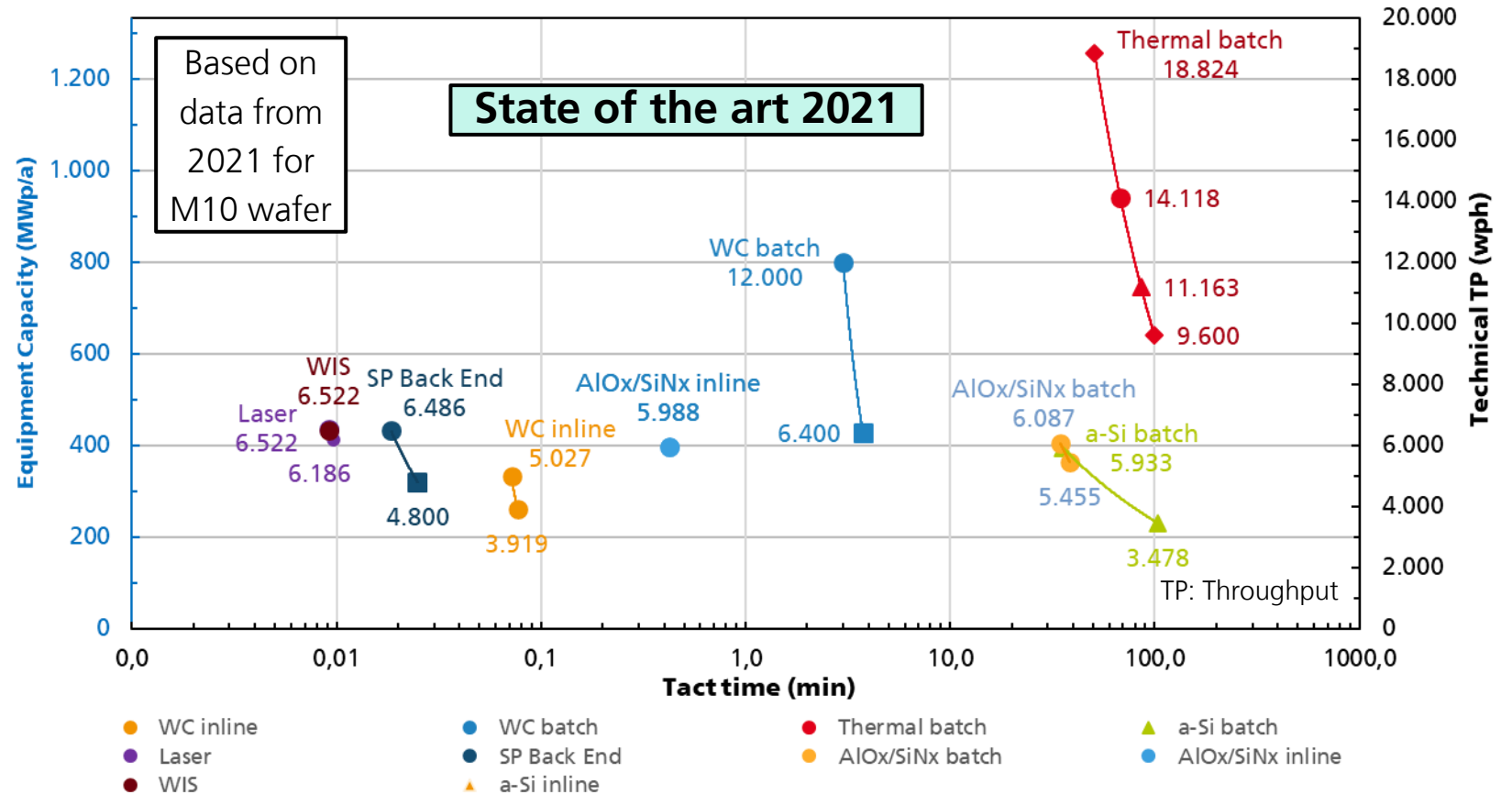
on the basis of a decision
by the German Bundestag

Contract Nr: 03EE1001A



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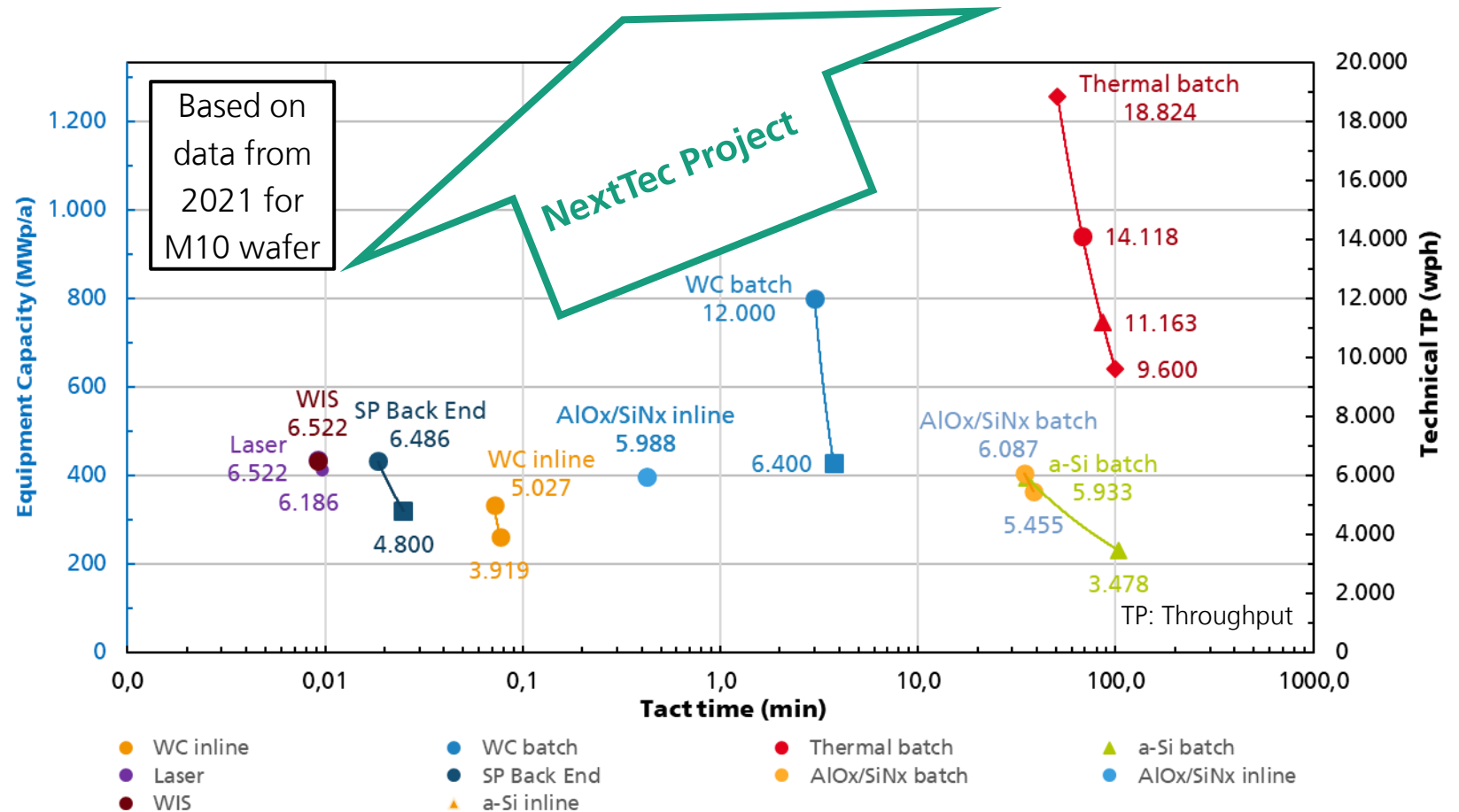
Aim of the NextTec Project



NextTec Project

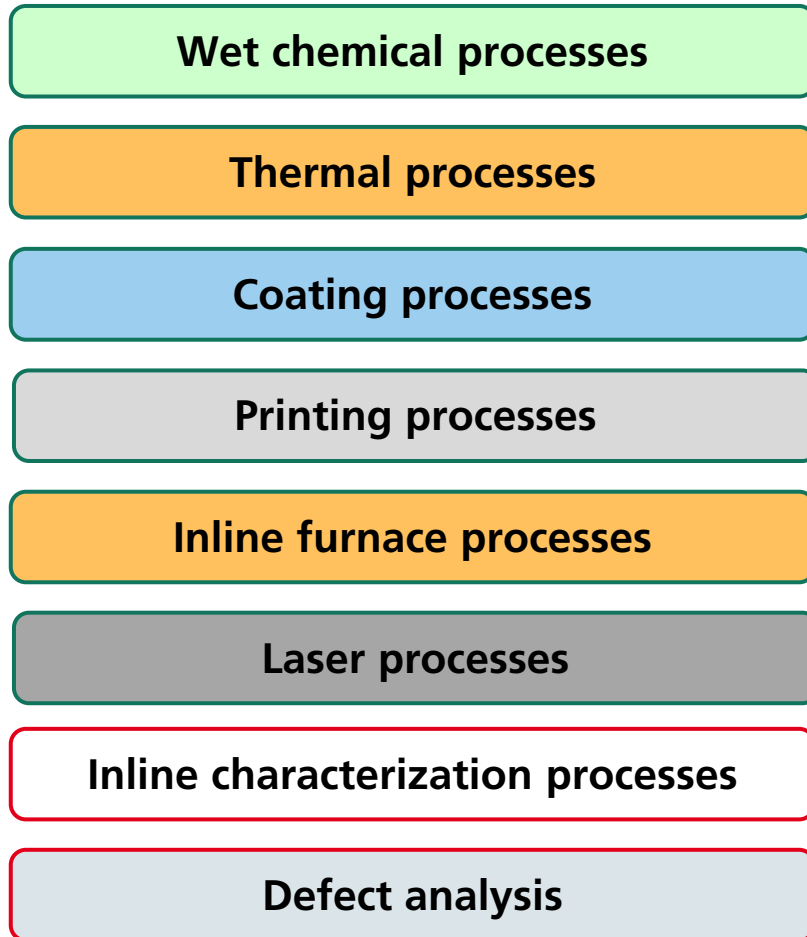
Aim of the NextTec Project

- Increase throughput rates by factor 2 to 3
 - Similar cell efficiency
 - No significant increase in equipment footprint and costs
- System throughputs: > 13,000 wafers per hour (M10 wafer)
- Production capacity: > 1 GW per system and year



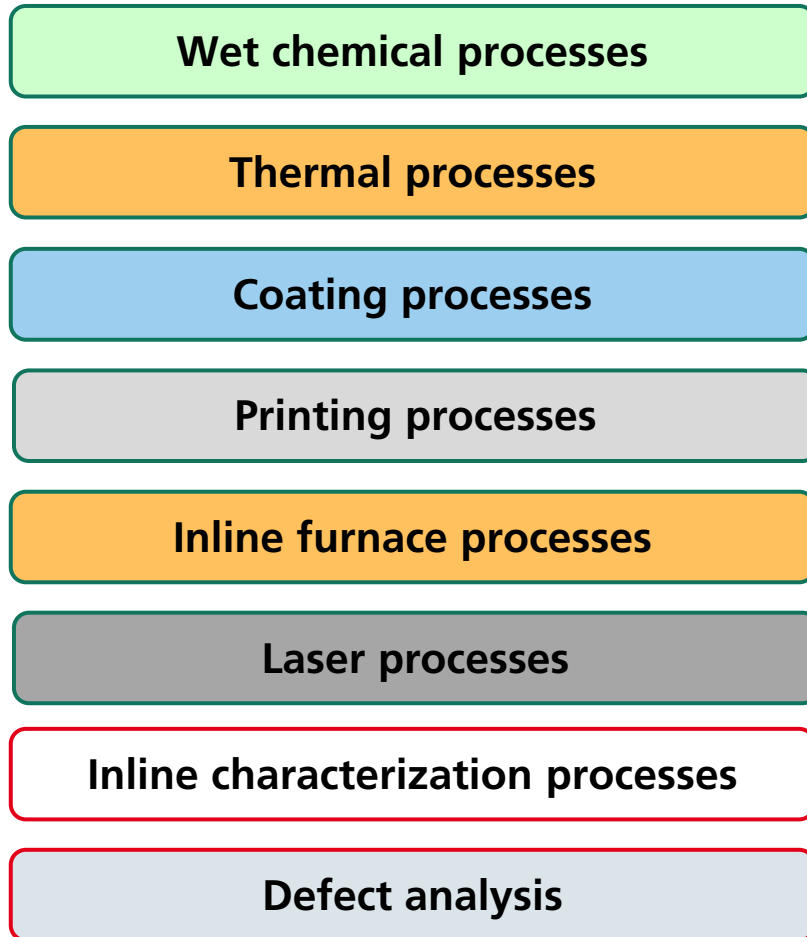
NextTec Project

NextTec Processes – Overview

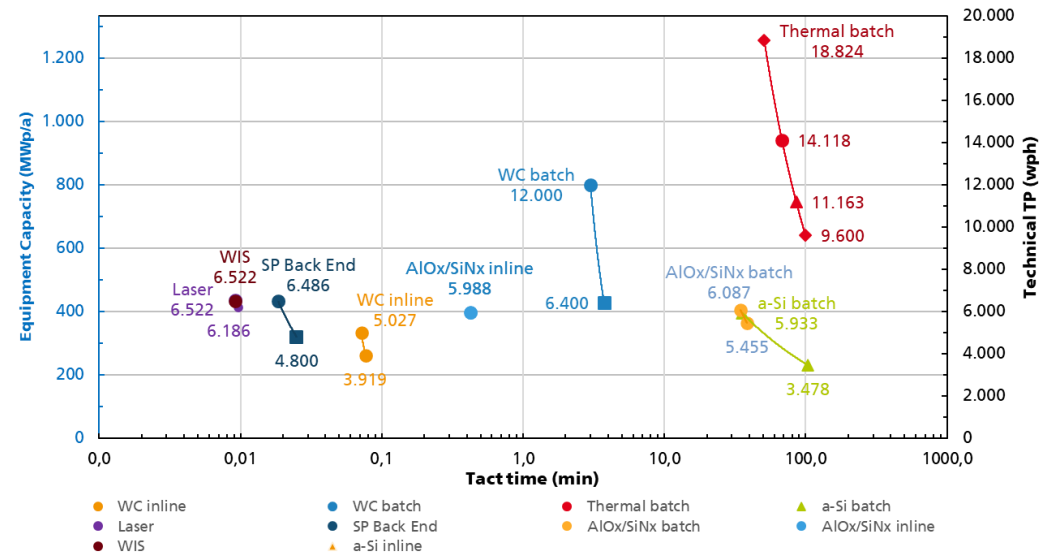


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NextTec Processes – Overview



Techno-economic analysis [1a]: for all NextTec processes



[1a] PhD thesis Sebastian Nold, 2019

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NextTec Processes – Overview

Wet chemical processes

Thermal processes

Coating processes

Printing processes

Inline furnace processes

Laser processes

Inline characterization processes

Defect analysis

NextTec Project

New concepts for (vertically passing) Si solar cells



For more information (this conference):

- Dannenberg et al. 1DO.11.1



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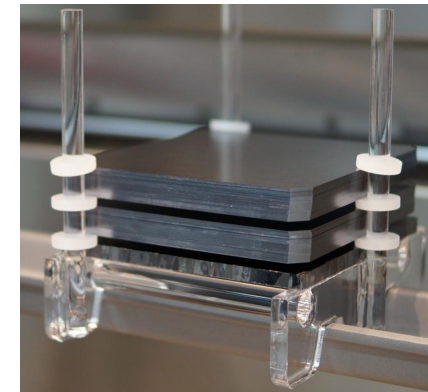
Laser processes

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NextTec Project

Stack diffusion with APCVD doping layers



NextTec Project

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High speed coating technologies: Spray pyrolysis, PVD



VON ARDENNE



For more information (this conference):

- Spray pyrolysis: Heitmann, Bartsch et al., 1BO.3.3
- PVD: Schneiderloechner et.al. 1DO.12.4, 1DV.4.40

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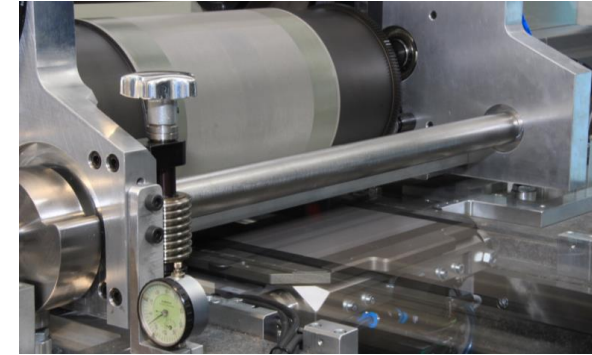
Inline furnace processes

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NextTec Project



Inline printing processes based on rotational printing



NextTec Project

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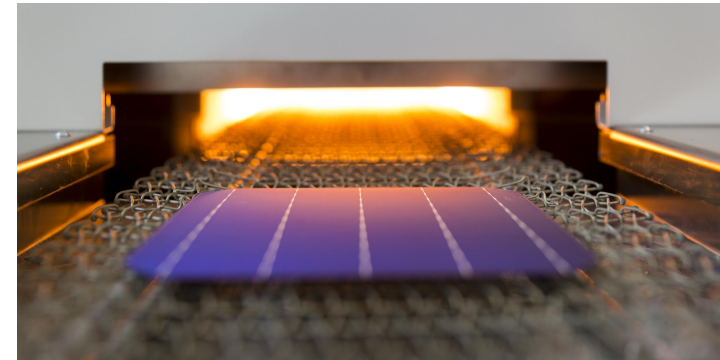
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NextTec Project



High belt speeds and novel heating elements

 **Fraunhofer**
ISE

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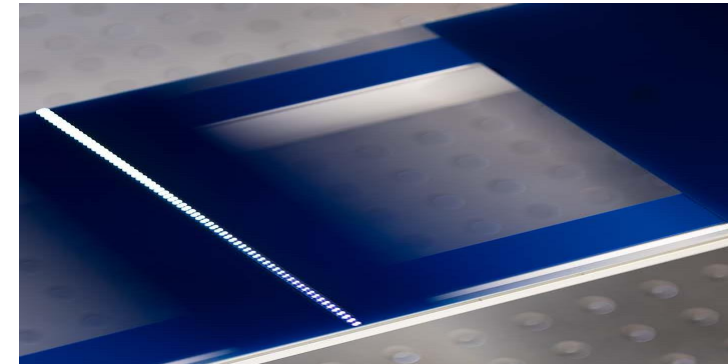
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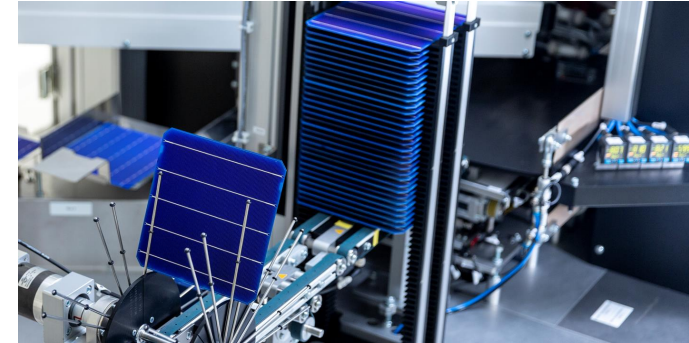
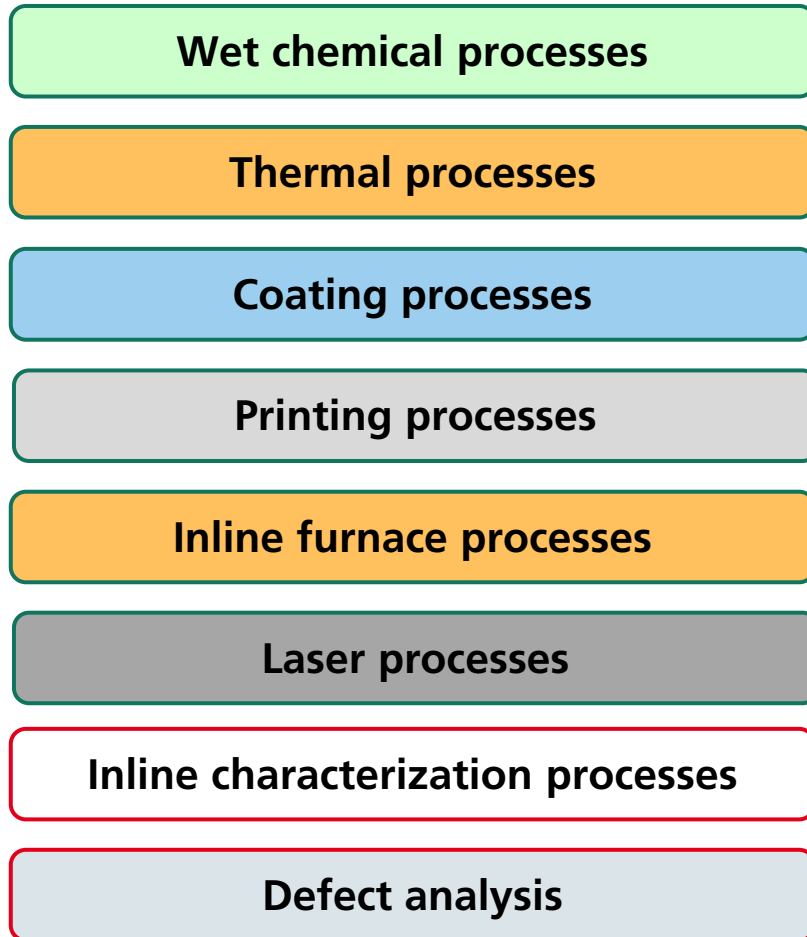


Inline laser processes with precise laser beam control

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NextTec Processes – Overview



For more information (this conference):

- *IV* contactless: Kunze et al. 2AO.2.2
- *IV* / *EL* on-the-fly: Kurumundayil et al. 1DV.4.36



Innovative on-the-fly *IV* / *EL* testing; contactless *IV*

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NextTec Processes – Overview

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NextTec Project



For more information (this conference):

- Buehler et al. 2BV.2.44
- Koepge et al. 1DV.4.29

 **Fraunhofer**
CSP

MecSim HTWK

Mechanical influences of high throughput processes

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NextTec Processes – Focus in this talk

Wet chemical processes

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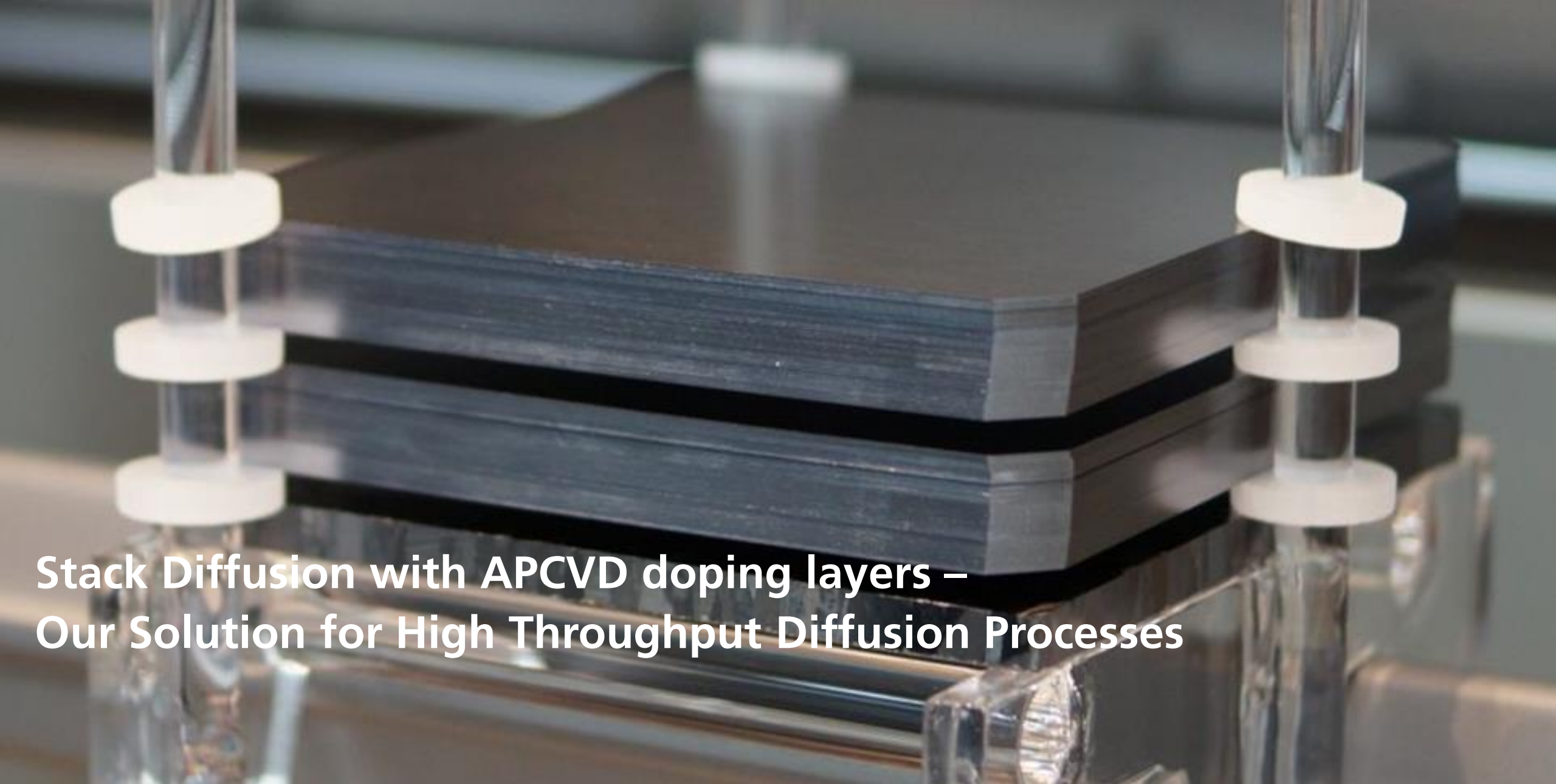
Stack diffusion with APCVD doping layers

Inline printing processes based on rotational printing

High belt speeds and novel heating elements

Inline laser processes with precise laser beam control

Innovative contactless *IV* testing

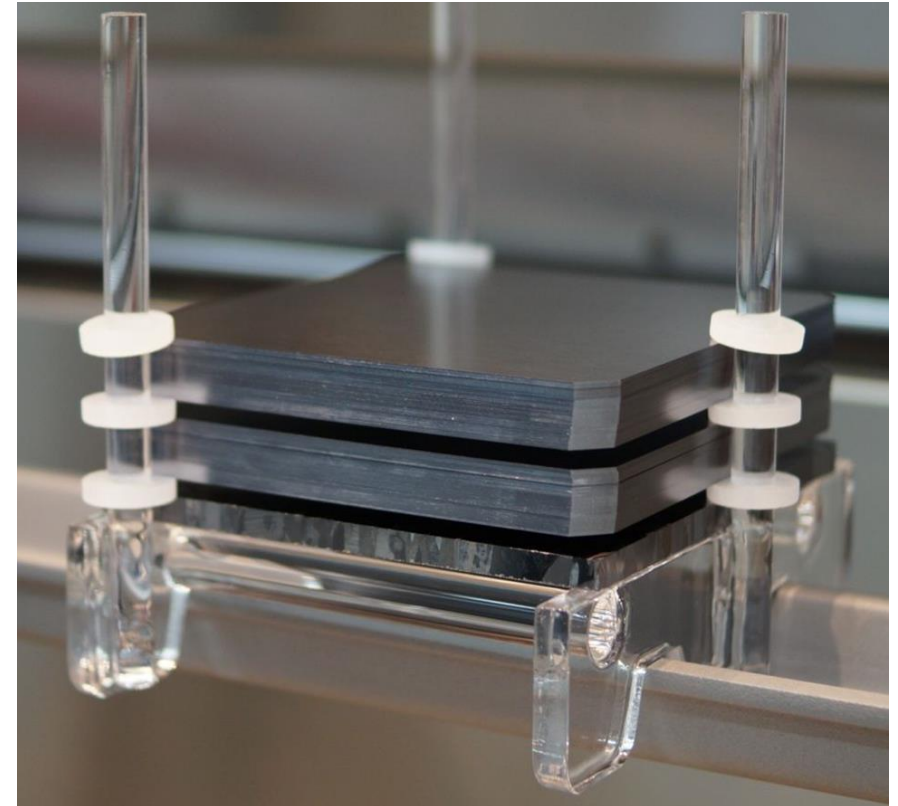


Stack Diffusion with APCVD doping layers – Our Solution for High Throughput Diffusion Processes

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Stack Diffusion / Oxidation [2]

- Stack oxidation / diffusion allows high throughput processes with similar quality
- Combination with pre-deposition of dopant sources e.g. by APCVD inline processing
- In total **6000 M10 Wafer per tube / process** (state of the art: approx. 1600 wafers)



Experimental setup for the stack diffusion in a special quartz boat

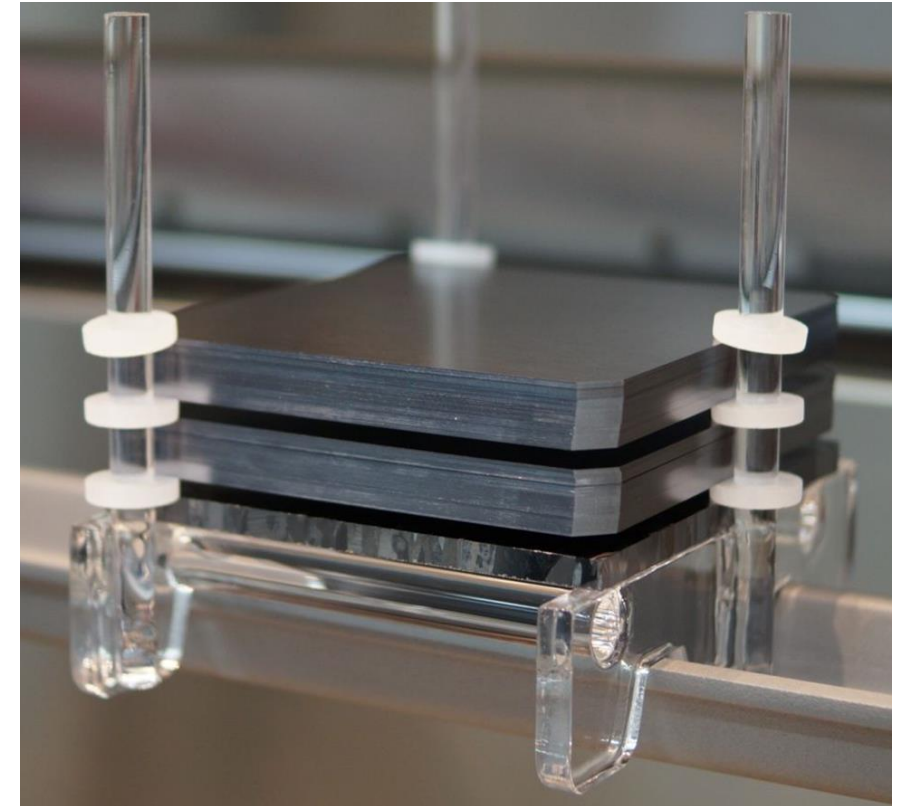
[2] Messmer et al, IEEE, 2022; Messmer et al. EUPVSEC 2021

NextTec Project

Stack Diffusion / Oxidation [1]


- Stack oxidation / diffusion allows high throughput processes with similar quality
- Combination with pre-deposition of dopant sources e.g. by APCVD inline processing
- In total **6000 M10 Wafer per tube / process** (state of the art: approx. 1600 wafers)
- Almost similar cell efficiencies for TOPCon solar cells are reached, process optimization ongoing

| Diffusion Configuration | V_{OC} (mV) | J_{SC} (mA/cm ²) | FF (%) | η (%) |
|----------------------------|---------------|--------------------------------|--------|------------|
| BBr ₃ reference | 705 | 40.9 | 81.6 | 23,6 |
| APCVD BSG stacked | 700 | 40.8 | 81.4 | 23,1 |



Experimental setup for the stack diffusion in a special quartz boat

[2] Messmer et al, IEEE, 2022; Messmer et al. EUPVSEC 2021



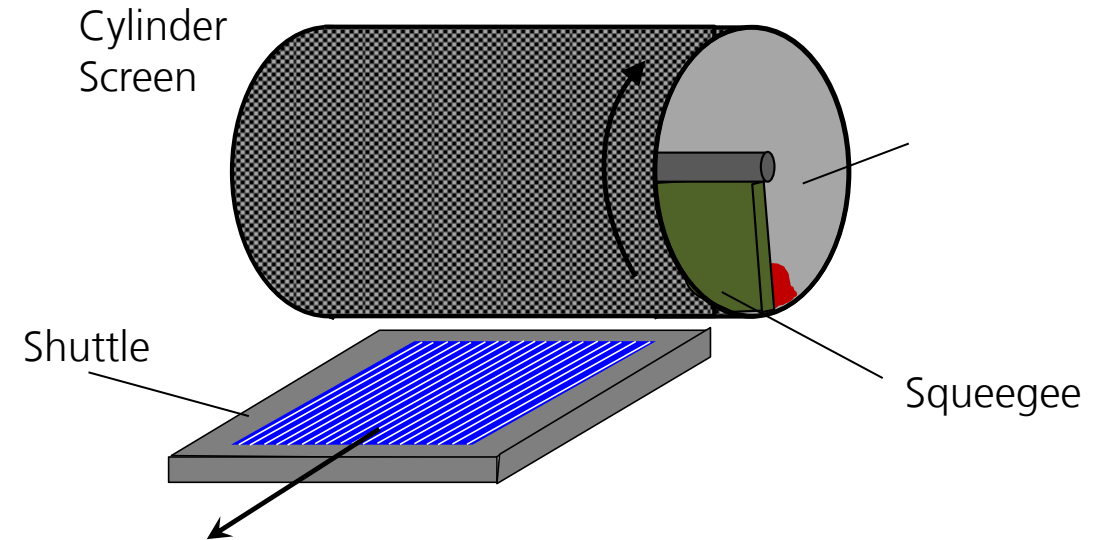
Rotary Printing – Our Solution for High Throughput Printing Processes

NextTec Project

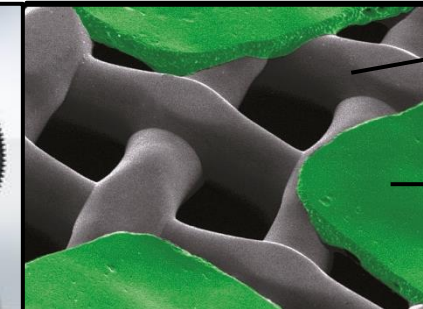
Rotary Printing Processes [3]

- Innovative inline printing processes based on rotary screen printing
- Highly promising to overcome the throughput limit of flatbed screen printing

Rotary Screen Printing:



Rotary screen



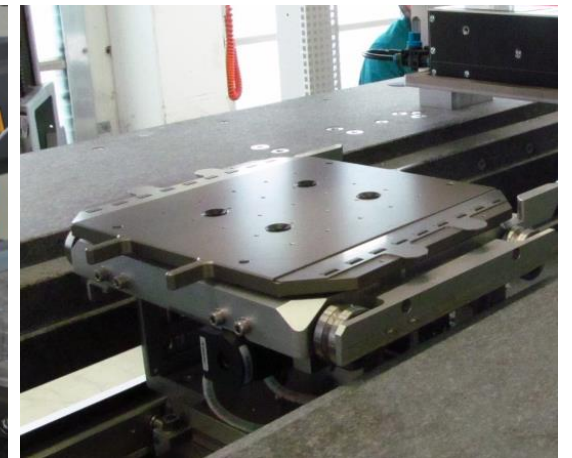
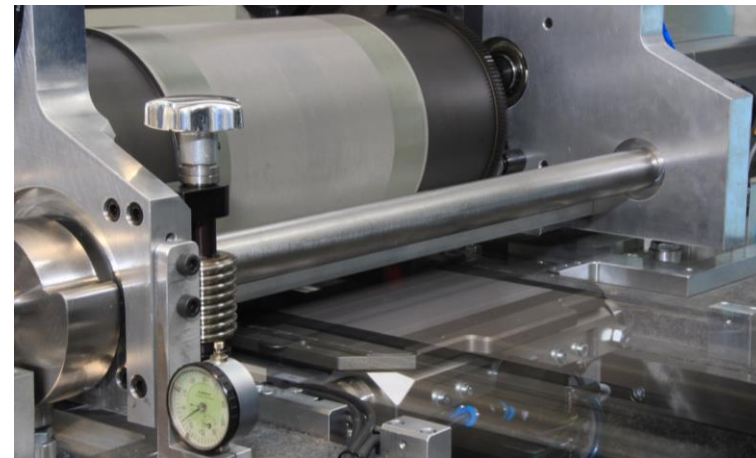
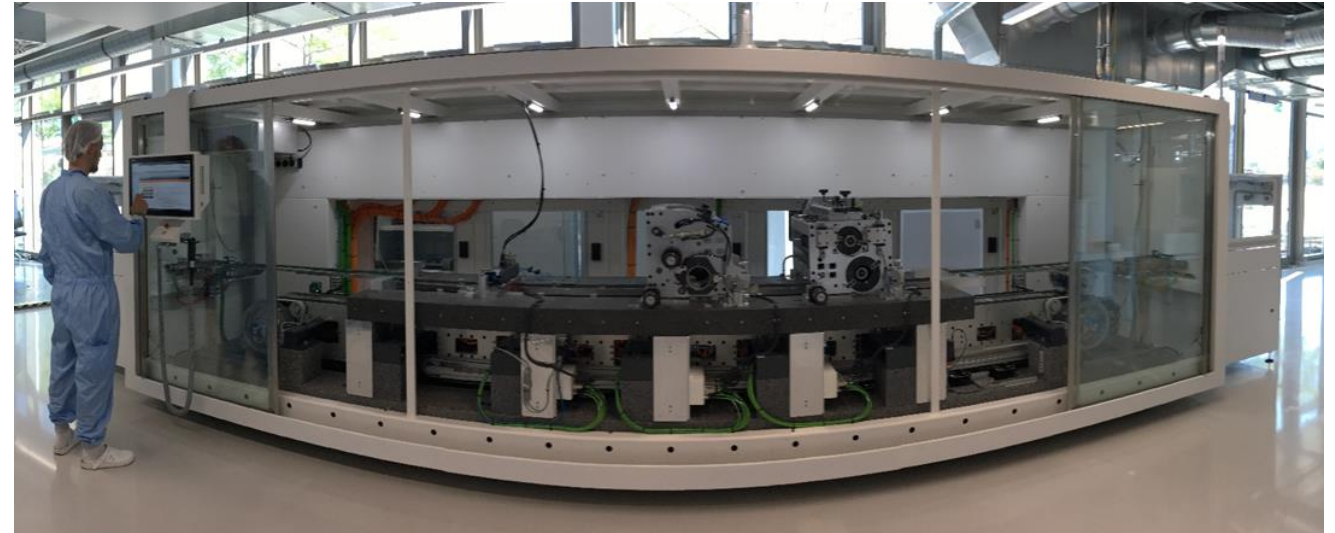
Open mesh
→ Printing

Emulsion
→ Non-printing

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Rotary Printing Processes [3]

- Innovative inline printing processes based on rotary screen printing
- Highly promising to overcome the throughput limit of flatbed screen printing
- Our demonstrator machine allows throughput rates of **15.000 wafers per hour for double lane** (state of the art: approx. 6.500 wafers)

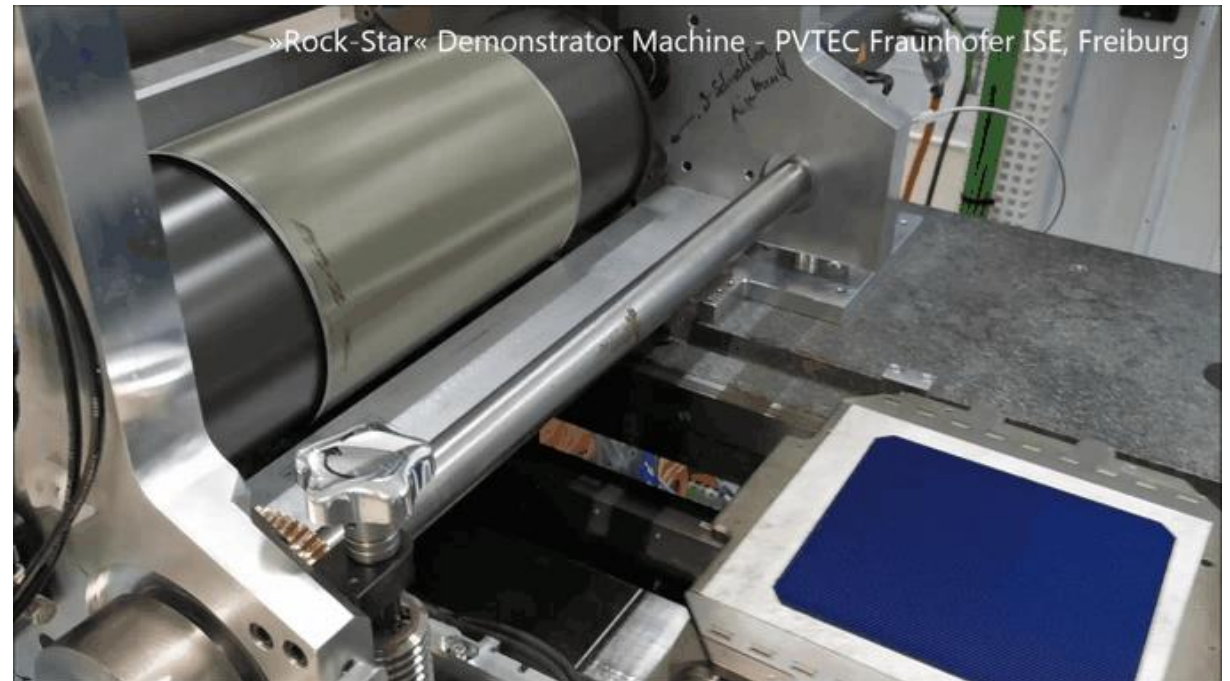


[3] Lorenz et al, Metallization Workshop, 2021

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Rotary Printing Processes [3]

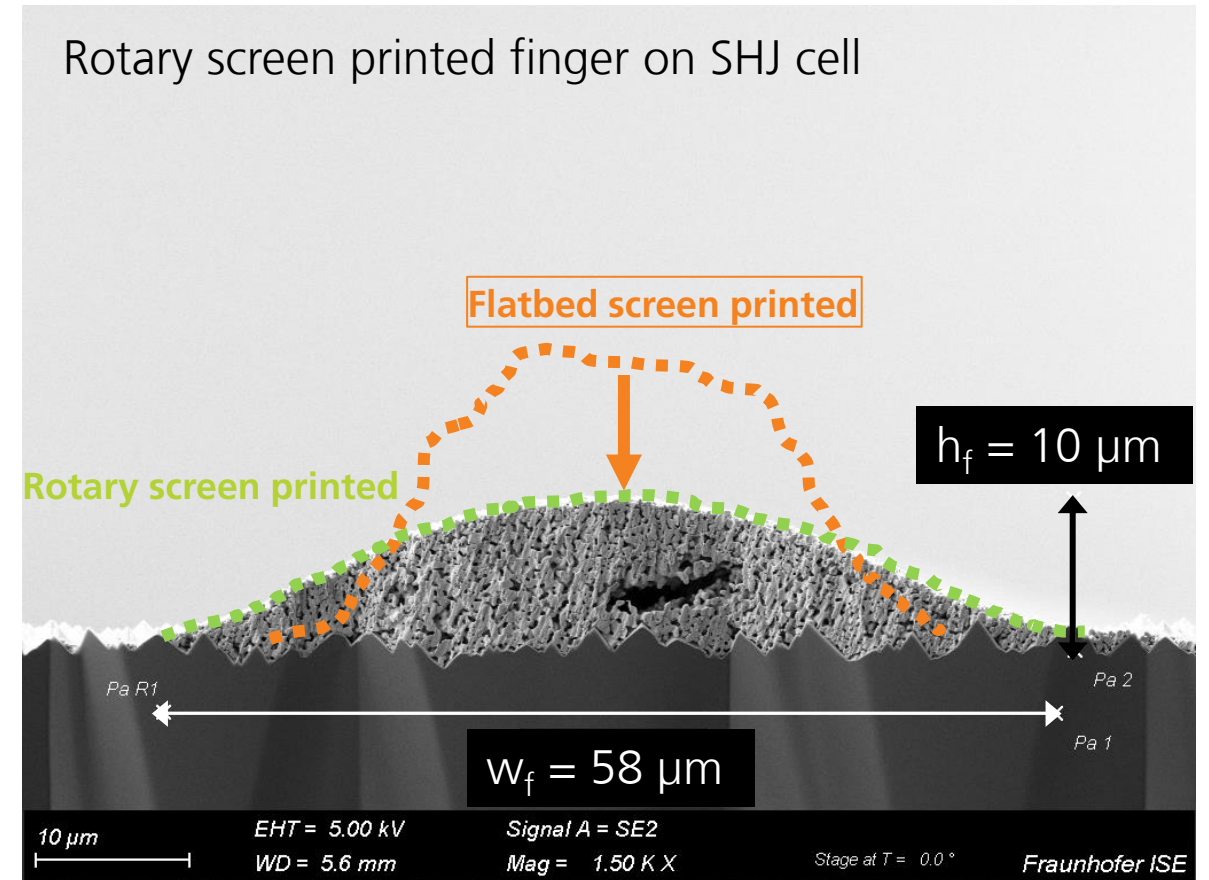
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- Rotary Printing allows silver paste reduction



[3] Lorenz et al, Metallization Workshop, 2021

NextTec Project

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- Innovative inline printing processes based on rotary screen
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- Rotary Printing allows silver paste reduction and similar efficiency level

| Method | Avg/Best | Jsc [mA/cm ²] | Voc [mV] | FF [%] | η [%] |
|-------------------------------|-----------|---------------------------|----------|--------|-------------|
| Rotary SP (rear side) | Avg | 38.5 | 727 | 78.6 | 22.0 |
| | Best Cell | 38.7 | 729 | 79.4 | 22.2 |
| Flatbed SP (rear side) | Avg | 38.5 | 727 | 78.9 | 22.1 |
| | Best Cell | 38.7 | 731 | 79.7 | 22.4 |

Two groups of SHJ cells (approx. 20 cells per group)

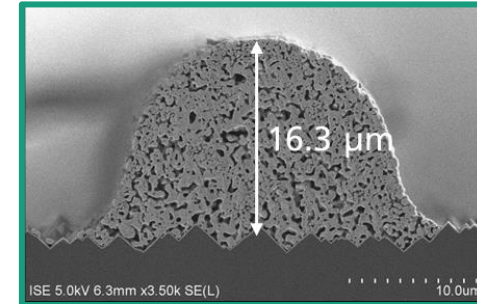
Performance of material (SHJ precursors) generally limited to around 22.5%

[3] Lorenz et al, Metallization Workshop, 2021

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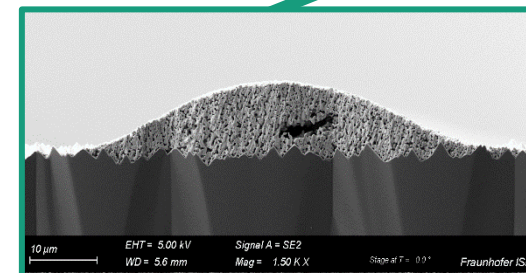
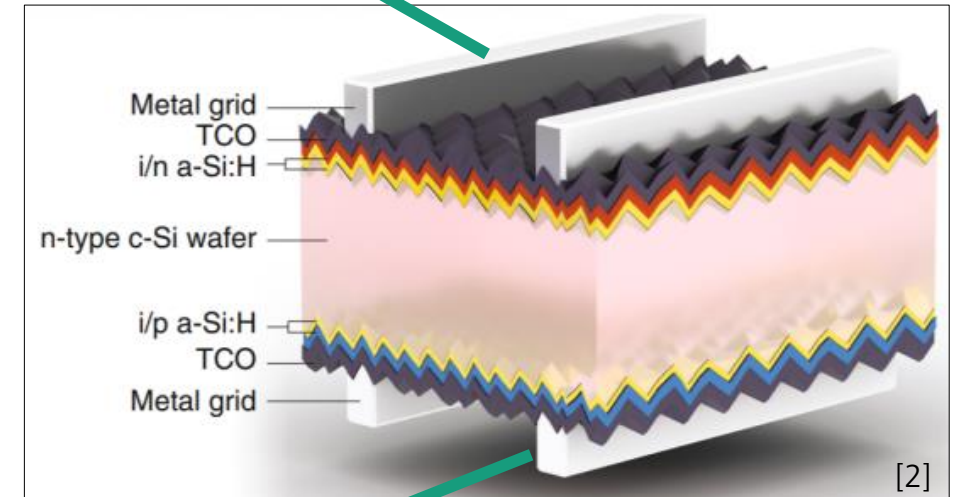
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- Innovative inline printing processes based on rotary screen
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- Our demonstrator machine allows throughput rates of 15.000 wafers per hour for double lane (state of the art: approx. 6.500 wafers)
- Rotary Printing allows silver paste reduction and similar efficiency level
- Combination with Multi-Nozzle Dispensing very promising approach for future cell metallization



HIGHLINE
TECHNOLOGY

Dispensed LTP contact on SHJ solar cell [4]



Rotary printed LTP contact on SHJ solar cell

[3] Lorenz et al, Metallization Workshop, 2021; [4] Gensowski et al., 9th Metallization Workshop / AIP Conf. Proc. 2367 (2021)

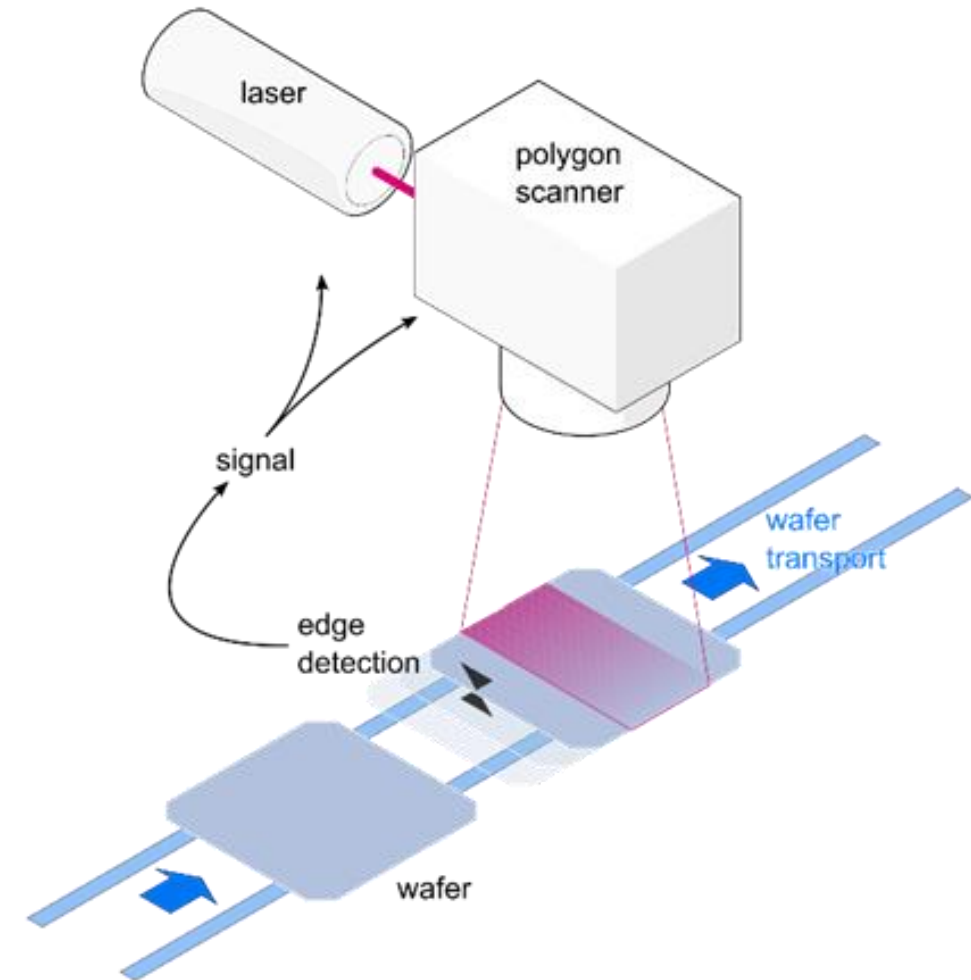


„On the Fly“ Laser – Our Solution for High Throughput Laser Processes

NextTec Project

„On The Fly“ Laser Processes [5]

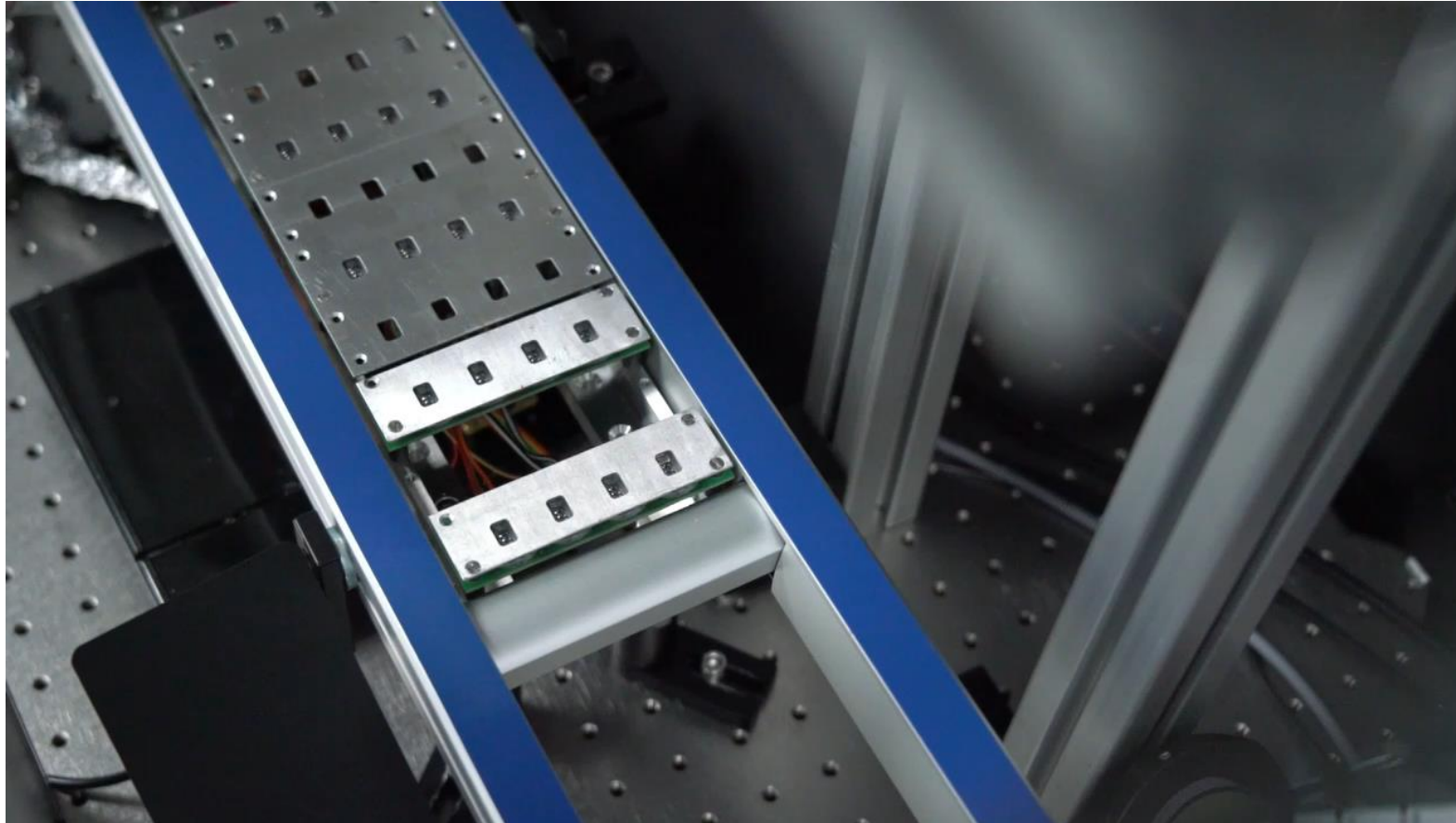
- Novel inline “on the fly” laser processes with precise laser beam control
 - Simple conveyor belt
 - On-the-fly laser processing with polygon scanner
 - Location of the cell determined using optical sensor
 - Laser process automatically triggered upon arrival of the moving wafer



[5] press release Fraunhofer ISE #9 / 2022, 25.04.2022

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„On The Fly“ Laser Processes [5]

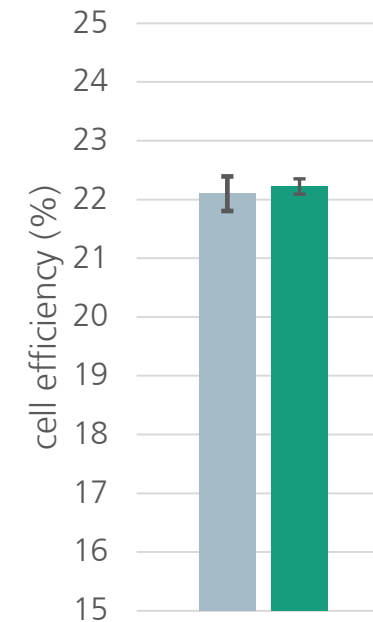


[5] press release Fraunhofer ISE #9 / 2022, 25.04.2022

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„On The Fly“ Laser Processes [5]

- Novel inline “on the fly” laser processes with precise laser beam control
 - Simple conveyor belt
 - On-the-fly laser processing with polygon scanner
 - Location of the cell determined using optical sensor
 - Laser process automatically triggered upon arrival of the moving wafer
- New concept allows **throughput rates of 15.000 wafer per hour** (state of the art: approx. 6.500 wafer)
- Similar cell efficiency for PERC solar cells achieved



■ LCO reference process
■ LCO “on the fly” laser process

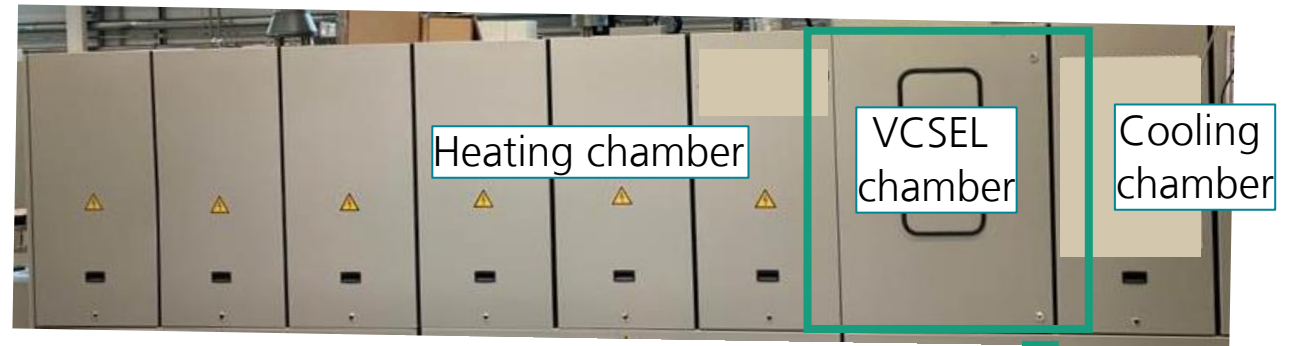


High Throughput Inline Furnace Processes

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Inline Furnace Processes – Approach A [6]

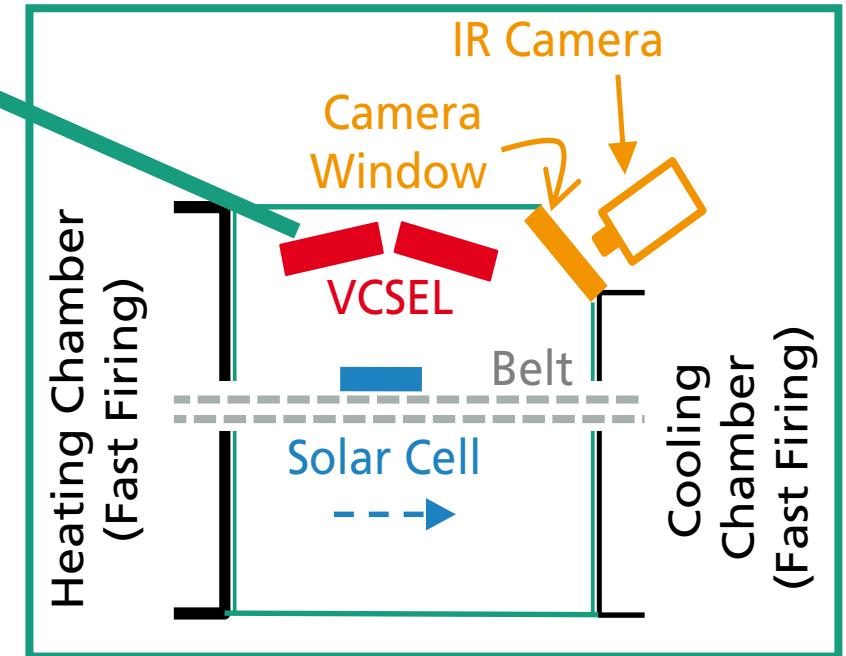
- Inline furnace processes with novel light sources, e.g. VCSEL modules, allow higher throughputs



Firing furnace at PV-TEC laboratory at Fraunhofer ISE



VCSEL module

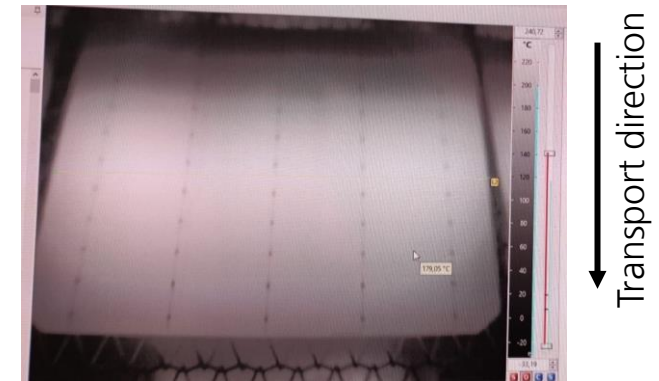


Lateral scheme of VCSEL heating equipment

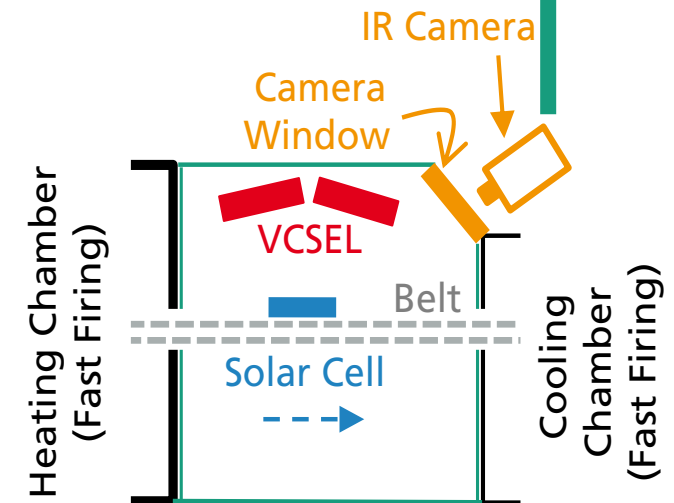
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Inline Furnace Processes – Approach A [6]

- Inline furnace processes with novel light sources, e.g. VCSEL modules, allow higher throughputs
- Successful demonstration of short contact drying processes down to 5 s for PERC devices
- Thermography shows good process homogeneity



Thermography snapshot of a passing solar cell

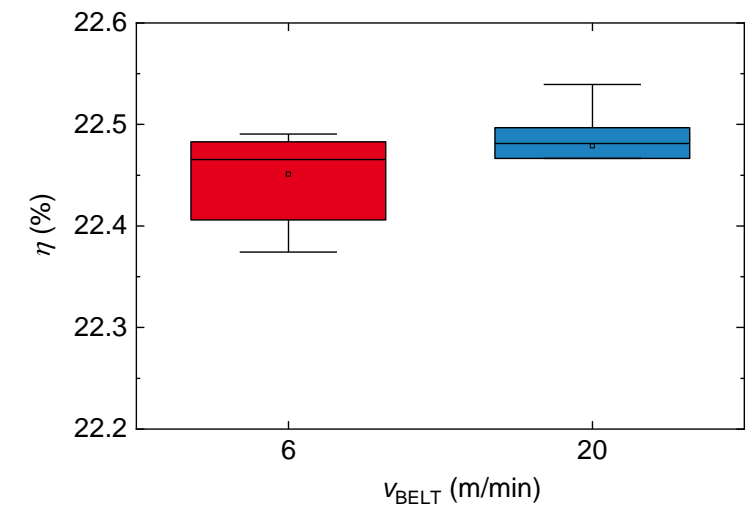
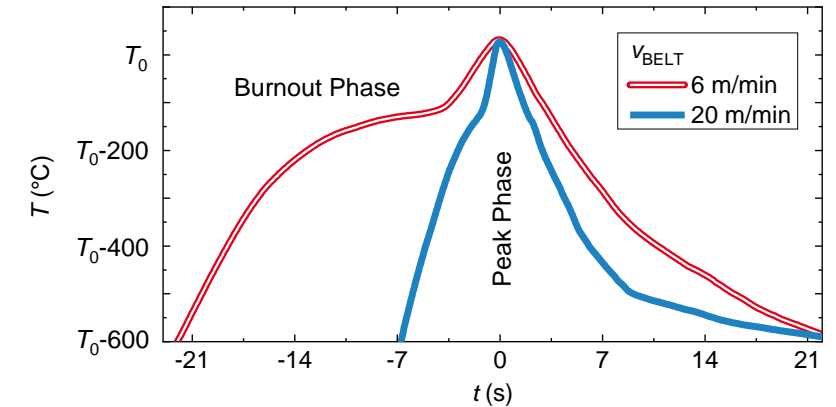


Lateral scheme of VCSEL heating equipment

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Inline Furnace Processes – Approach B [7]

- Inline furnace processes with novel light sources, e.g. VCSEL modules, allow higher throughputs
- Successful demonstration of short contact drying processes down to 5 s for PERC devices
- Thermography shows good process homogeneity
- Inline furnace processes with belt speeds up to 20 m/min
- Similar cell efficiencies for contact firing (PERC)
- **Throughput of approx. 13000 wafers/h for double lane** (state of the art: approx. 6.500 wafer)





Contactless IV Measurement – Our Solution for High Throughput Cell Testing

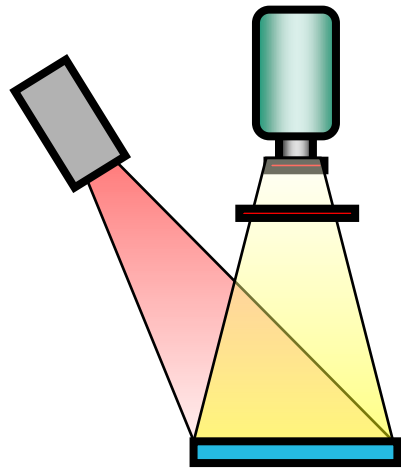
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Inline *I/V* Characterization Contactless [8]

Contactless Current-Voltage Measurement

Pseudo-*I/V* Characteristics

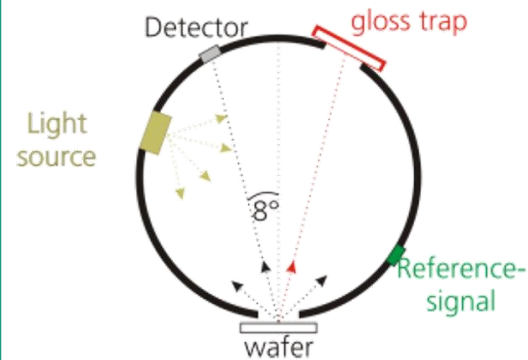
Suns-Photoluminescence



Short-Circuit Current

Reflectance

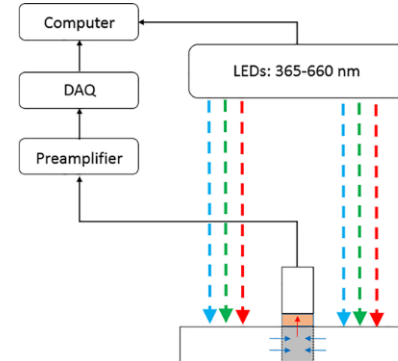
Spectrophotometry



Relative EQE

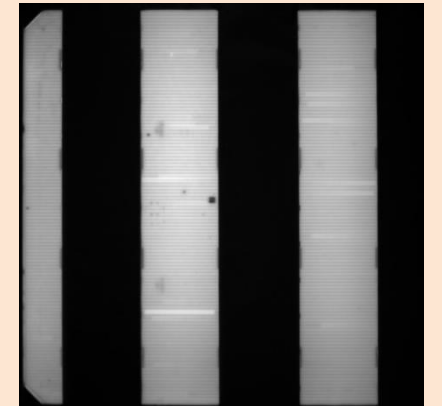
Contactless Electroluminescence Spectroscopy

[A. Paduthol, et al., JAP, 2018]



Series Resistance

Partially Shaded Photoluminescence

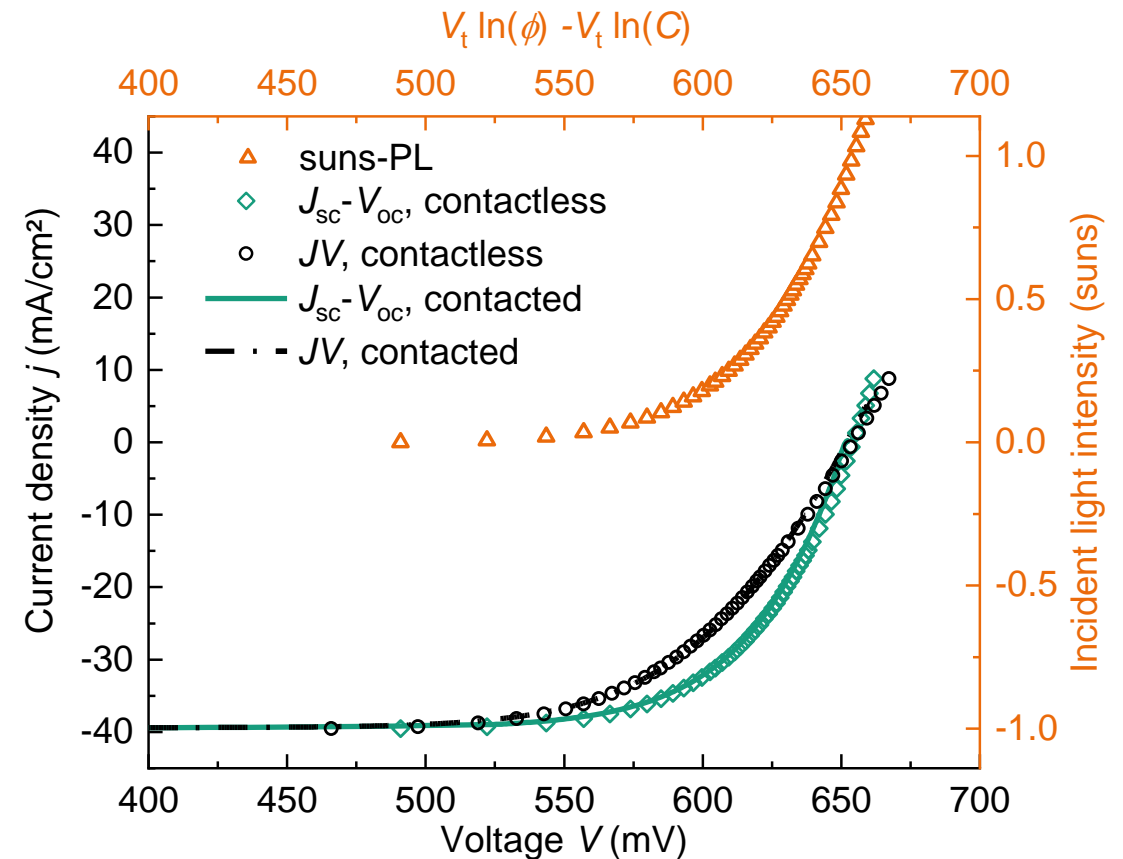


[8] Greulich et al., Silicon PV, 2022

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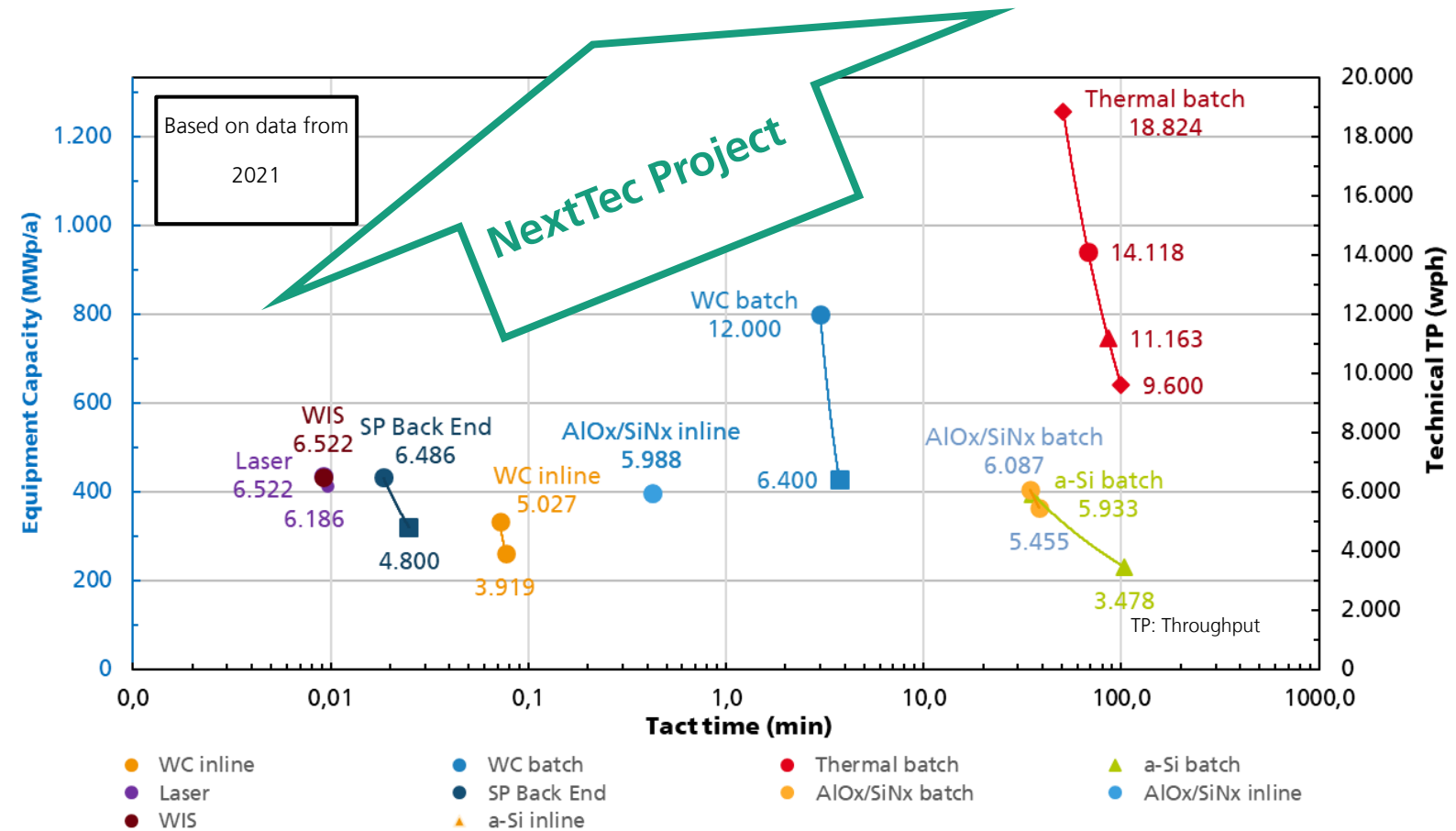
Inline I/V Characterization Contactless [8]

- Contactless I/V Characterization
 - Suns-PL data calibrated to voltage
 - Shift suns-PL to get pseudo- I/V or $J_{SC}-V_{OC}$ curve
 - Account for series resistance \gg JV contactless
- Close match with conventionally measured JV curve
- Proof of principle successful
- **Measurement speed limited by cell physics, not by metrology \gg high throughput rates achievable**



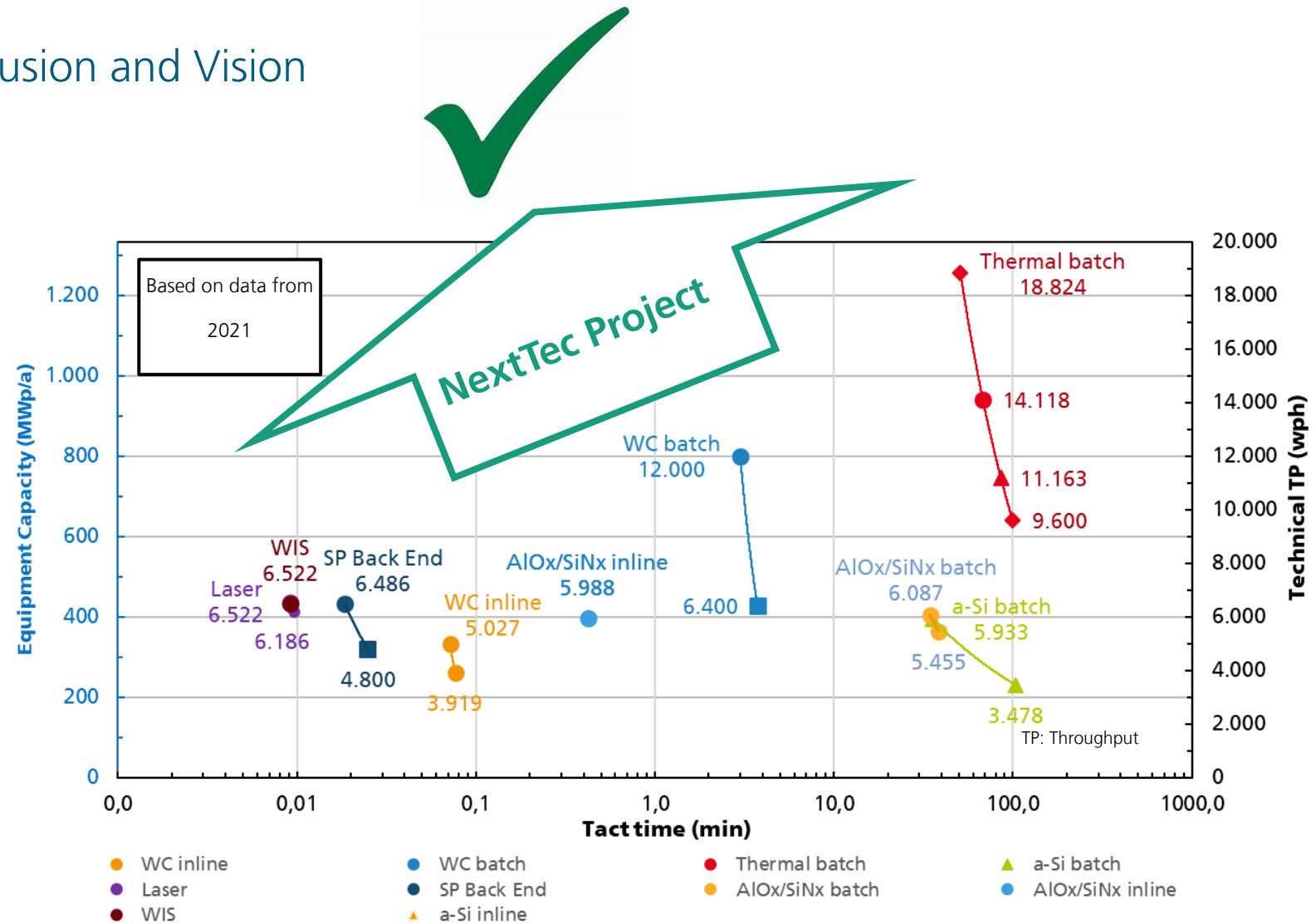
NextTec Project

NextTec Processes – Conclusion and Vision



NextTec Project

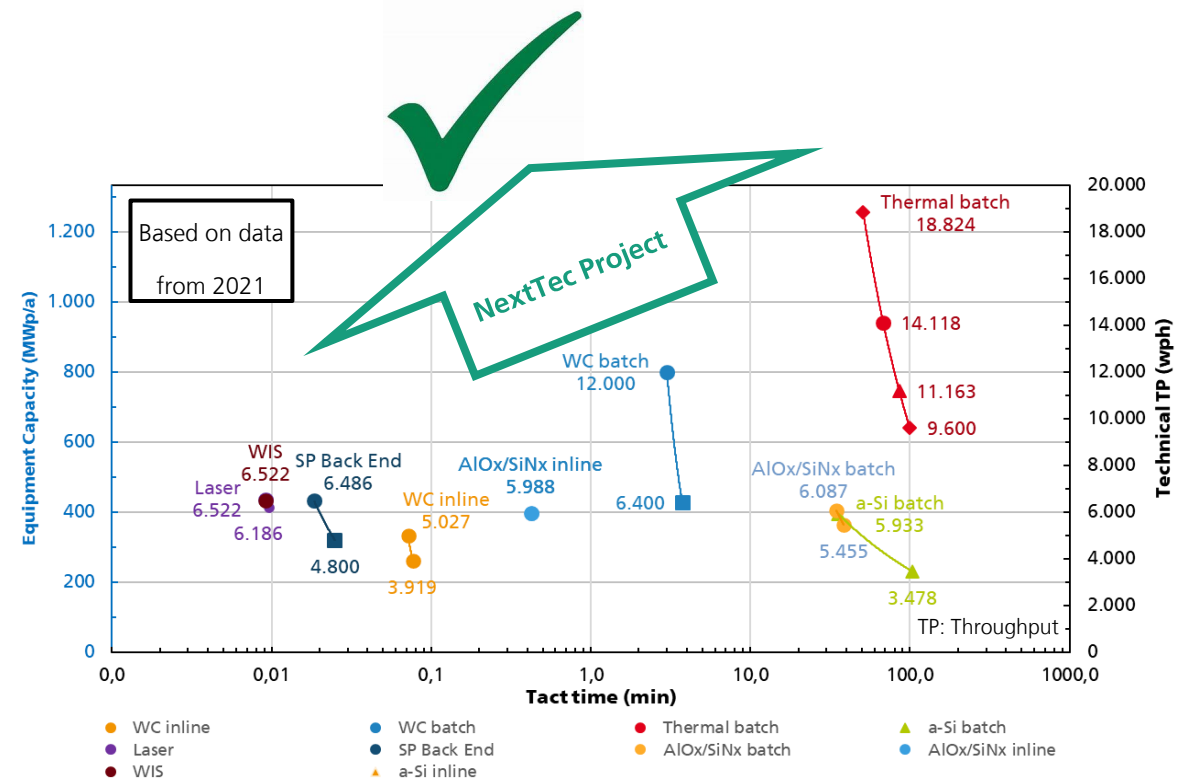
NextTec Processes – Conclusion and Vision



NextTec Project

NextTec Processes – Conclusion and Vision

- New solutions for high throughput processes and equipment developed
- Throughput rates > 13.000 wafer per hour and system demonstrated at PV-TEC pilot-line [9]
- New processes allow (almost) the same efficiency level
- Equipment capacity > 1GW is reachable

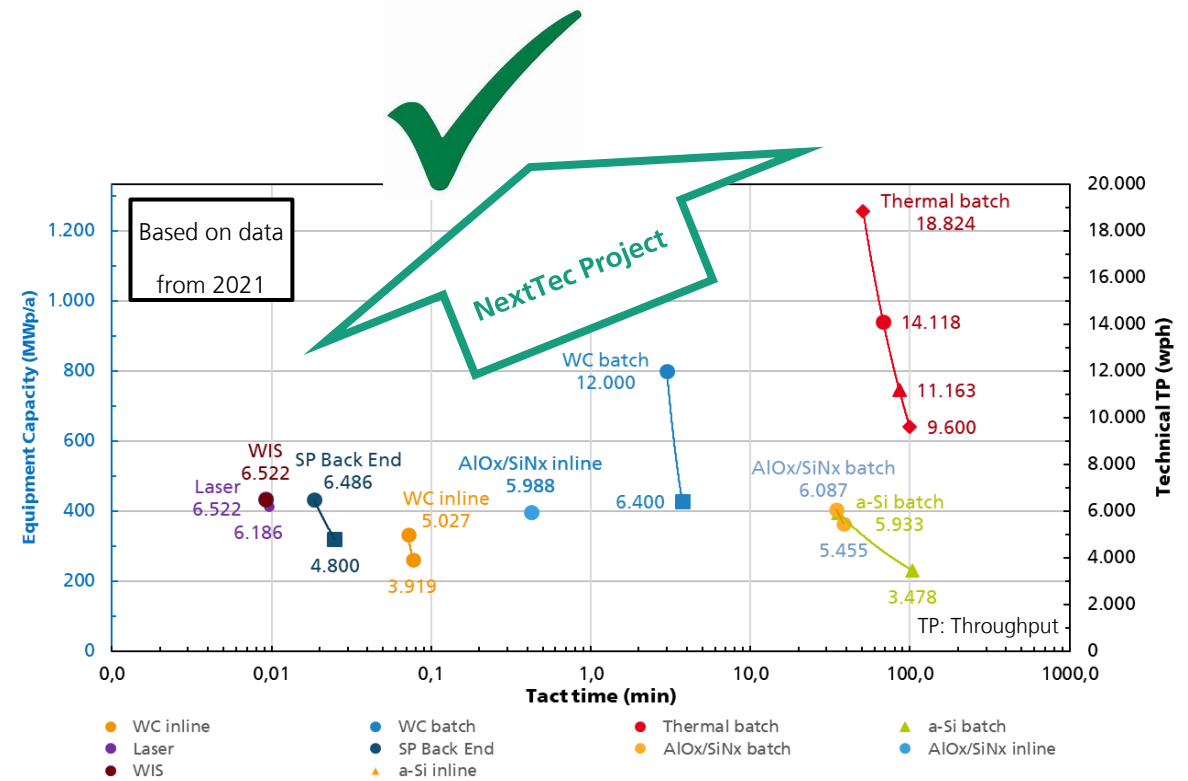


[9] Preu et al., this conference, 1CP.2.1.

NextTec Project

NextTec Processes – Conclusion and Vision

- New solutions for high throughput processes and equipment developed
- Throughput rates > 13.000 wafer per hour and system demonstrated at PV-TEC pilot-line [9]
- New processes allow (almost) the same efficiency level
- Equipment capacity > 1GW is reachable
- Vision: Implementation and demonstration of NextTec Processes in a running cell production line



[9] Preu et al., this conference, 1CP.2.1.

Many thanks to all my co-authors Thank you for your attention!

Dr. Florian Clement
florian.clement@ise.fraunhofer.de

link to Fraunhofer ISE contributions of
the WCPEC-8, available as of 30.09.2022



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Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

Contract Nr: 03EE1001A