Next Generation High Throughput Production Processes & Inline Characterization for Si Solar Cells

Fraunhofer ISE: Florian Clement, Marius Meßmer, Hannes Höffler, Daniel Ourinson, Baljeet Singh Goraya, Gernot Emanuel, Fabian Meyer, Andreas Lorenz, Jonas Bartsch, Matthias Demant, Sebastian Nold, Andreas Wolf, Martin Zimmer, Johannes Greulich, Ralf Preu;
h.a.l.m.: Klaus Ramspeck; ISRA: Marc Hemsendorf; RENA: Bendikt Straub; Schmid: Christian Ebert;
ASYS: Matthias Drews; RCT Solutions: Wolfgang Jooss;
ISC Konstanz: Elina Schmid; HTWK: Stephan Schoenfelder; Fraunhofer CSP: Ringo Koepge

PVCellTech Conference 2023
Berlin, 14.03.2023
www.ise.fraunhofer.de

Why High Throughput Production?

25 Years Production Technology [1]

Module production 1997

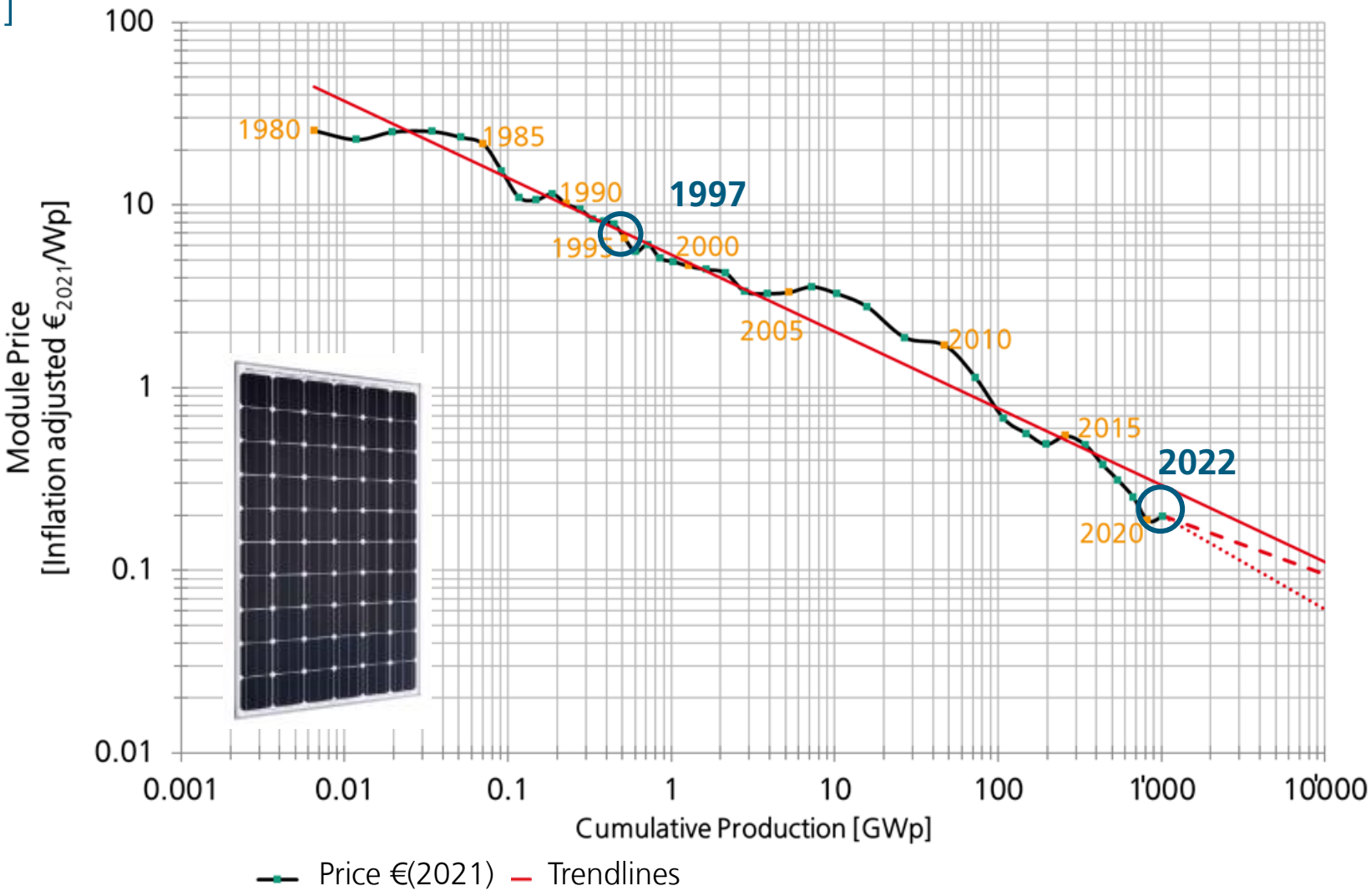
- Shipments global: 110 **M**Wp/a
- Module Price: 6 Euro/Wp

Today 2022

- Shipments global*: above 300 **G**Wp/a
- Module Price*: 0,2 -0.4 Euro/Wp

Learning rate
Each time the cumulative PV module production doubled the price went down by about 25% for the last 41 years.

➔ Market Size is the key for scaling / cost reduction



[1] Preu et al., EUPVSEC, Milano 2022

* Data form www.PV-TECH.org / www.pvxchange.com

Why High Throughput Production?

Learning Rate Differentiation [1]

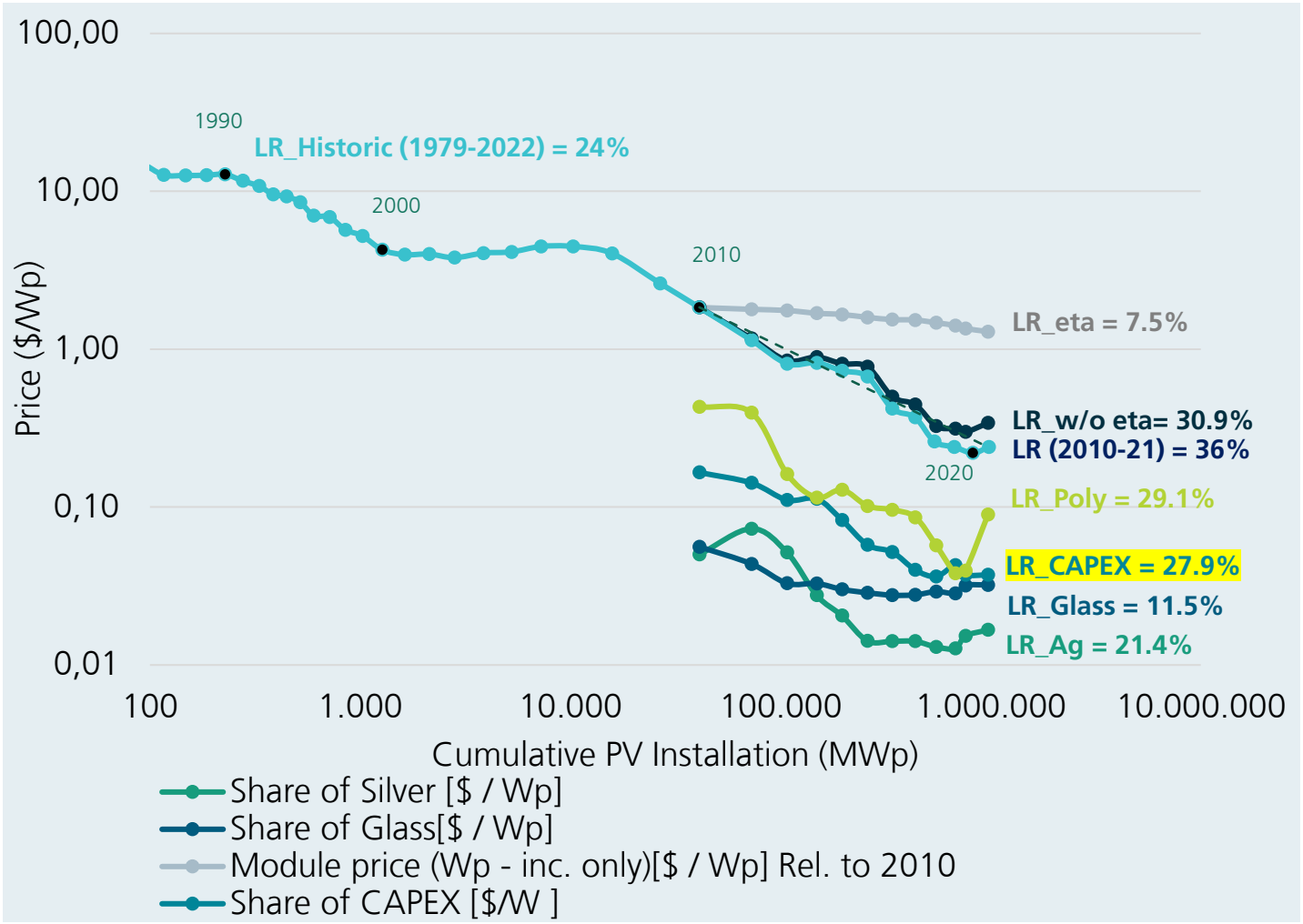
Impact on cost:

- Module efficiency (eta) as a factor
- Differentiation in CAPEX and OPEX (here: Glass, Poly, Ag)

➔ Silver and glass do not "learn" as quickly as CAPEX and "poly-Si"

➔ **CAPEX learning is strongly supported by productivity increases**

➔ More Details: Ralf Preu tomorrow

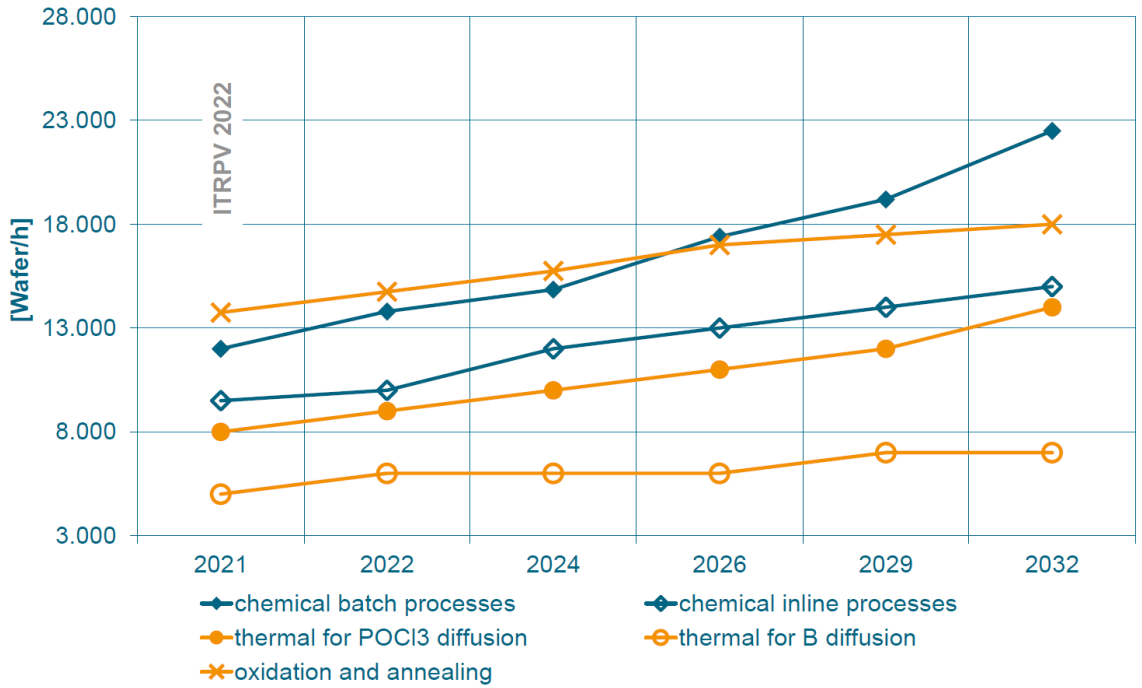


[1] Preu et al., EUPVSEC, Milano 2022

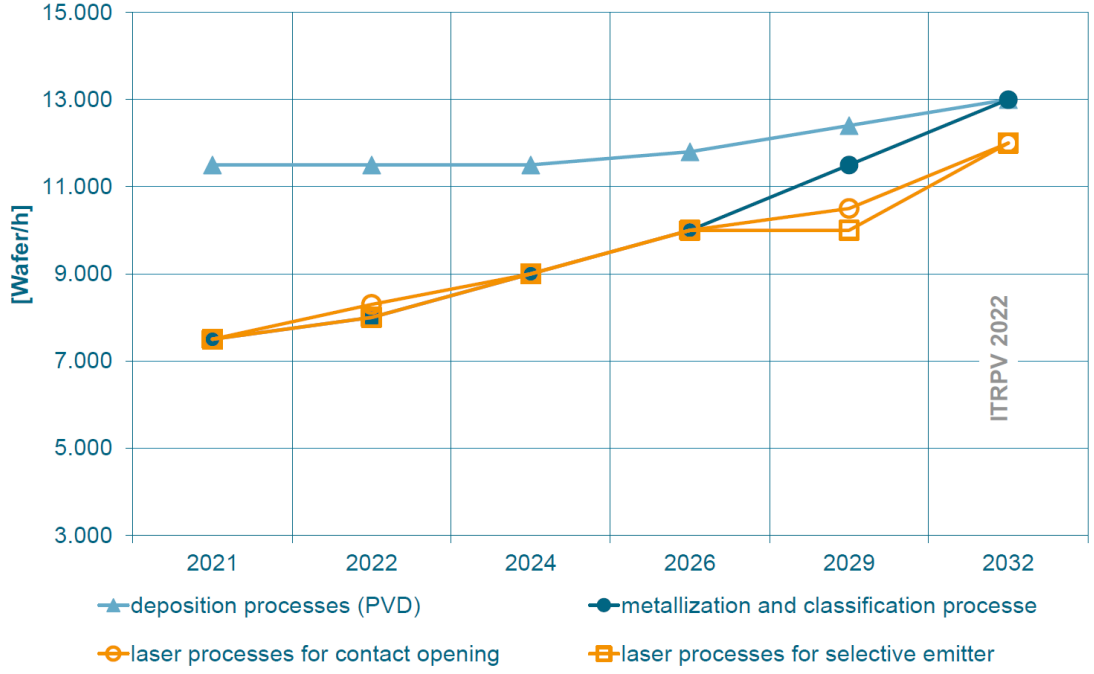
What Throughput Rates will be Realistic?

ITRPV Roadmap 2022 [2]

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)



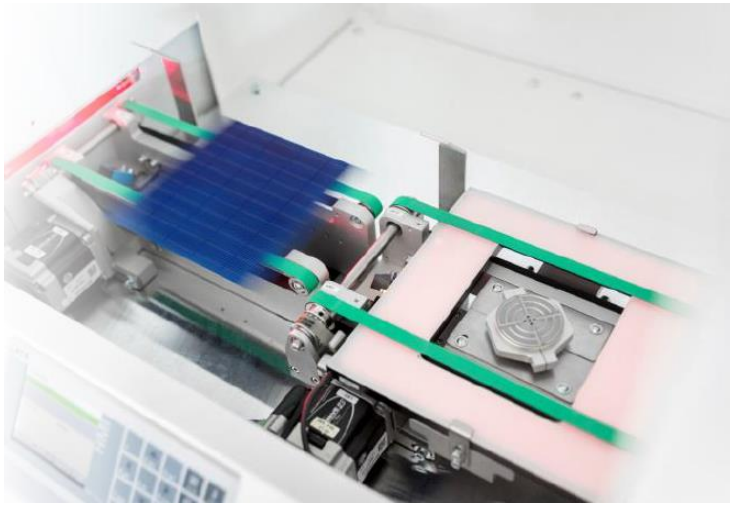
- ITRPV: Increase in throughput rates **by approx. factor 2** estimated in the **next ten years**
- The question is: How can we achieve high throughput rates?

[2] VDMA, ITRPV, 2022

What Throughput Rates will be Realistic?

R&D Project NextTec – Short Project Description

- R&D project NextTec
- 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
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and Climate Action

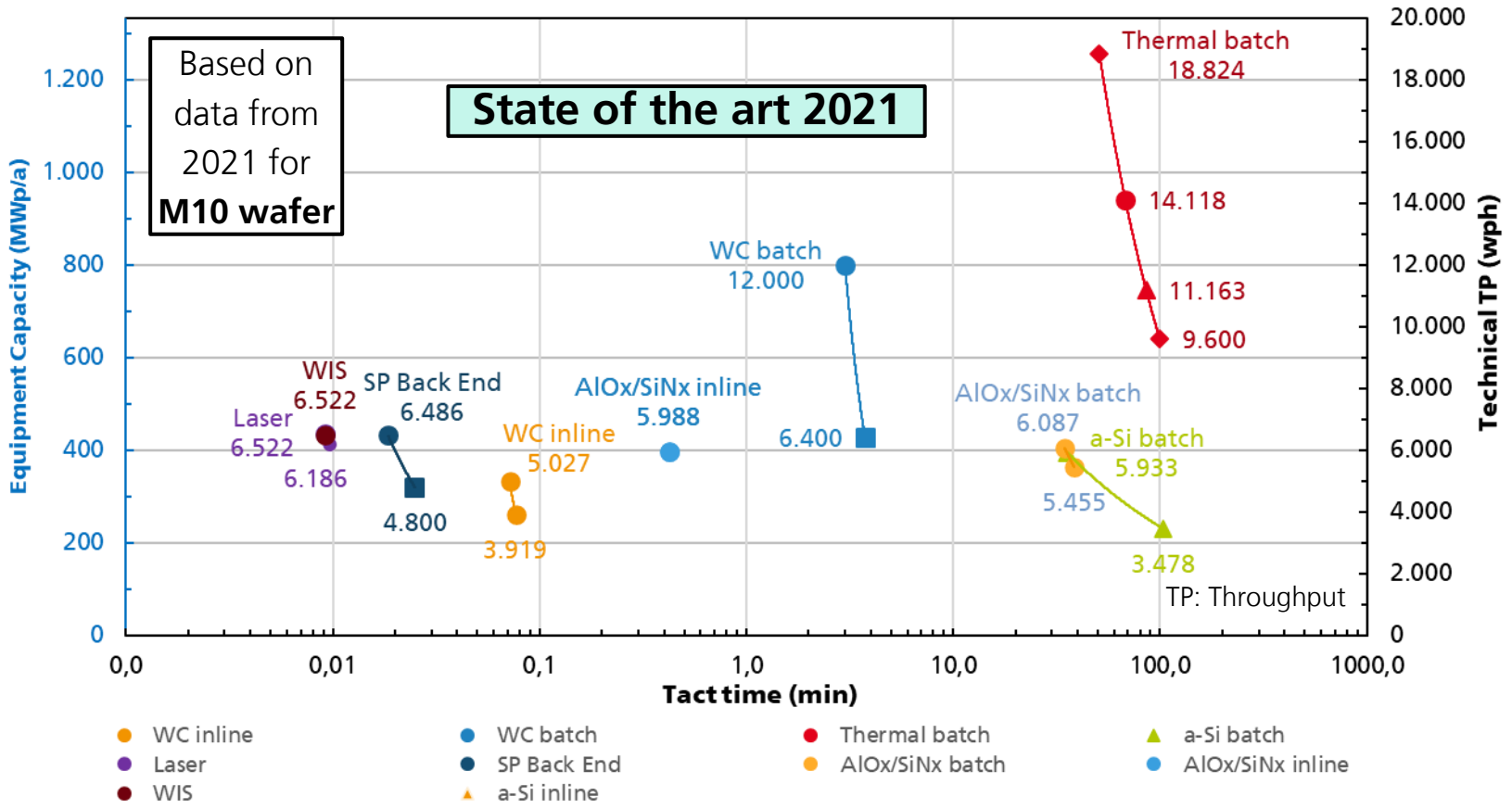
on the basis of a decision
by the German Bundestag

Contract Nr: 03EE1001A

Fraunhofer CSP
Fraunhofer ISE
MecSim
HTWK
ISC International Solar Energy Research Center Konstanz
RCT solutions
VDMA
SCHMID Expect Solutions
ISRA VISION
VON ARDENNE
.h.a.l.m.
INDEOtec PLASMA PROCESS EQUIPMENT
R|E|N|A
ASYS SOLAR

High Throughput Production

Aim of the NextTec Project



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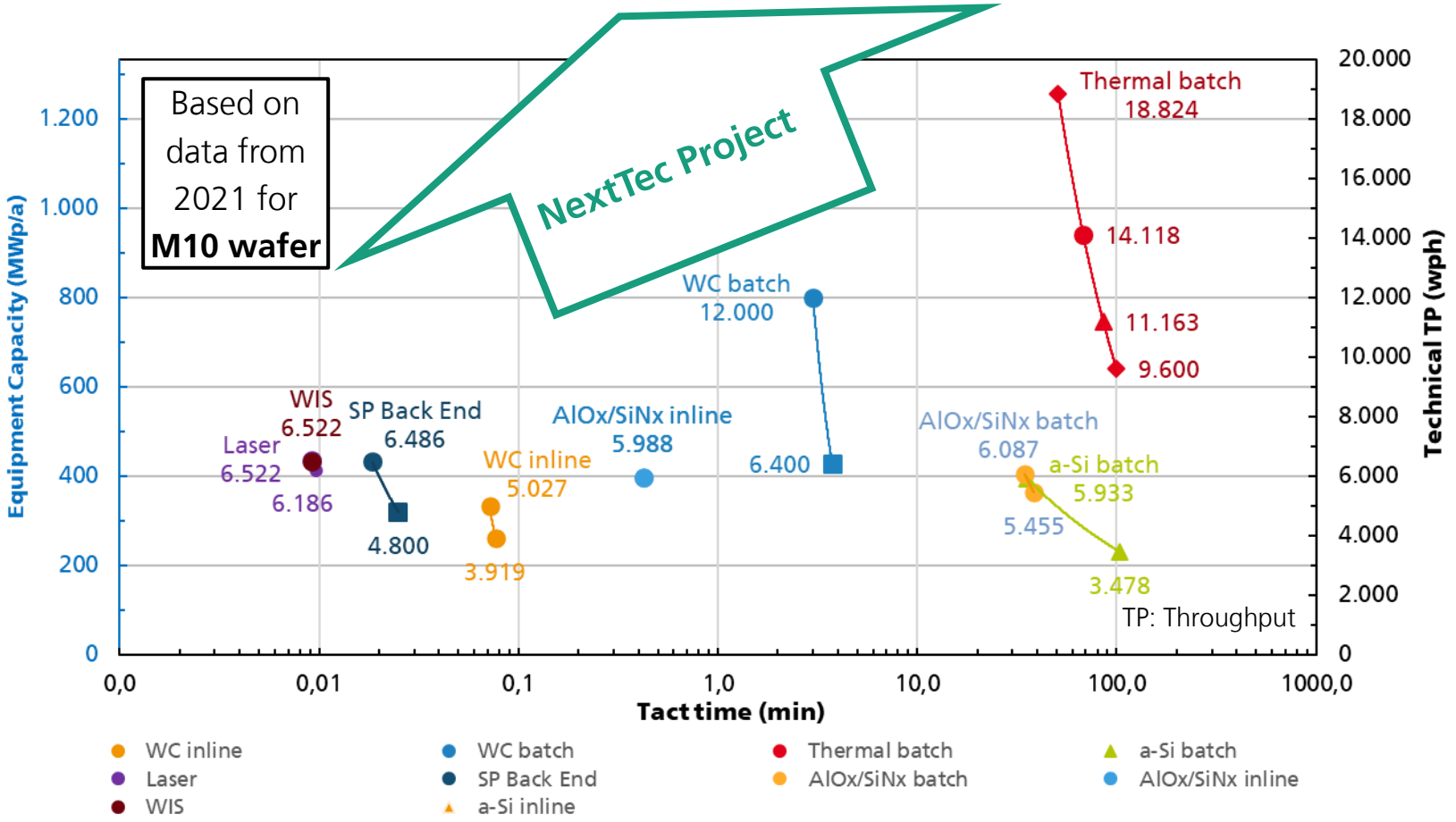
High Throughput Production

Aim of the NextTec Project

- Increase throughput rates by factor 2 to 3
  - Similar cell efficiency
  - No significant increase in equipment footprint and costs

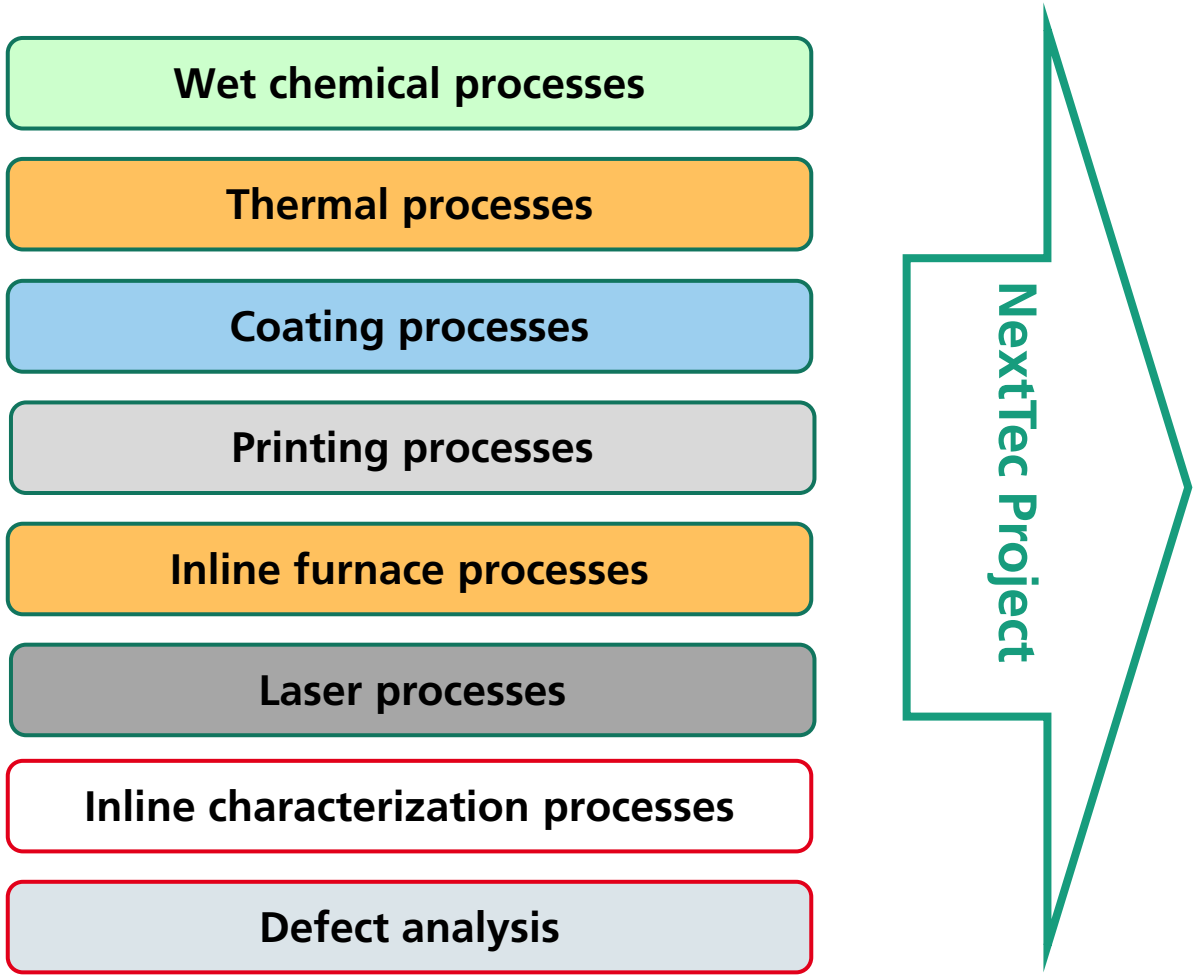
➢ System throughputs: > 13,000 wafers per hour (M10 wafer)

➢ Production capacity: > 1 GW per system and year



High Throughput Production

NextTec Processes – Overview



High Throughput Production

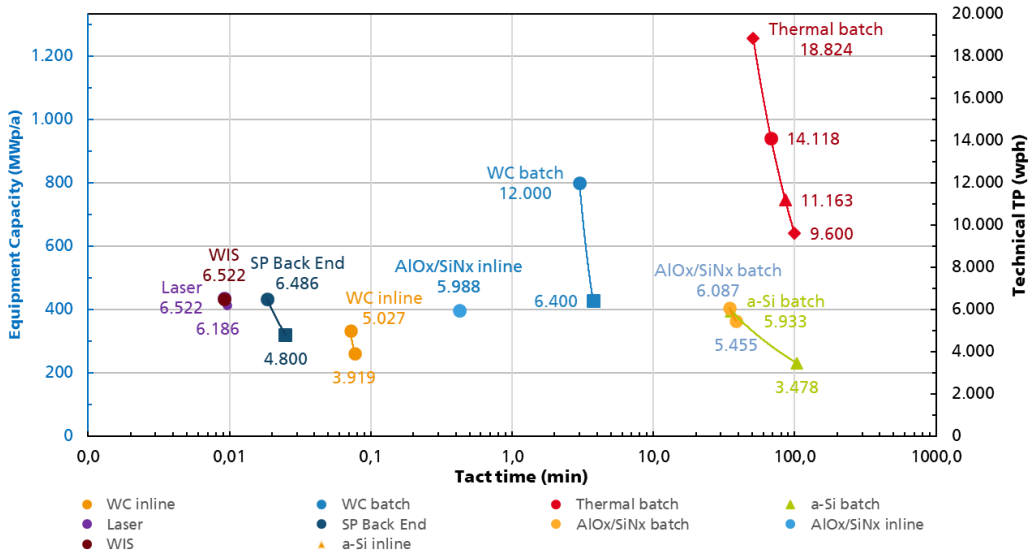
NextTec Processes – Overview

- Wet chemical processes
- Thermal processes
- Coating processes
- Printing processes
- Inline furnace processes
- Laser processes
- Inline characterization processes
- Defect analysis

NextTec Project

Techno-economic analysis [2a]: for all NextTec processes

Fraunhofer ISE | ISC International Solar Energy Research Center Konstanz | RCT solutions



[2a] PhD thesis Sebastian Nold, 2019

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High Throughput Production

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NextTec Project

New concepts for (vertically passing) Si solar cells

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R|E|N|A

ISC International Solar Energy Research Center Konstanz

SCHMID Expect Solutions

For more information:

- Dannenberg et al., WCPEC-8 2022

High Throughput Production

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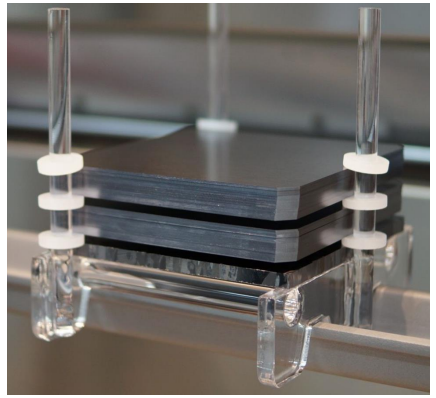
NextTec Project

Stack diffusion with APCVD doping layers



High Throughput Production

NextTec Processes – Overview

- **Wet chemical processes**
- **Thermal processes**
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- **Inline furnace processes**
- **Laser processes**
- **Inline characterization processes**
- **Defect analysis**

NextTec Project

High speeed coating technologies: Spray pyrolysis, PVD

SCHMID Expect Solutions VON ARDENNE Fraunhofer ISE

For more information:

- Spray pyrolysis: Heitmann, Bartsch et al., WCPEC-8 2022
- PVD: Schneiderloechner et.al., WCPEC-8 2022

High Throughput Production

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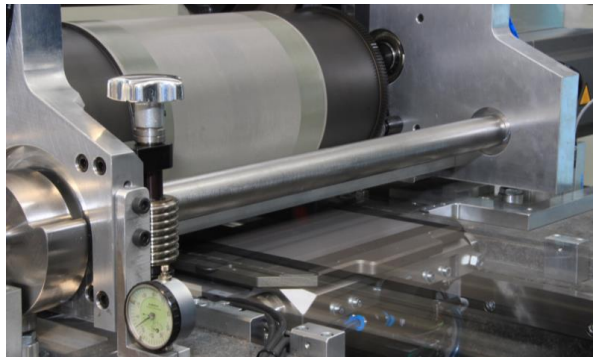
NextTec Project



Inline printing processes based on rotational printing

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ASYS SOLAR

High Throughput Production

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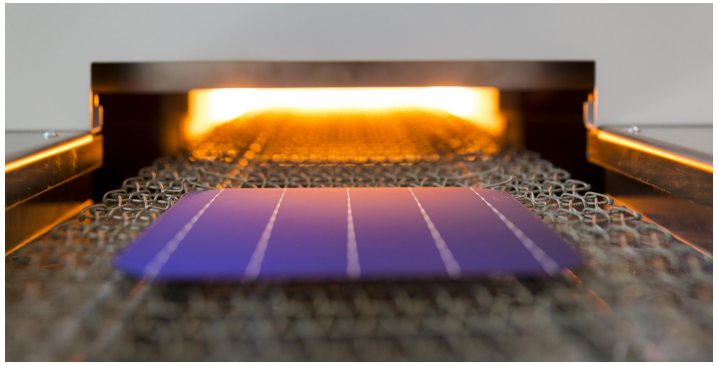
NextTec Project



High belt speeds and novel heating elements

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High Throughput Production

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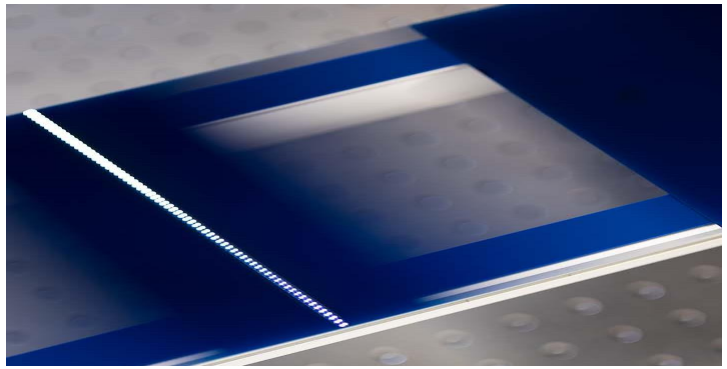
NextTec Project



Inline laser processes with precise laser beam control

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High Throughput Production

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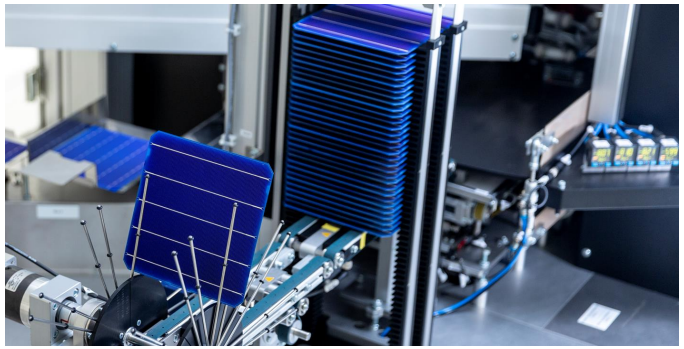

For more information:

- *IV* contactless: Kunze et al., WCPEC-8 2022
- *IV* / EL on-the-fly: Kurumundayil et al., WCPEC-8 2022

Fraunhofer ISE ISRA VISION .h.a.l.m.

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

High Throughput Production

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NextTec Project

For more information:

- Buehler et al. , WCPEC-8 2022
- Koepge et al. , WCPEC-8 2022

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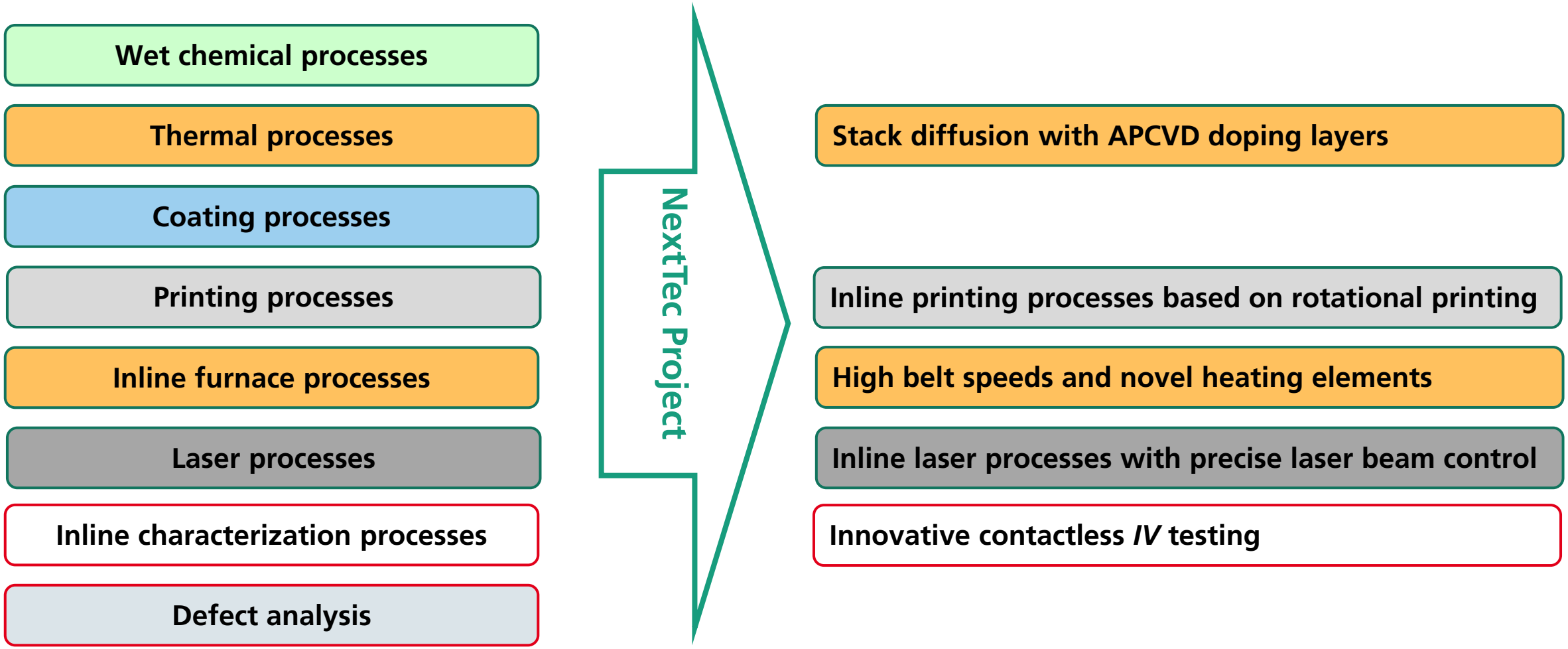
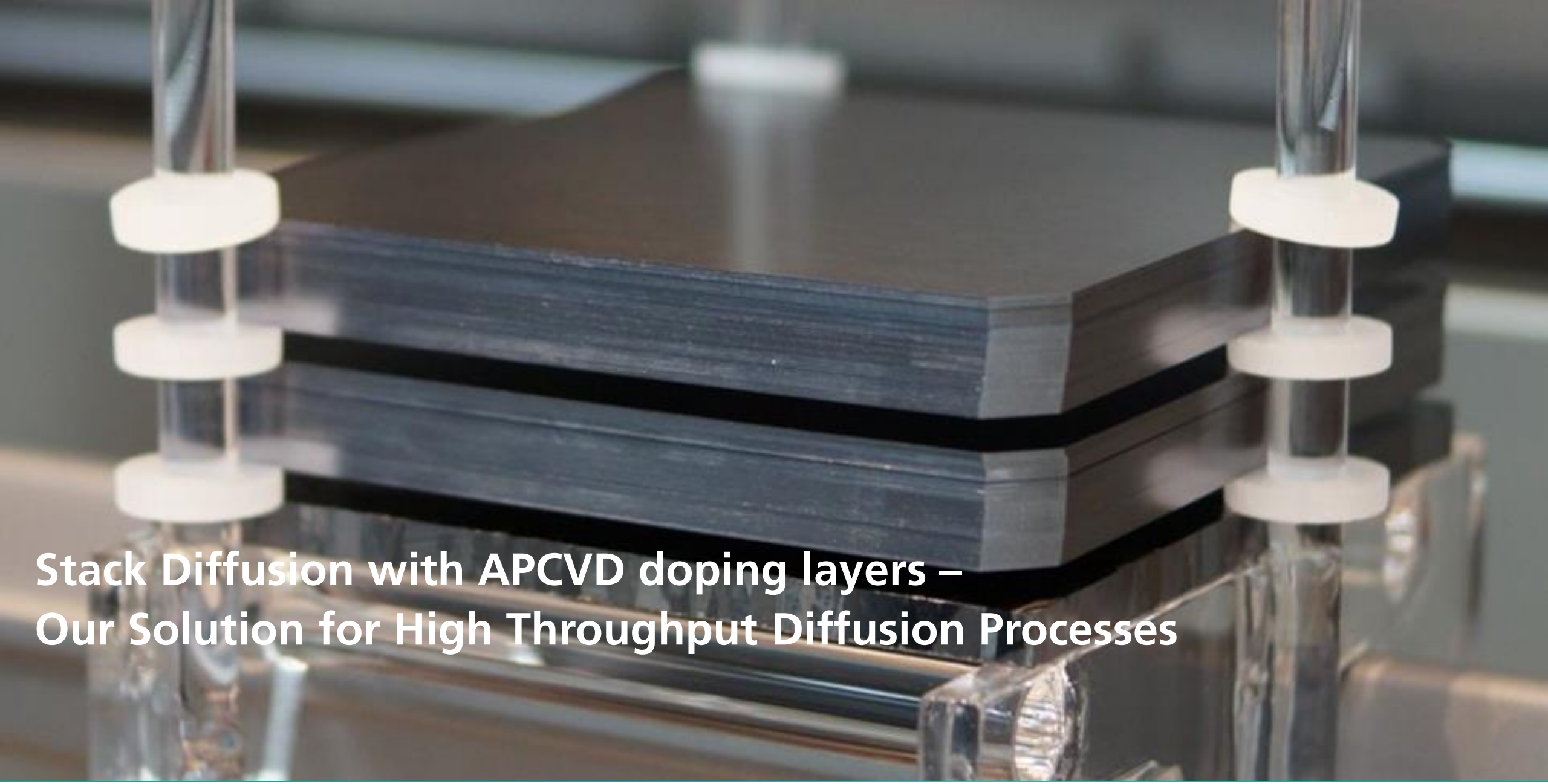
Mechanical influences of high throughput processes

High Throughput Production

NextTec Processes – Focus in this talk





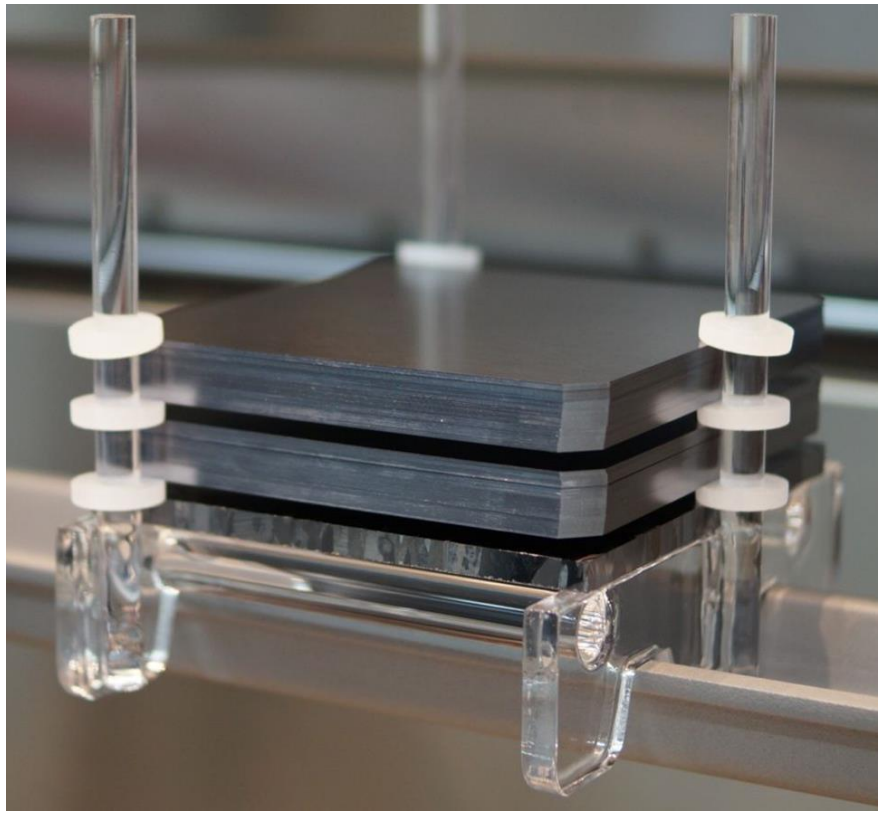
Stack Diffusion with APCVD doping layers – Our Solution for High Throughput Diffusion Processes

High Throughput Production

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/cm²)	*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

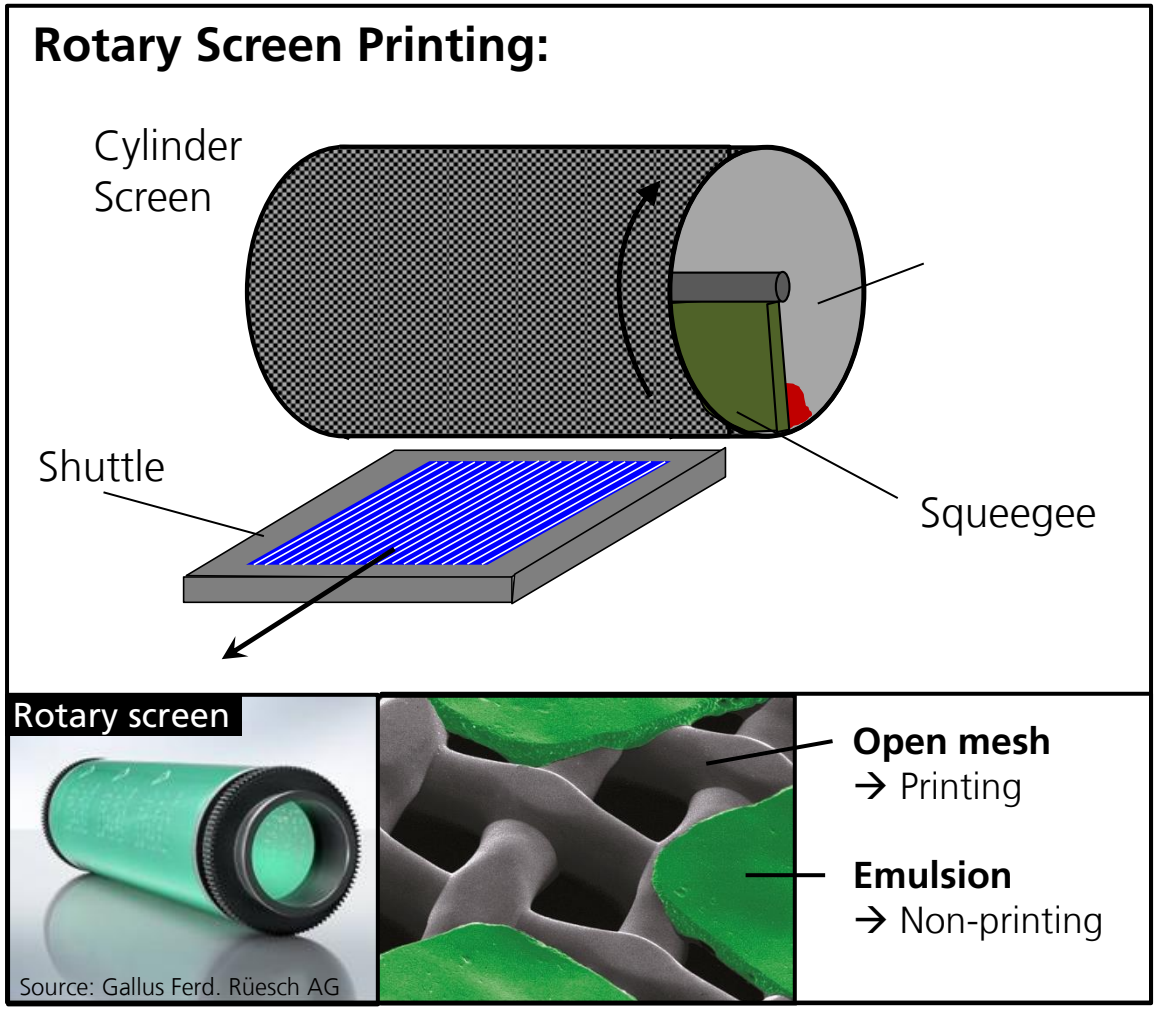
[2] Messmer et al, IEEE, 2022; Messmer et al. EUPVSEC 2021

Rotary Printing – Our Solution for High Throughput Printing Processes

High Throughput Production

Rotary Printing Processes [3]

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



[3] Lorenz et al, Metallization Workshop, 2021

High Throughput Production

Rotary Printing Processes [3]

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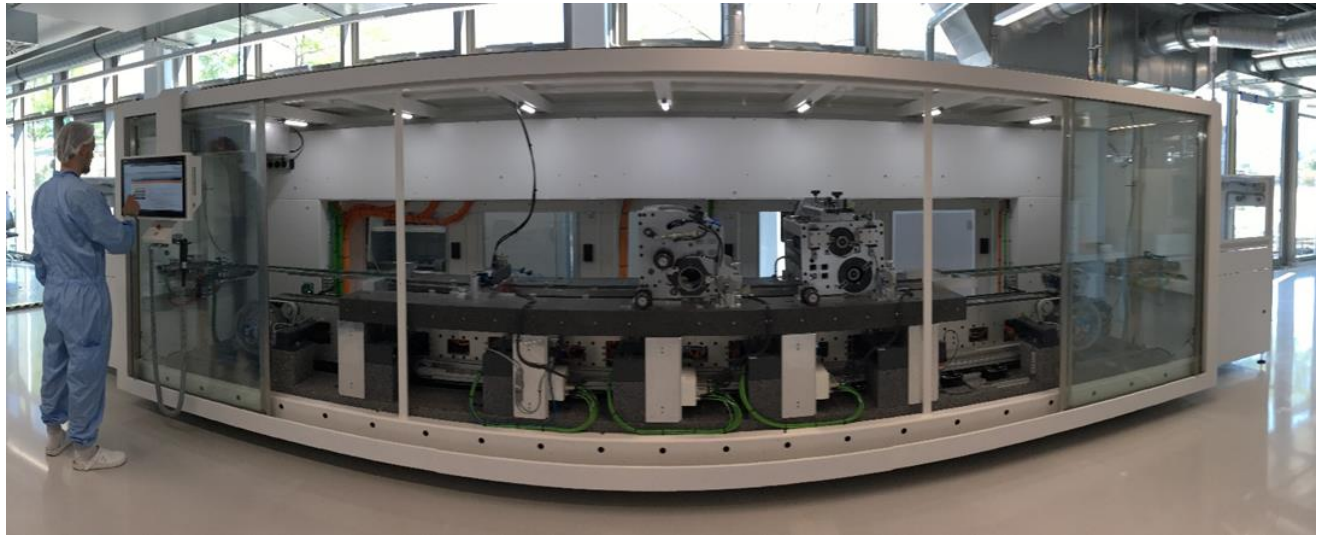
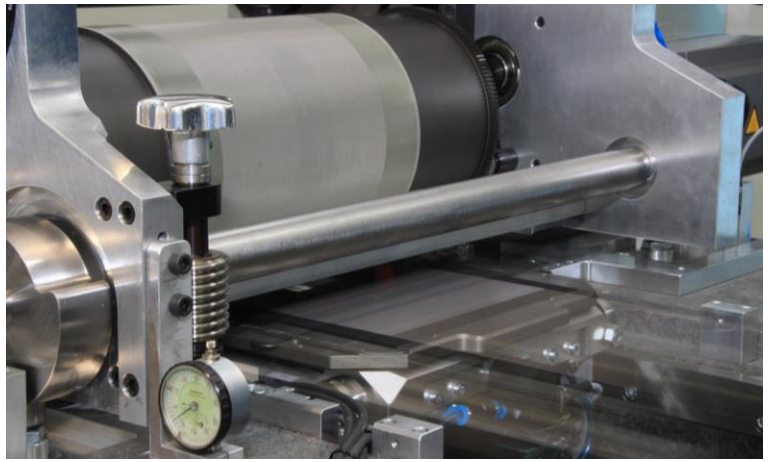
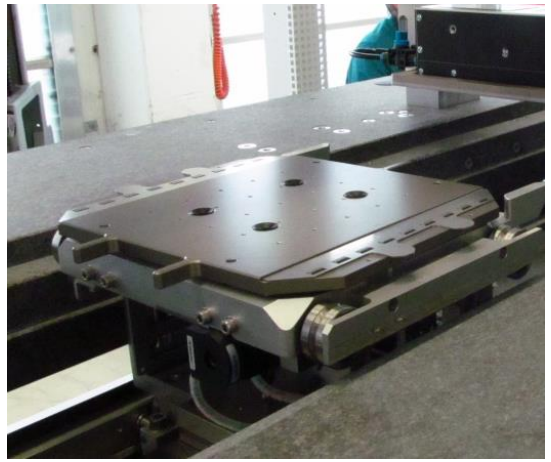
- Our demonstrator machine allows throughput rates of **15.000 wafers per hour for double lane** (state of the art: approx. 6.500 wafers)







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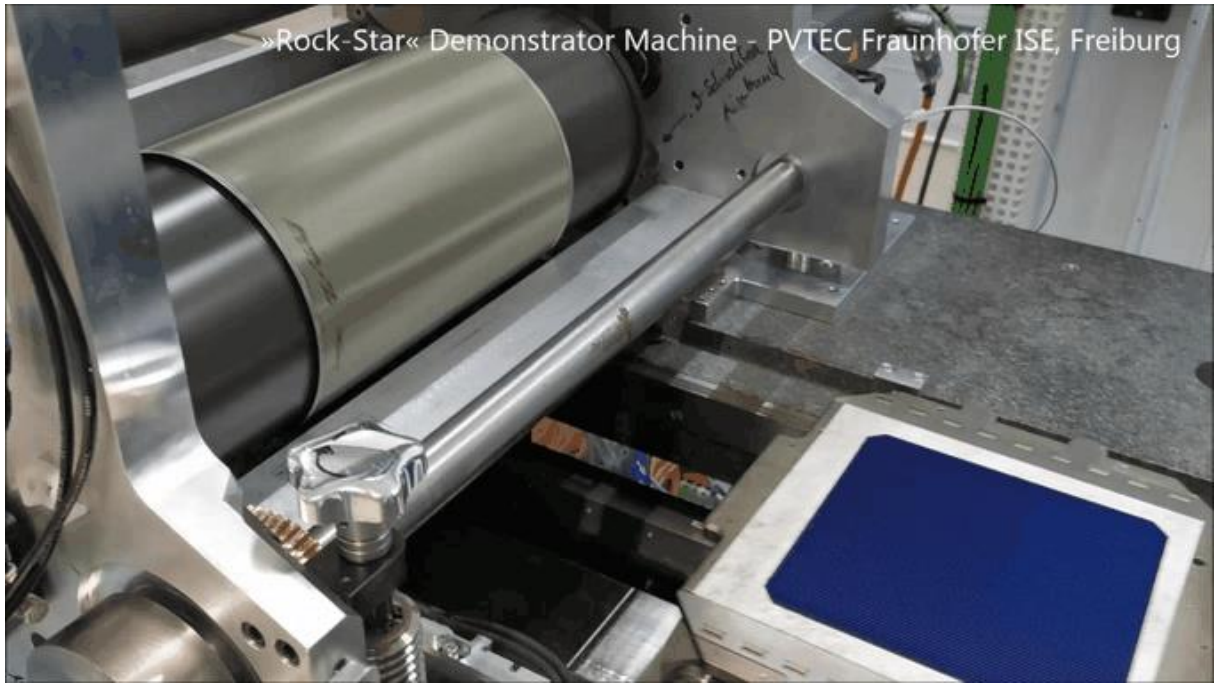

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High Throughput Production

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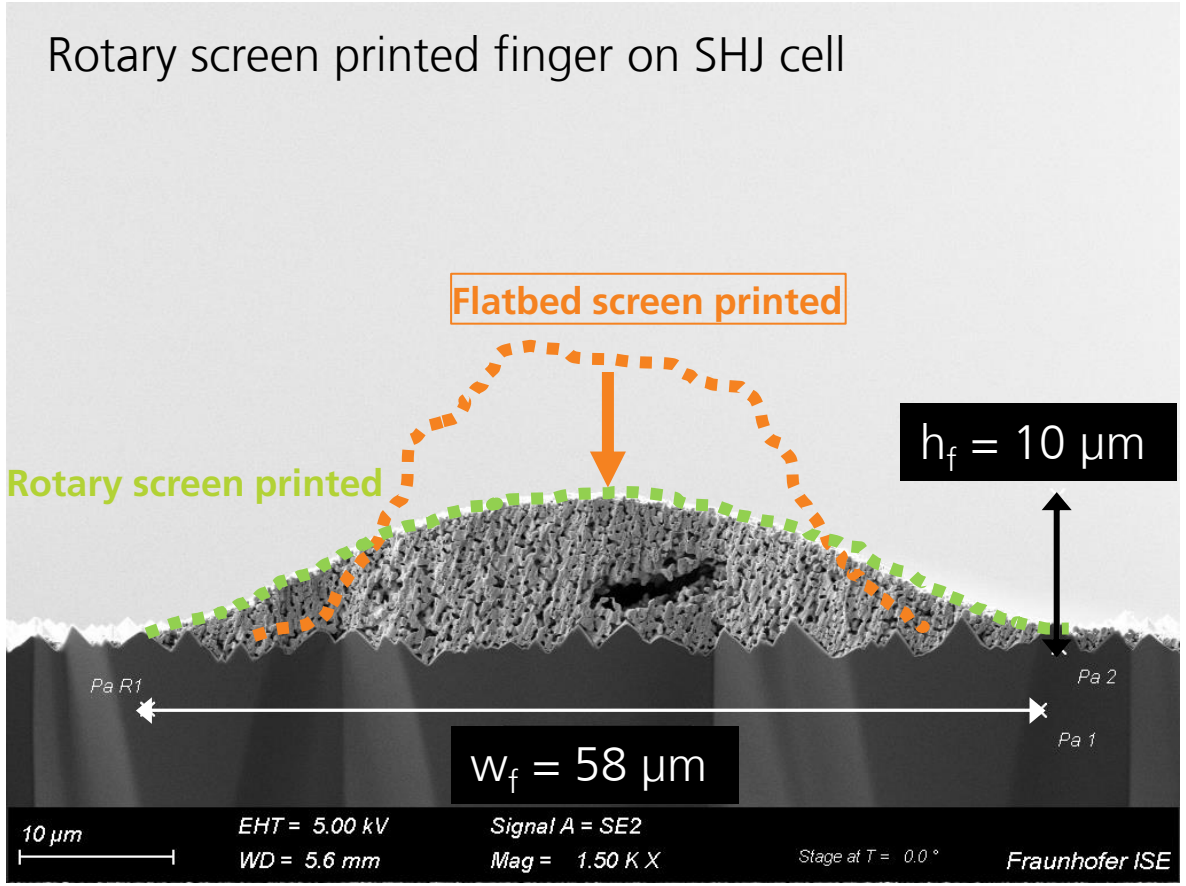
- Rotary Printing allows silver paste reduction



[3] Lorenz et al, Metallization Workshop, 2021

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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

Method	Avg/Best	Jsc [mA/cm²]	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

High Throughput Production

Rotary Printing Processes [3]

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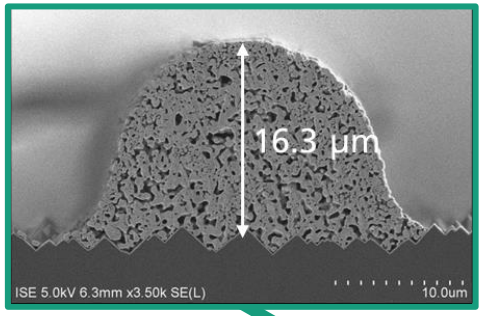
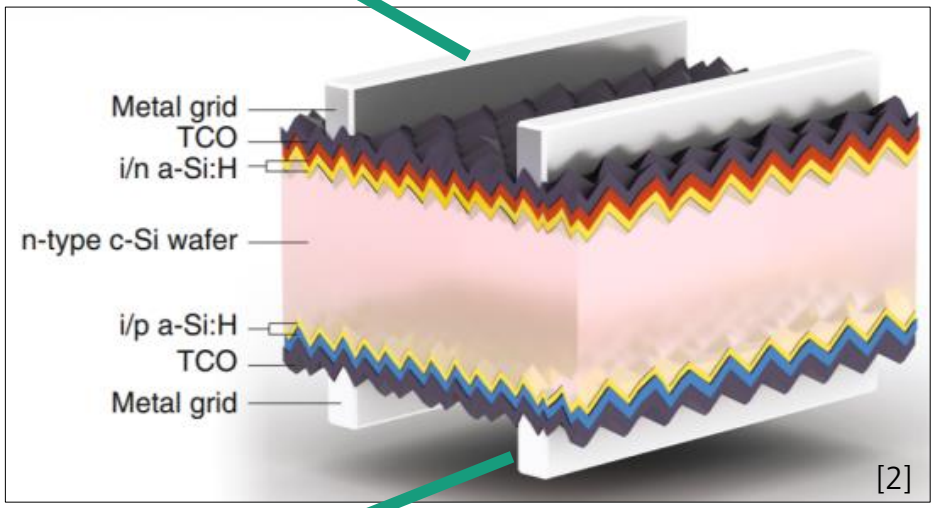
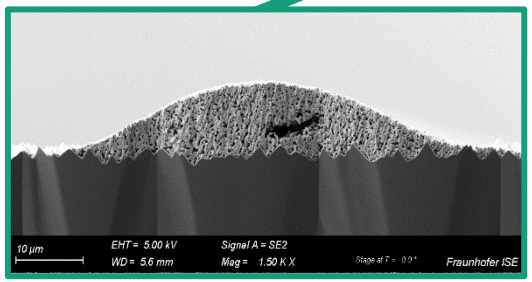
- Our demonstrator machine allows throughput rates of 15.000 wafers per hour for double lane (state of the art: approx. 6.500 wafers)
- Rotary Printing allows silver paste reduction and similar efficiency level
- Combination with Multi-Nozzle Dispensing very promising approach for high throughput cell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



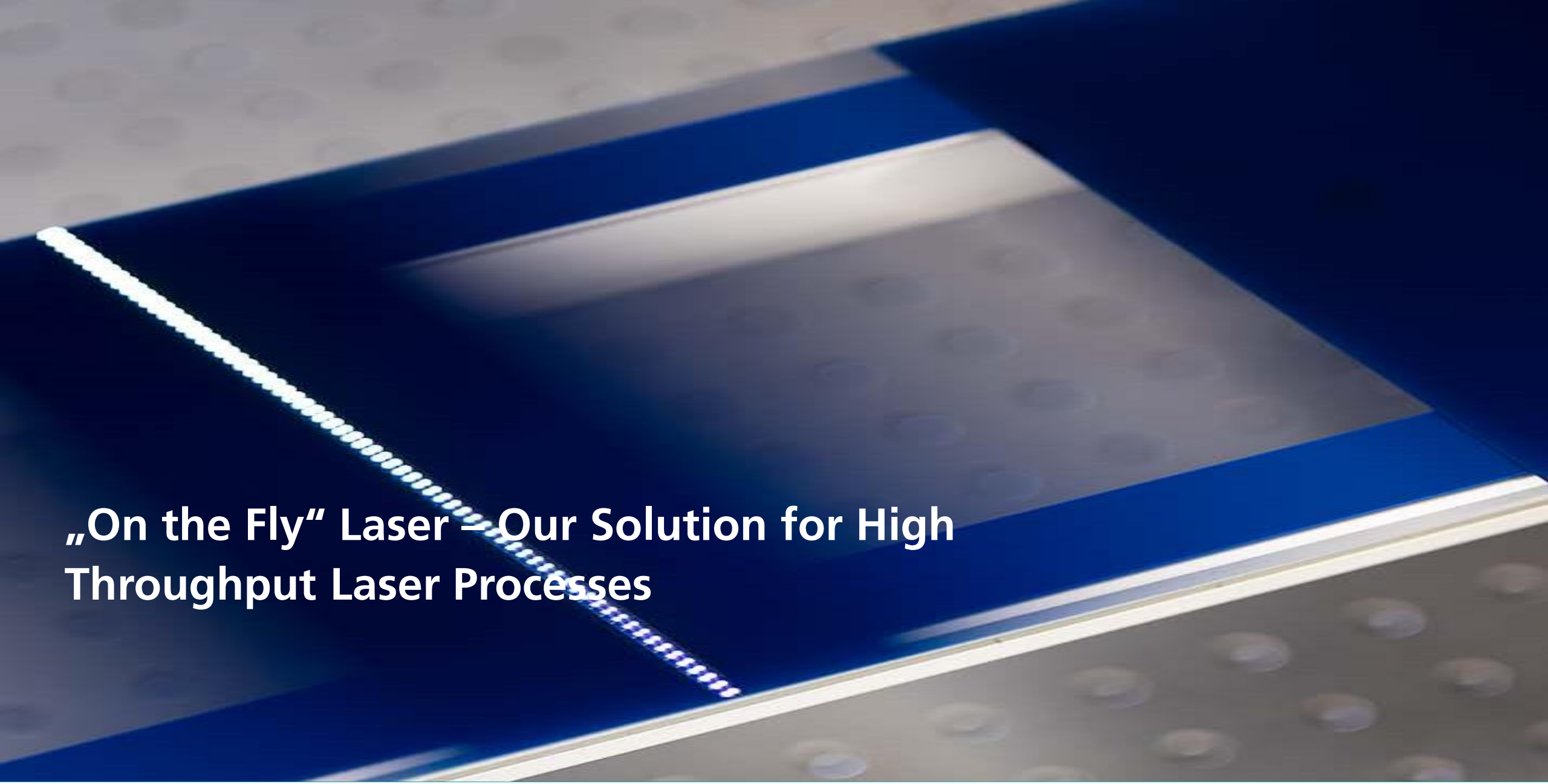
Dispensed LTP contact on SHJ solar cell [4]





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)

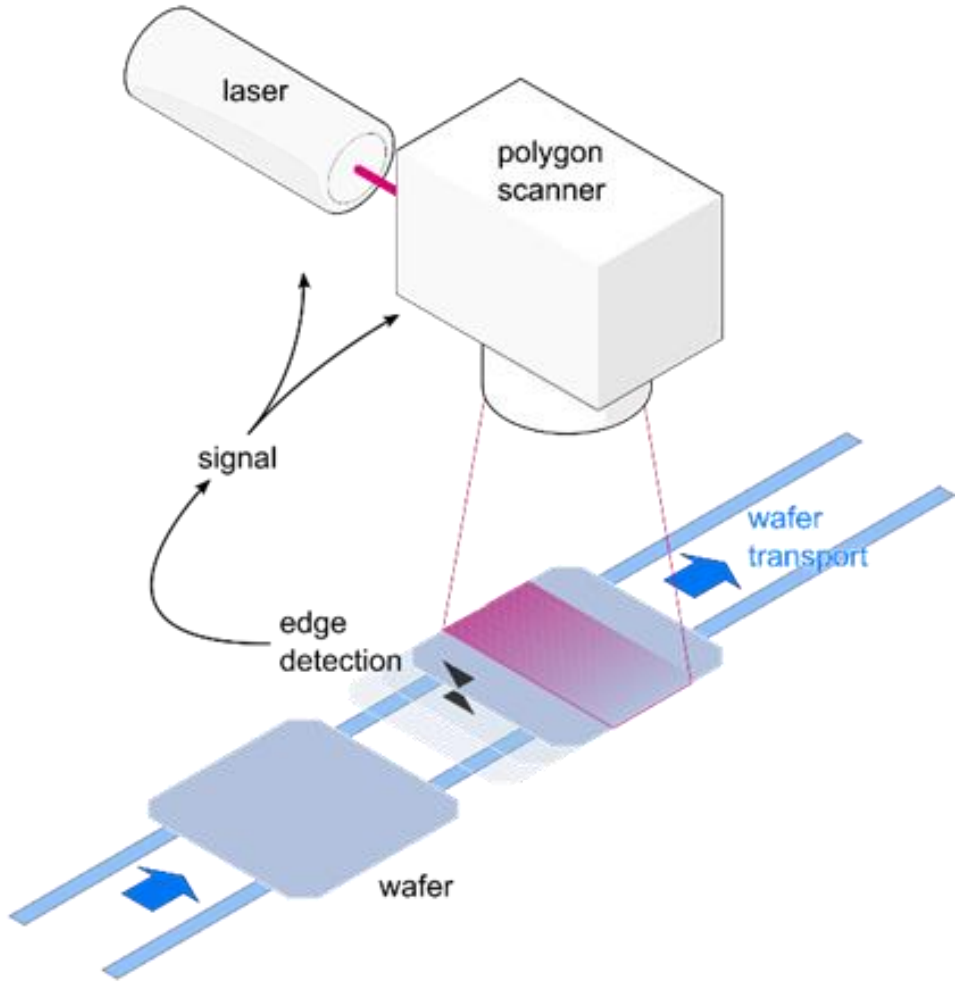


„On the Fly“ Laser – Our Solution for High Throughput Laser Processes

High Throughput Production

„On The Fly“ Laser Processes [5]

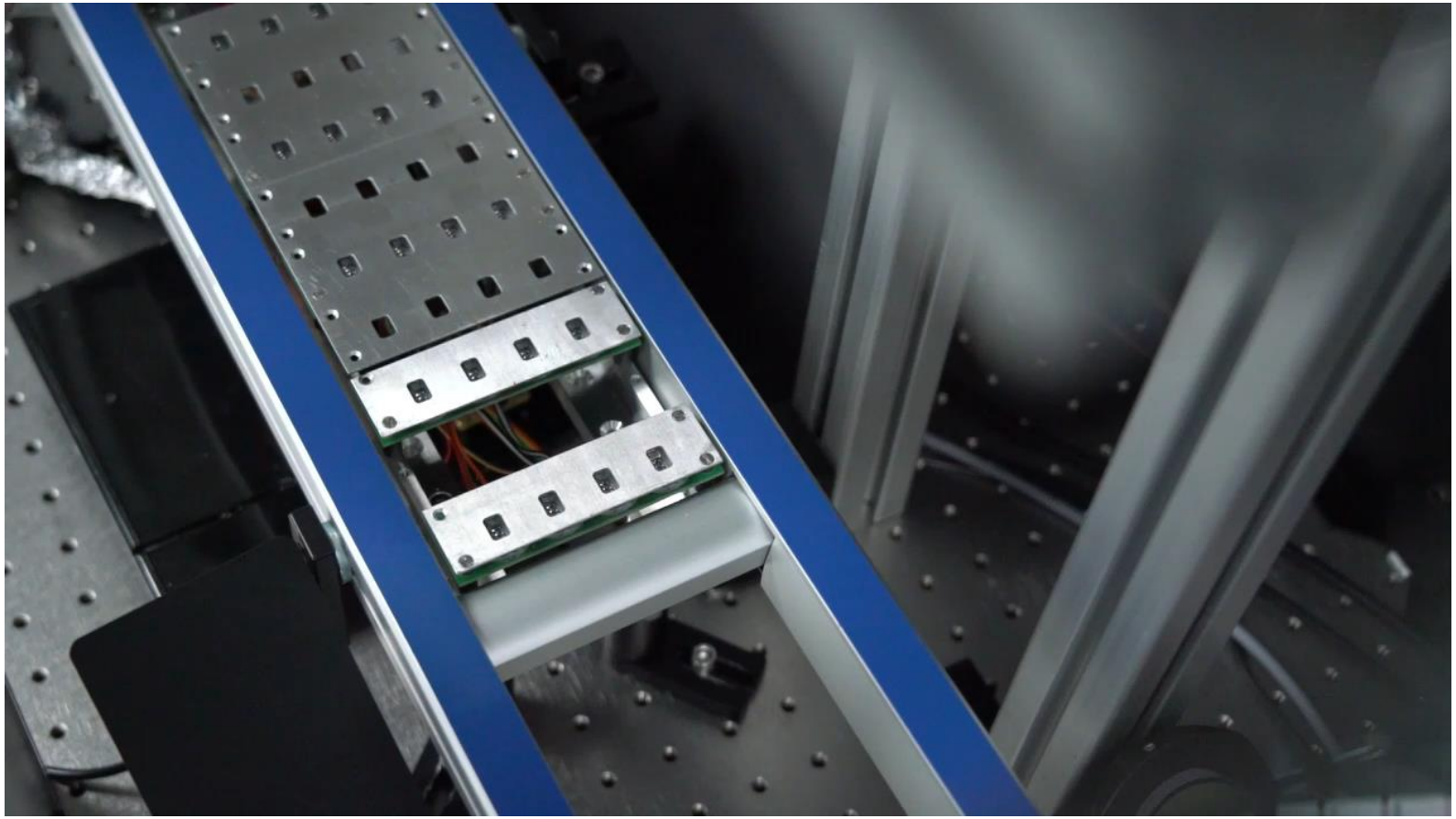
- Novel inline “on the fly” laser processes with precise laser beam control
  - Simple conveyor belt
  - On-the-fly laser processing with polygon scanner
  - Location of the cell determined using optical sensor
  - Laser process automatically triggered upon arrival of the moving wafer



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

High Throughput Production

„On The Fly“ Laser Processes [5]

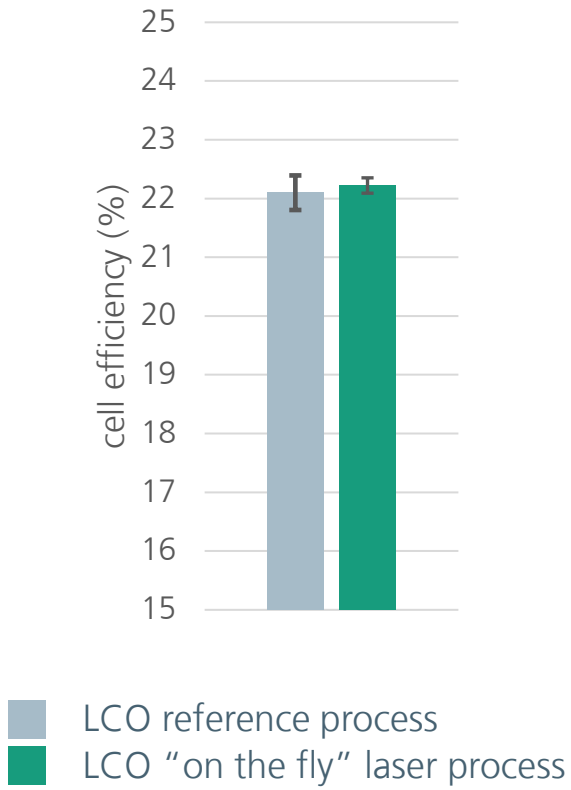


[5] press release Fraunhofer ISE #9 / 2022, 25.04.2022

High Throughput Production

„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



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

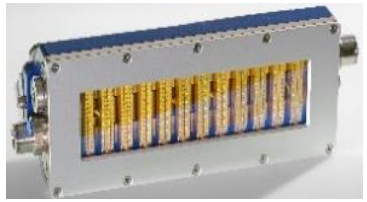
High Throughput Inline Furnace Processes

High Throughput Production

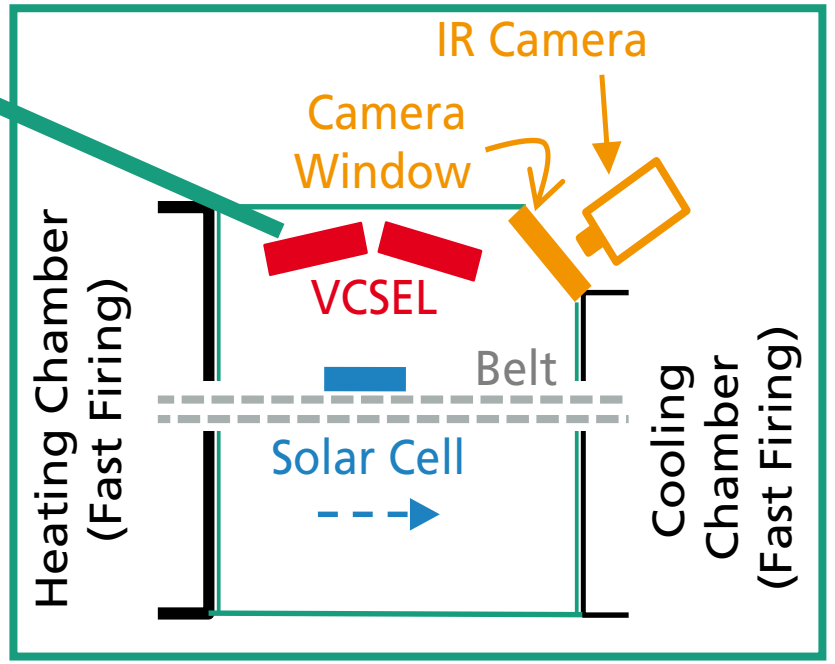
Inline Furnace Processes – Approach A [6]

- 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

[1] MDMA, ITPPV, 2022
[6] Dumsnon et al., IEEE, 2022

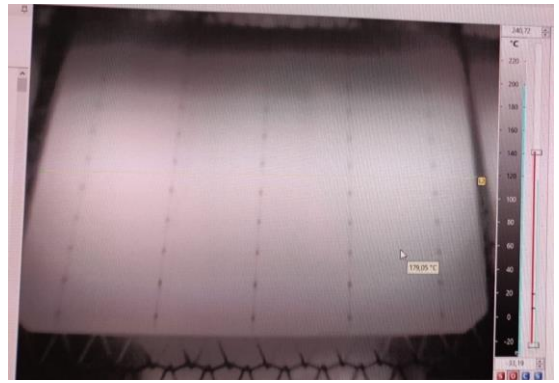
VCSEL: vertical cavity surface-emitting laser

Fraunhofer ISE

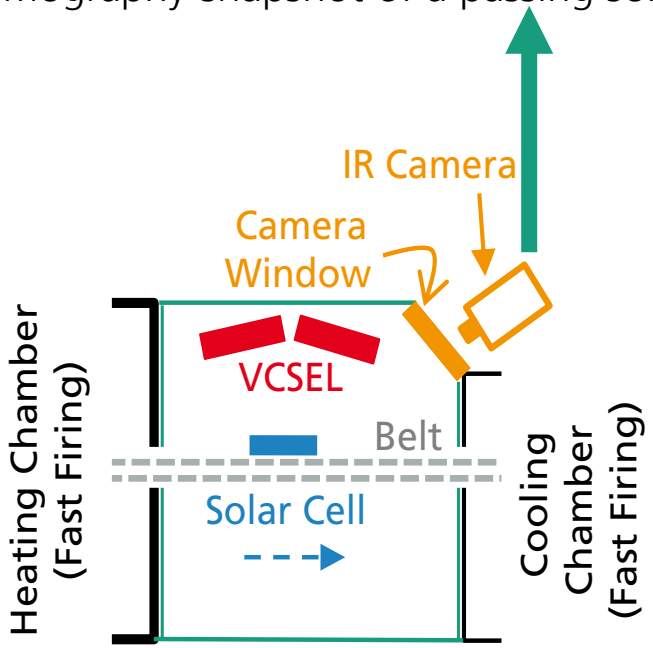
High Throughput Production

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



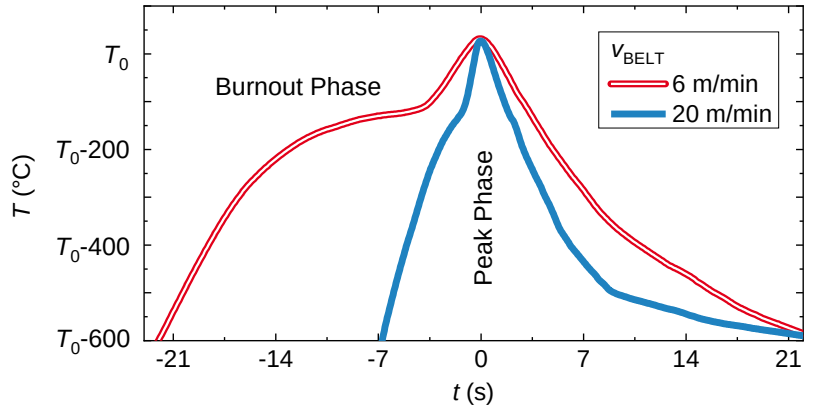
Lateral scheme of VCSEL heating equipment

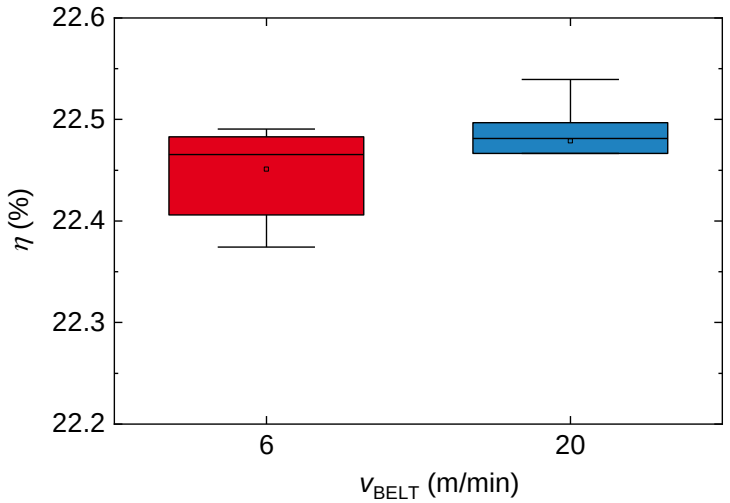
[6] Ourinson et al., IEEE, 2022

High Throughput Production

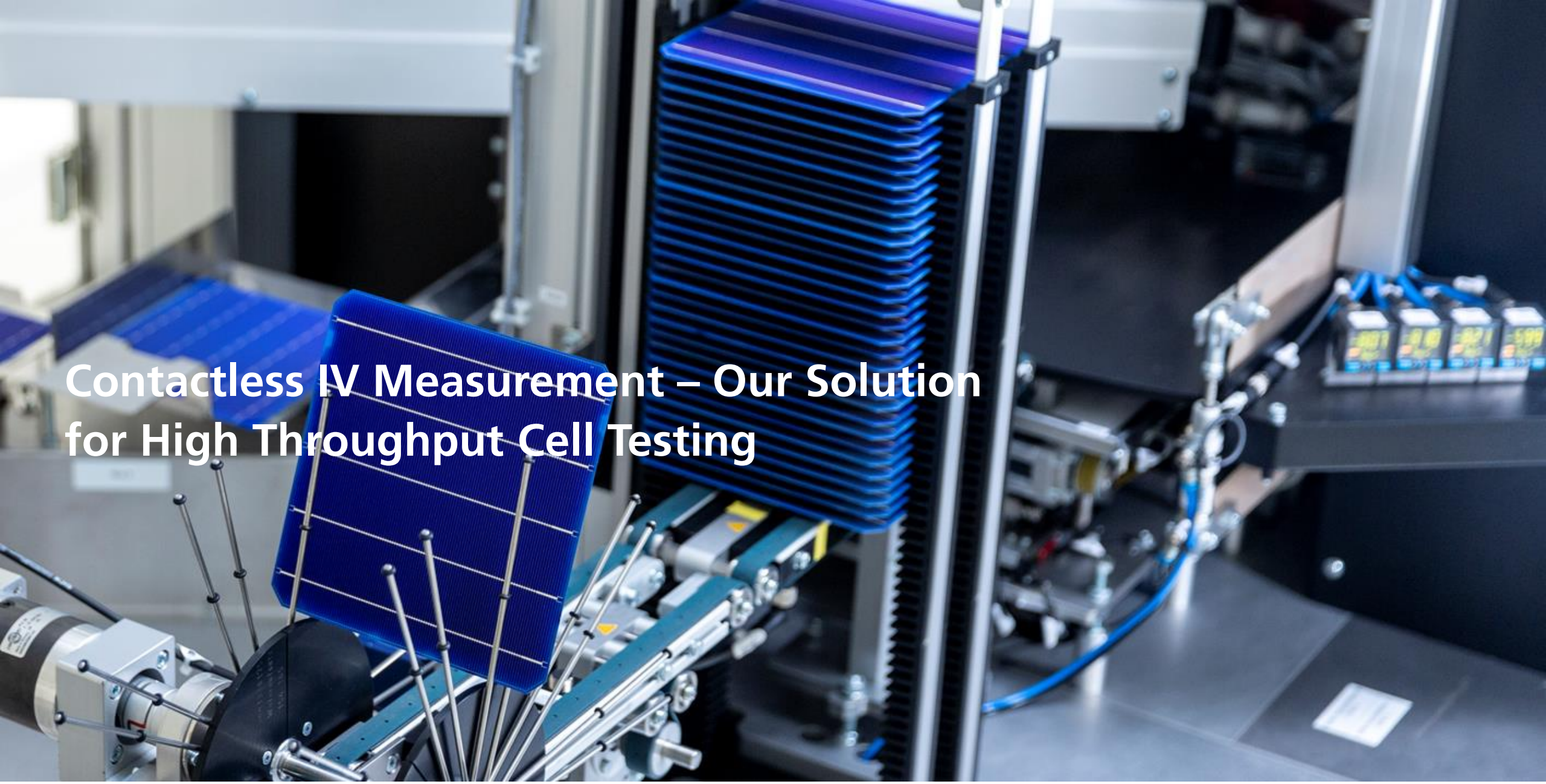
Inline Furnace Processes – Approach B [7]

- 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 dual lane** (state of the art: approx. 6.500 wafer)





[7] Ourinson et al., Silicon PV, 2022



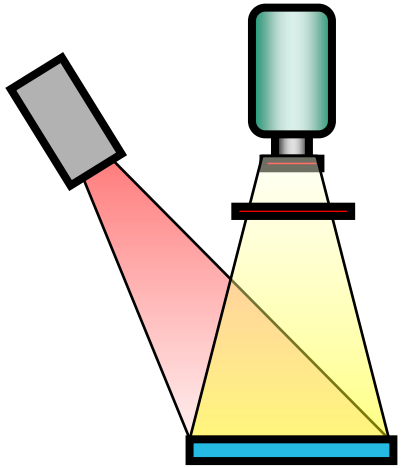
Contactless IV Measurement – Our Solution for High Throughput Cell Testing

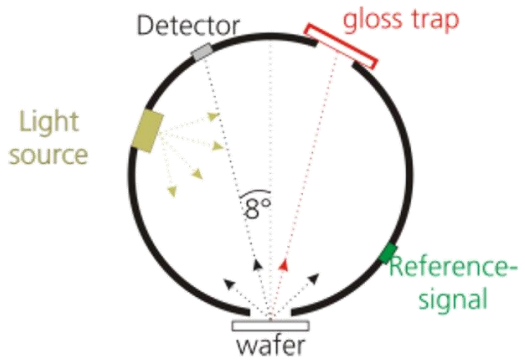
High Throughput Production

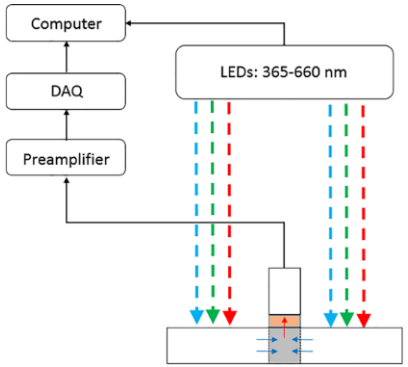
Inline *IV* Characterization Contactless [8]

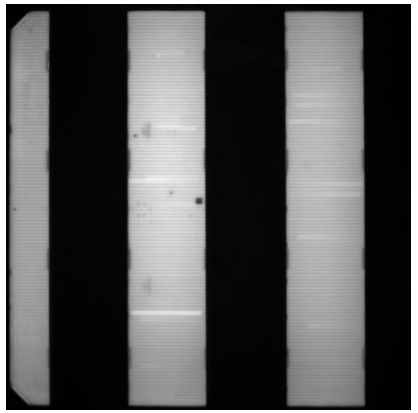
Contactless Current-Voltage Measurement

Pseudo-*IV* Characteristics	Short-Circuit Current		Series Resistance
	Reflectance	Relative EQE	
Suns-Photoluminescence	Spectrophotometry	Contactless Electroluminescence Excitation Spectropscopy [A. Paduthol, et al., JAP, 2018]	Partially Shaded Photoluminescence







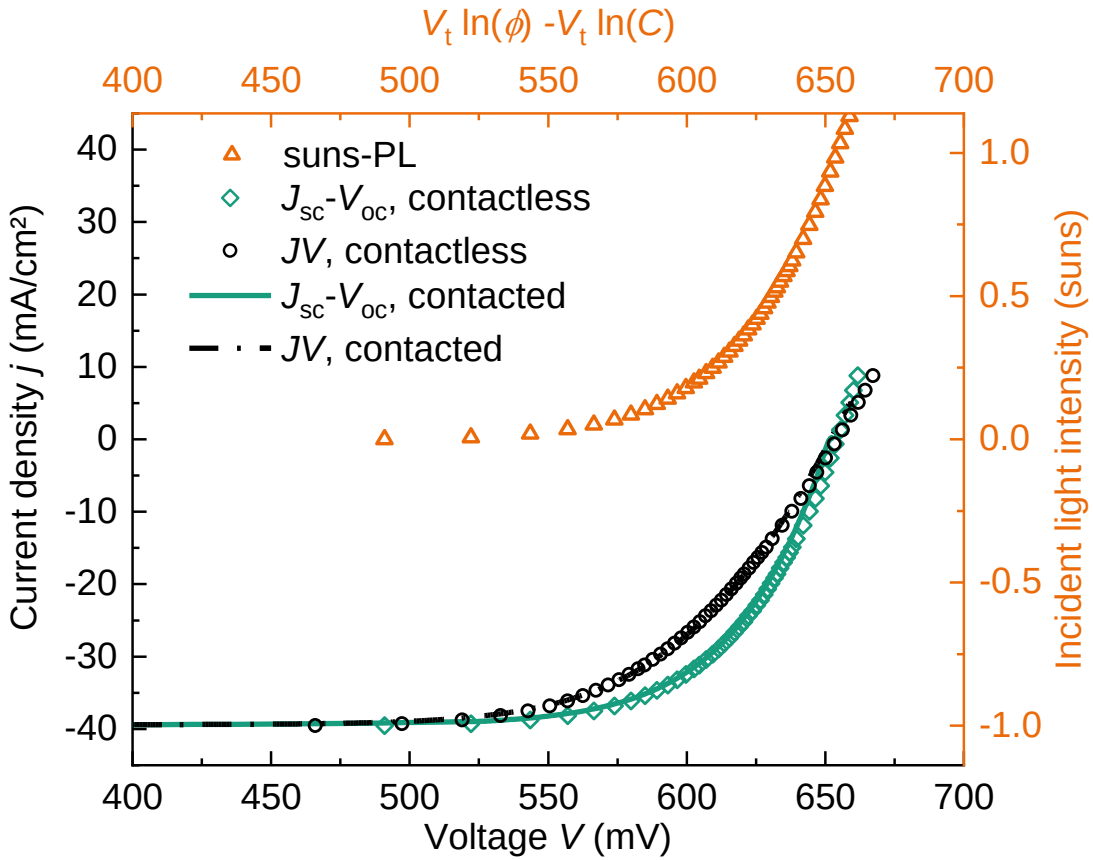


[8] Greulich et al., Silicon PV, 2022

High Throughput Production

Inline *IV* Characterization Contactless [8]

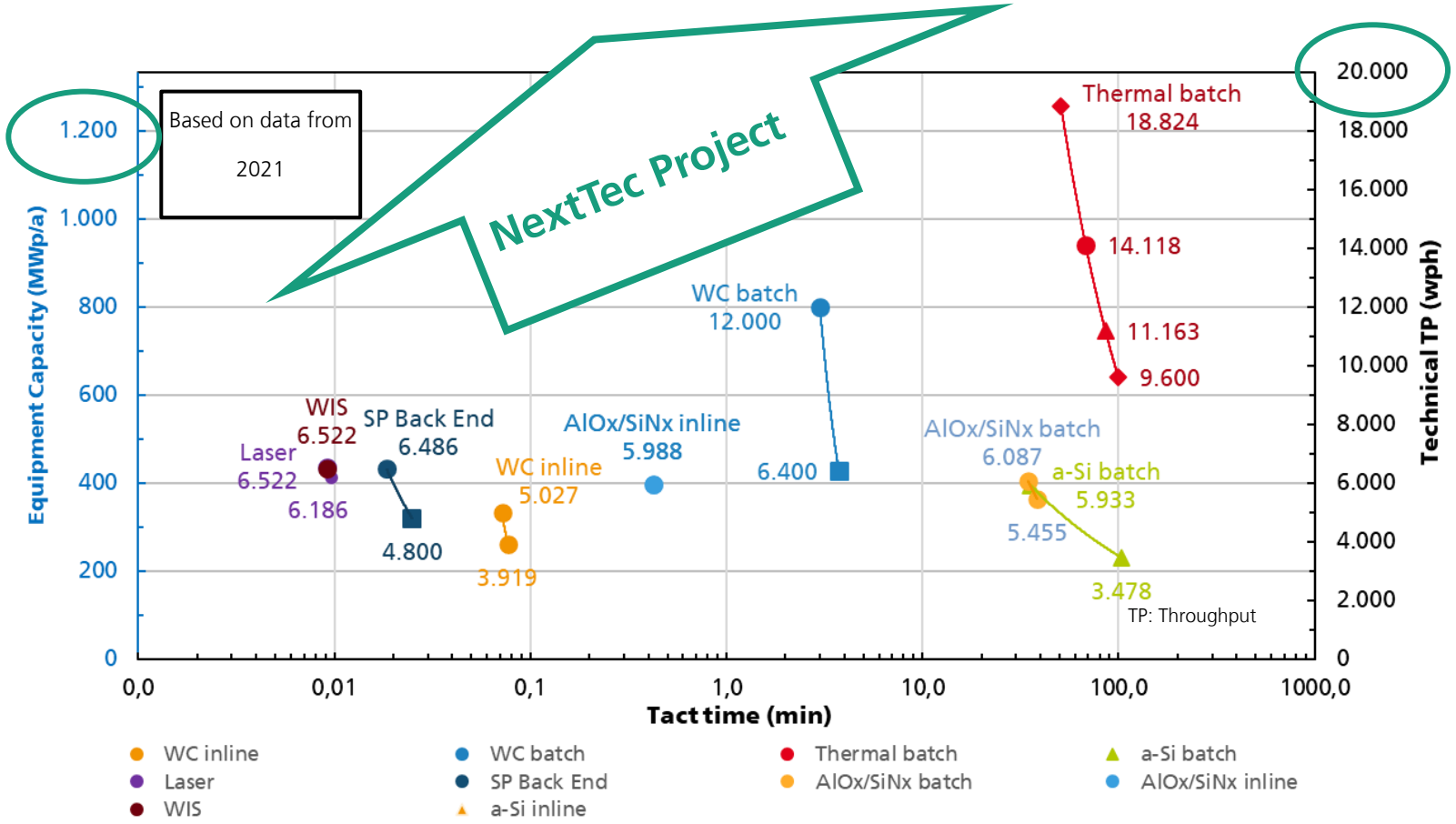
- Contactless *IV* Characterization
  - Suns-PL data calibrated to voltage
  - Shift suns-PL to get pseudo-*IV* or J_{SC}-V_{OC} curve
  - Account for series resistance >> *JV* contactless
- Close match with conventionally measured *JV* curve
- Proof of principle successful
- **Measurement speed limited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



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

High Throughput Production

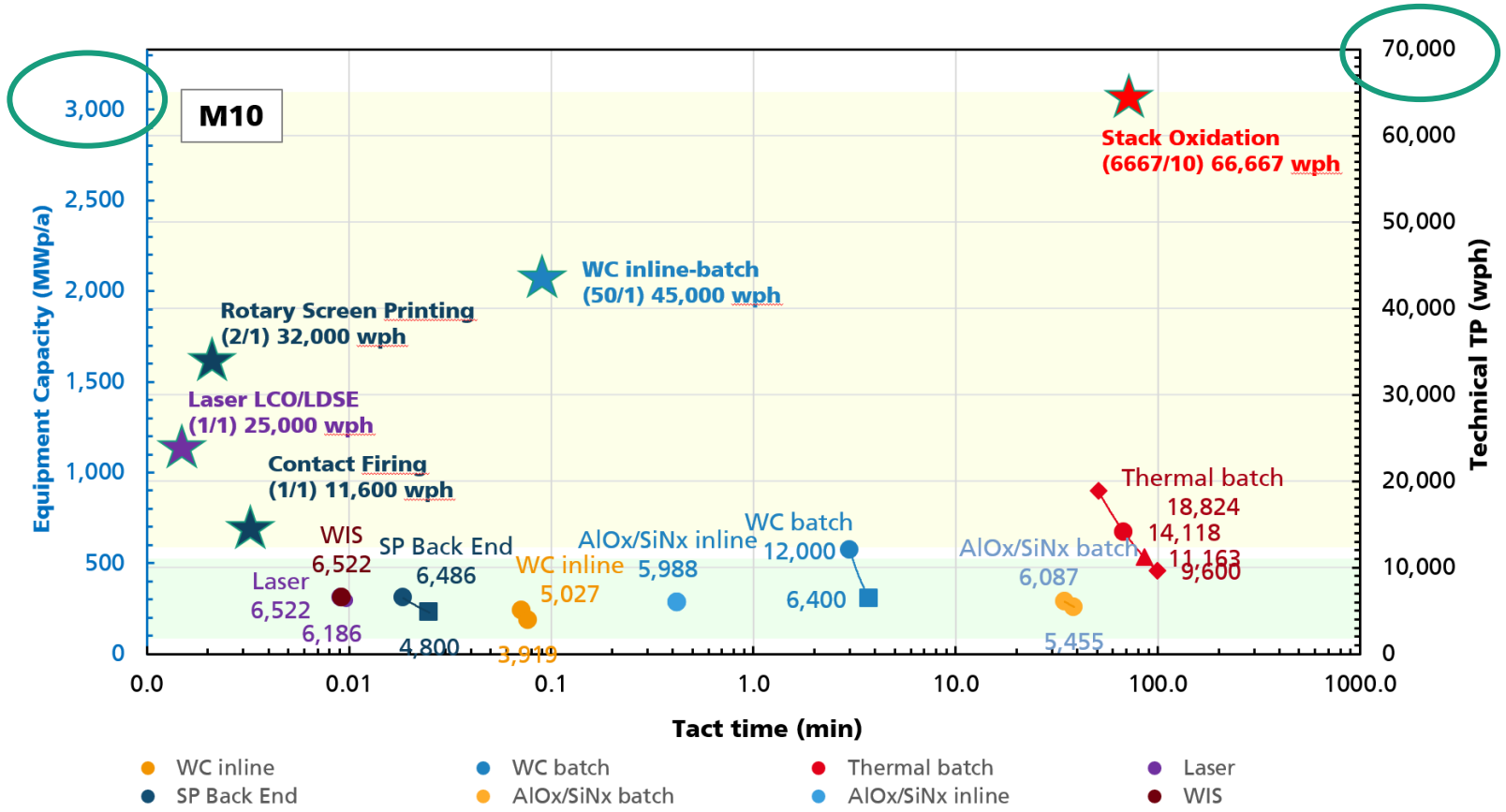
NextTec Processes – Conclusion



High Throughput Production

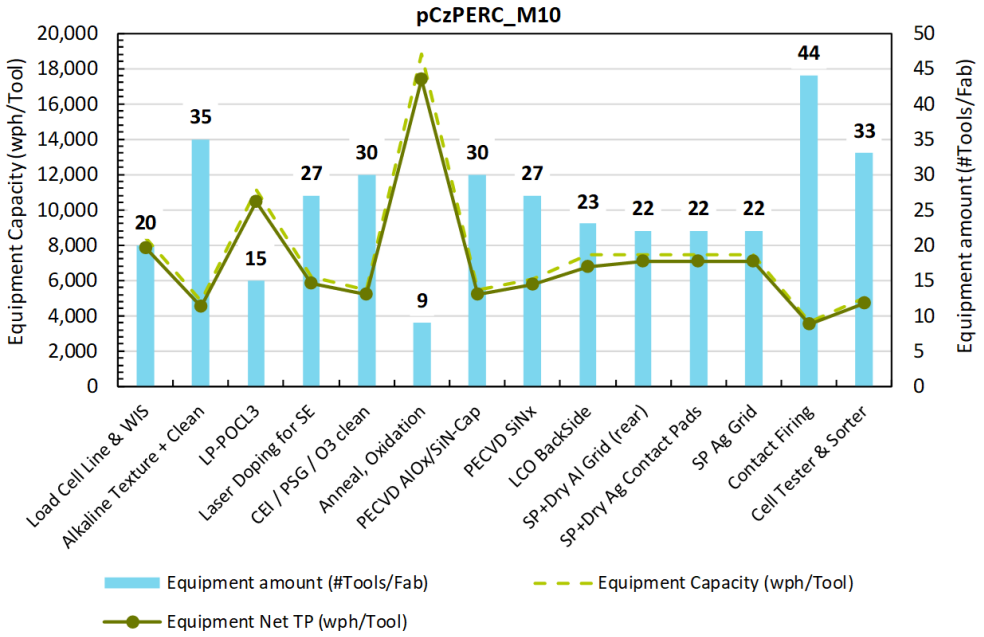
NextTec Processes – Conclusion

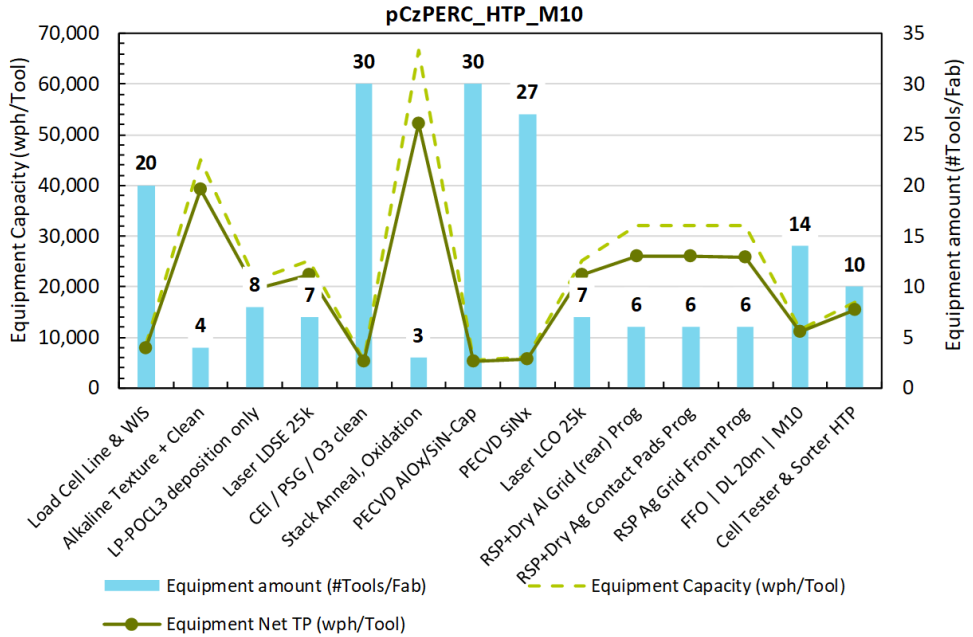
- New solutions for high throughput processes and equipment developed
- Throughput rates >> 10.000 wafer per hour and system demonstrated within the NextTec project
- New processes allow (almost) the same efficiency level
- Equipment capacity > 1GW is reachable



High Throughput Production

NextTec Processes – Our Vision [9]





PERC Reference	**359 Tools per 10,1 GWp-Fab**
	35.4 Tools / GWp

PERC HTP	**178 Tools per 10,1 GWp-Fab**
	17,6 Tools / GWp → -50% lesser Equipment with HTP

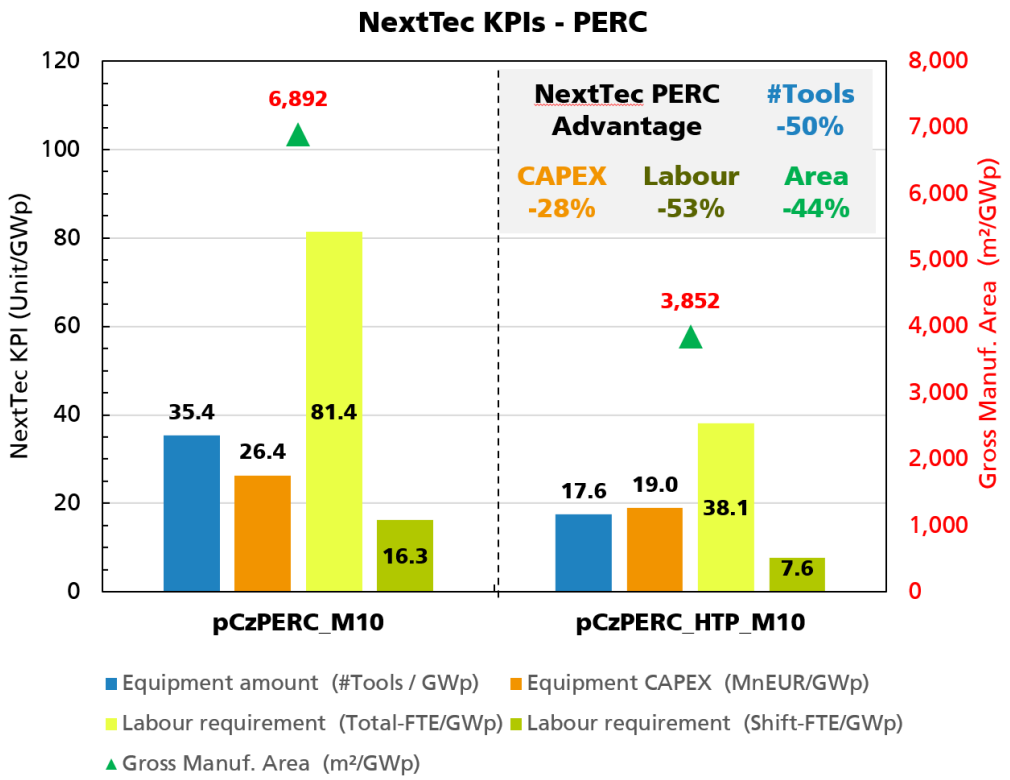
Vison: Implementation and demonstration of NextTec Processes in a running cell production line* to realize production cost savings ➔ **Number of production tools reduced by approx. 50%**

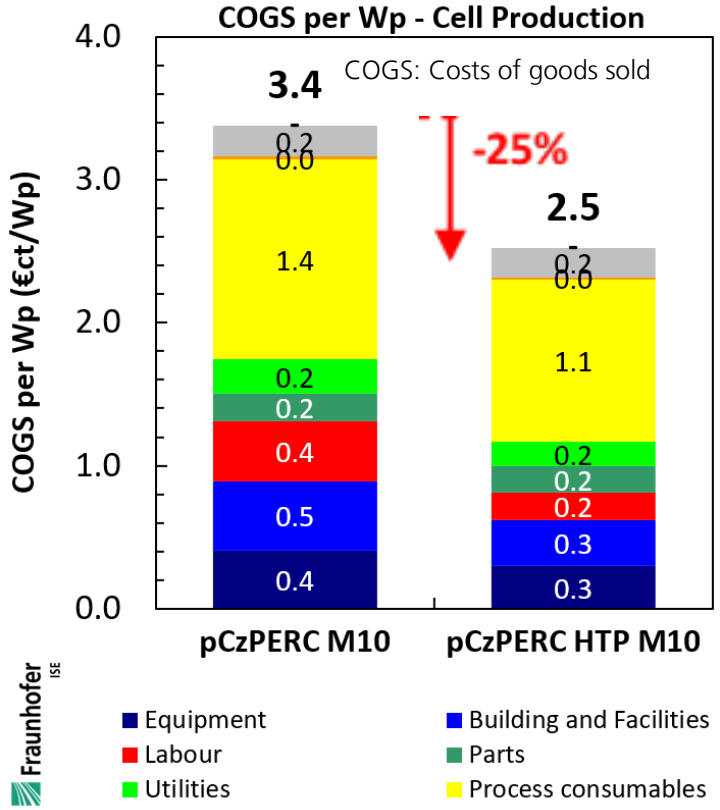
*Assumption: 10 GWp PERC production line for M10 wafers

[8] Goraya et al., EUPVSEC 2023, submitted

High Throughput Production

NextTec Processes – Our Vision [9]





Vison: Implementation and demonstration of NextTec Processes in a running cell production line* to realize production cost savings: #tools, CAPEX, labour costs and production line area reduced ➔ **Total Cost of Ownership reduced by approx. 25%**

*Assumption: 10 GWp PERC production line for M10 wafers

[8] Goraya et al., EUPVSEC 2023, submitted

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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