Intersolar Europe 2021

High Productive Vacuum Deposition Equipment for High Efficiency Solar Cells

October 6th, 2021

SINGULUS

Outline

- Introduction SINGULUS TECHNOLOGIES AG
- Crystalline Silicon Solar Cells
- GENERIS PVD
- GENERIS PECVD
- From R&D to High Volume Production
- Summary
- Q&A and Contact

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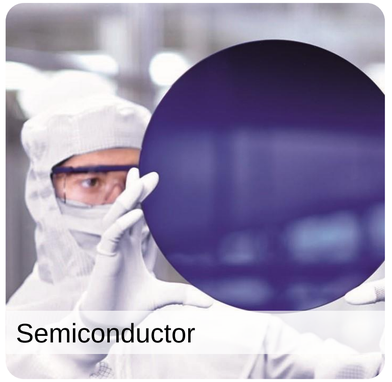
Introduction SINGULUS TECHNOLOGIES AG

Company Overview



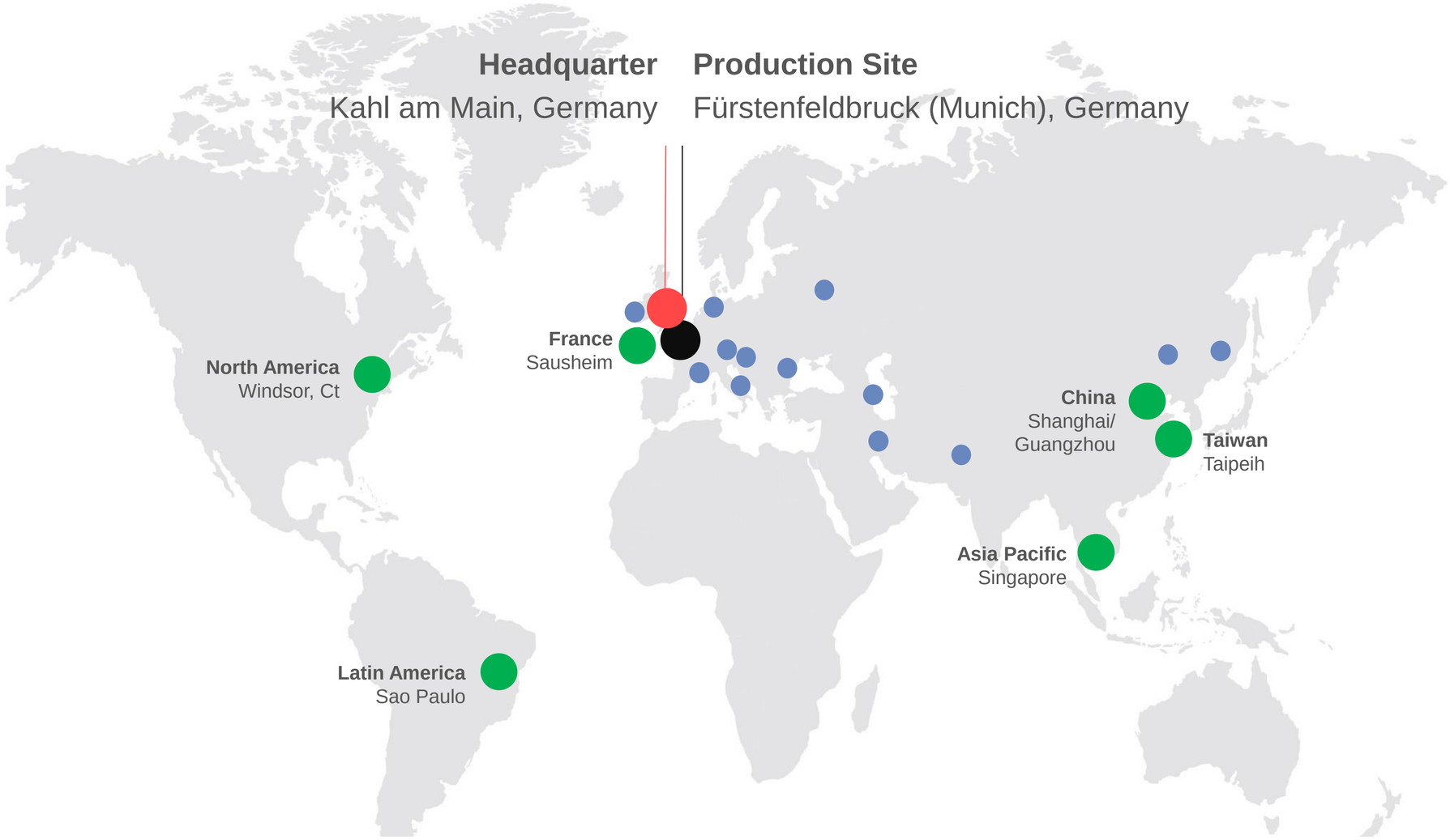
- Established: 1995 (Buyout at Merger Balzers/Leybold)
- IPO: 1997
- Employees: 350

- Research & Development
- Consulting
- Engineering & Design
- Project Management
- Production

- Installation
- Commissioning
- Service/Maintenance
- Hotline24/7
- Training

Introduction SINGULUS TECHNOLOGIES AG

Worldwide Connected – Close to the Market – Close to the Customer Base



Subsidiaries & Agents Worldwide

- Headquarter
- Subsidiaries/Sales & Services
- Production Site Fürstenfeldbruck (Munich)
- Agents

Introduction SINGULUS TECHNOLOGIES AG

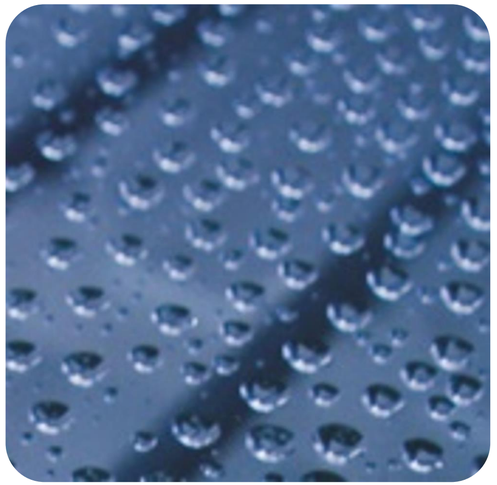
State-of-the-Art Equipment Supplier in Combination with Market Orientated Technology Know-How

Thin Film Deposition
At a wide range of coating applications, for the enhancement of surfaces with specific functionalities

- Sputter (PVD) deposition
- Evaporation (thermal evaporation)
- PECVD (ICP, µ-Wave)

Thermal Processing
used at photovoltaic and semiconductor applications, core focus on high temperature and diffusion processes.

- Rapid thermal processing
- Conditioning
- Annealing



Wet Chemical Treatment
is used in a wide range of applications, for the cleaning, etching, structuring and surface treatment of substrates.

- Etching, Cleaning and Washing
- Texturing, Oxidation and Polishing
- Coating and Developing

Introduction SINGULUS TECHNOLOGIES AG

Vacuum Deposition Product Portfolio (PV)

VISTARIS
Vertical Large Area
Inline PVD Sputter System

HISTARIS
Horizontal Large Area
Inline PVD Sputter System

GENERIS PVD
Multi Substrate
Inline PVD Sputter System

GENERIS PECVD
Multi Substrate
Inline PECVD System

VISTARIS EVA
Horizontal Large Area
Inline Evaporation System

CISARIS RTP
Horizontal Large Area
Inline RTP System

Vaccum Applications for Crystalline High Efficiency Solar Cells

Introduction SINGULUS TECHNOLOGIES AG

Over 20 Years of Know-how in Vacuum Deposition

- Over 8,000 sputtering devices worldwide in the field
- In-house cathode design with magnetron development
- Simulation of sputtering-, thermal and evaporation processes
- In-house PVD and PECVD lab equipment
- Cooperation with scientific institutes in Europe, USA, China and Singapore
- R&D Department dedicated to PVD and PECVD applications/activities
- Electrical- and mechanical design department with high experience in thin-film technology and vacuum process technology

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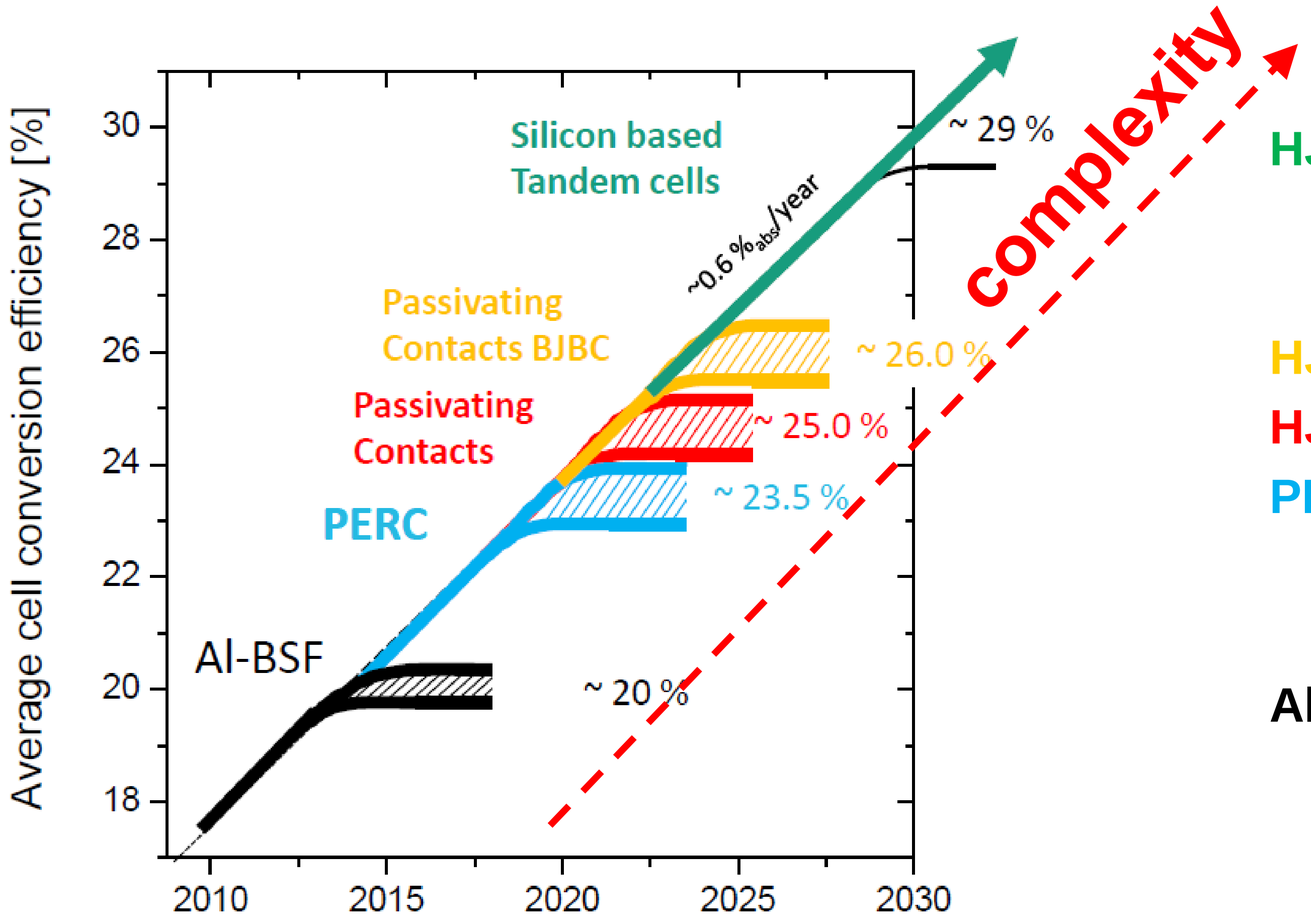
Crystalline Silicon Solar Cells

Complexity Increase at the Crystalline Solar Cell Structures



HJT /TopCon - Perovskite Tandem	multi layer
HJT BC BJBC	> 8 layers
HJT, TOPCon, POLO, MonoPoly	> 6 layers
PERC	3 layers
Al-BSF	1 layer

Figure: **Hermle, M.,** *Solar Industry Forum*, 26. Sep 2017

Crystalline Silicon Solar Cells

Roadmap of High Efficiency

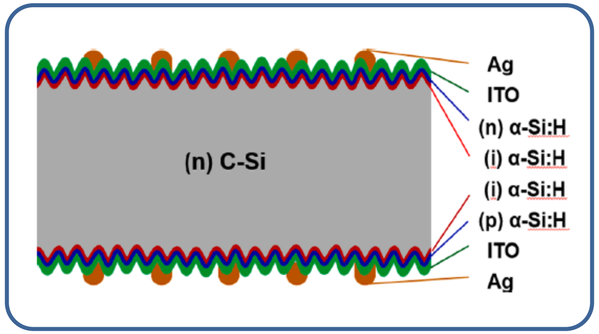
PERC
from 2015 until now

Anticipated efficiency **limit ~24.5%** [1]
Efficiency record 24.06 % [2]
Mass production ~22.5%

New Technology

HJT
highlight since 2019

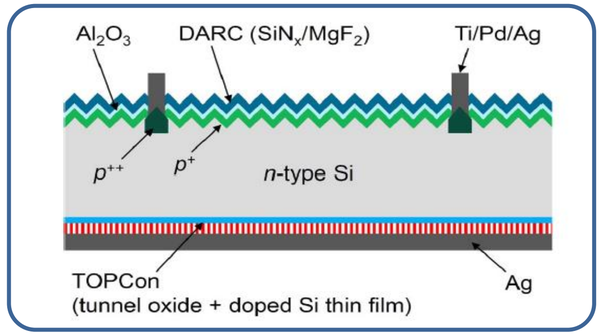
Anticipated efficiency **limit ~27.5%** [1]
Lab efficiency record 26.7% [3]
Large area efficiency record 25.11% [6]
Mass production ~24%



Techn. Upgrade

TOPCon
developed since 2013

Anticipated efficiency **limit ~28.7%** [1]
Lab efficiency record 25.7% [3]
Large area efficiency record 25.26% [4]
Mass production ~23.5%



[1] J. Schmidt, R. Peibst, and R. Brendel, *Sol. En. Mat. Sol. Cells* **187**, 39 (2018)
[2] LONGi, 244,32 cm² (M2),http://taiyangnews.info/technology/longi-24-06-efficiency-perc-cell-world-record/ (Jan 2019)
[3] Glunz S. et al., Richter, Armin, et al. Solar Energy Materials and Solar Cells 173 (2017): 96-105
[4] http://taiyangnews.info/technology/jinkosolar-record-25-25-efficiency-for-n-type-mono-cell/
[5] Kaneka, NREL Best Efficiency Chart 11 (Mar 2020)
[6] Xiaoning Ru et al Solar Energy Materials and Solar Cells 215 (2020)

Crystalline Silicon Solar Cells

SINGULUS Vacuum Deposition Platform for Crystalline High Efficiency Cells

GENERIS PVD

- **Horizontal Inline PVD System, with up to 10.000 wph gross throughput (M6)**
- Wafer size M2-M12, incl. half cells
- **HJT Application**: TCO, Cu, adhesive materials
- **TOPCon Application**: Tunnel SiOx+ poly-Si
- Single end or double end version selectable, all with integrated CRS
- Top-down and bottom-up sputtering

GENERIS PECVD

- **Horizontal Inline PECVD System, with up to 6.000 wph gross throughput (M6)**
- High-rate linear ICP sources
- Wafer size M2-M12, incl. half cells
- **PERC Application**: SiOx, SiNx, SiOxNy, AlOx etc.
- **TOPCon Application**: Tunnel SiOx+ poly-Si(i)
- **Complete PECVD sequence for PERC cells without vacuum interruption**

One Machine Platform Solution with comprehensive features for different applications

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GENERIS High Volume Inline PVD System

GENERIS PVD System

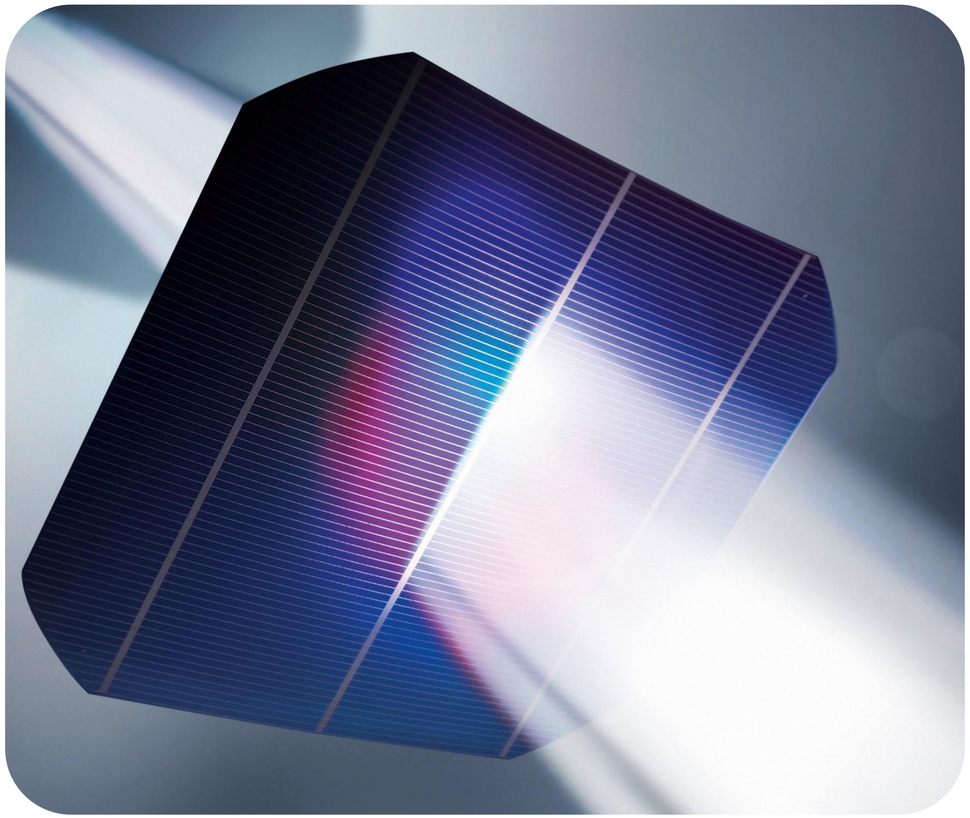
Features

- Horizontal **High Volume Inline PVD Sputter System**
- High throughput performance, **up to 10.000 wph (M6)**
- **Single end or double end version selectable**, all with integrated CRS
- Top-down and bottom-up sputtering, flexible multi layer deposition
- Compatible for **wafer size up to M12**, via special designed carriers; wafer thickness 140-200µm
- High-Speed automatization for carrier tray loading- and unloading
- Rotatable targets with high utilization (**target lifetime > 83%**)
- Power supplies mounting ensures **stable process parameter** due to short cable length and **excellent Arc Management**
- Fast and easy target exchange due quick-connectors

SINGULUS

GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition for HJT Mass Production



- High light transmittance
- Low resistivity/sheet resistance
- Low sputtering damage
- Temperature Uniformity (below 200°C)
- Layer Thickness uniformity
- Less breakage
- Compatible wafer format and High Throughput

GENERIS High Volume Inline PVD System

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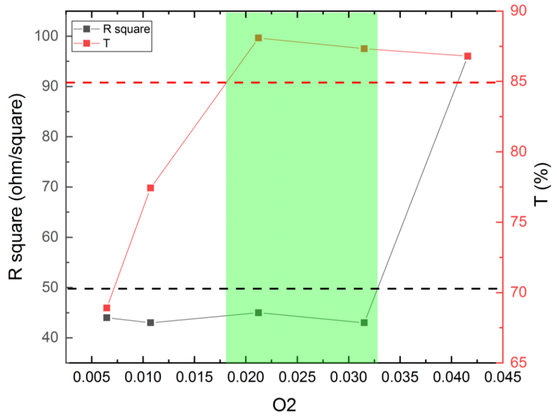

High light transmittance (T > 85%) and low sheet resistance (R < 50 ohm/square) can be easily achieved

The GENERIS PVD provides a stable and wide process window

GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition for HJT Mass Production

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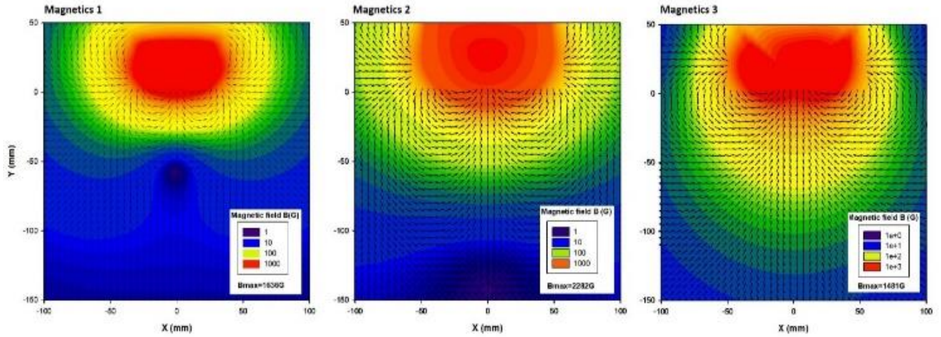

To reduce ion bombardment of a-Si layers, magnetics have to be well optimized

The GENERIS PVD system, minimize sputtering damages, shown by passivation performance before & after ITO sputtering ΔiVoc ≤ -3 mV)

GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition for HJT Mass Production

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- **Temperature Uniformity (below 200°C)**
- Layer Thickness uniformity
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Temperature uniformity is critical and can be fine-tuned according to process requirements

Controllable Isothermal multi-zone heaters, ensure a high uniformity on wafer temperature during sputtering in the range of ≤ ±4°C

GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition for HJT Mass Production

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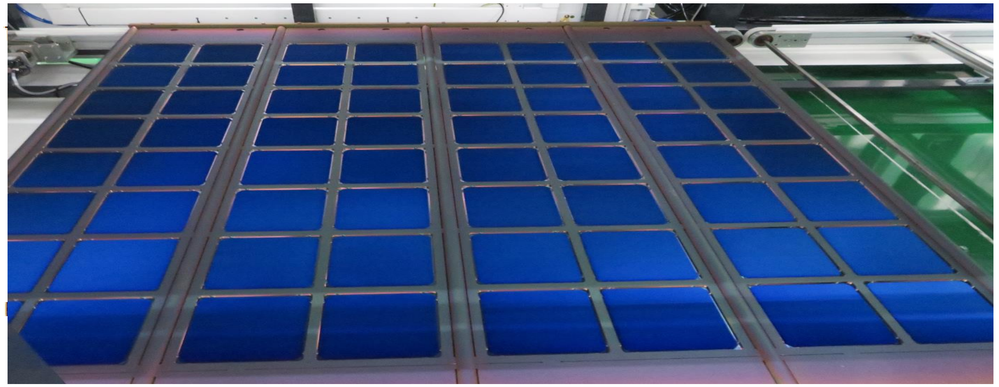

Thickness uniformity within single wafer and within carrier is ≤ ±5%

The GENERIS PVD provides the required thickness uniformity over the full deposition tray surface

GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition for HJT Mass Production

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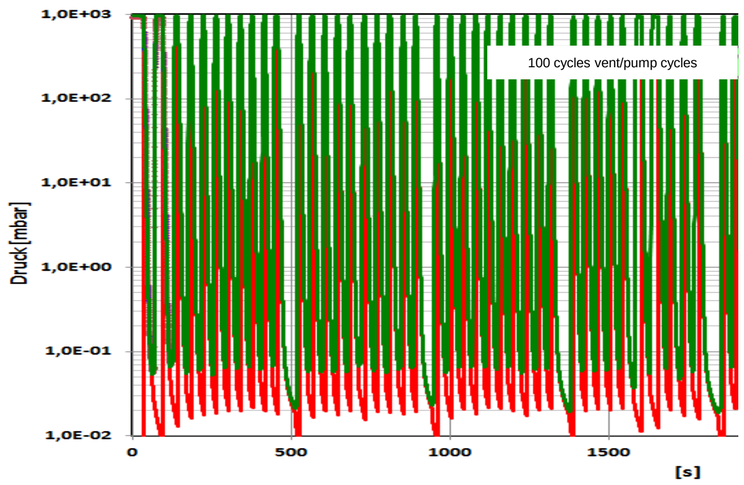
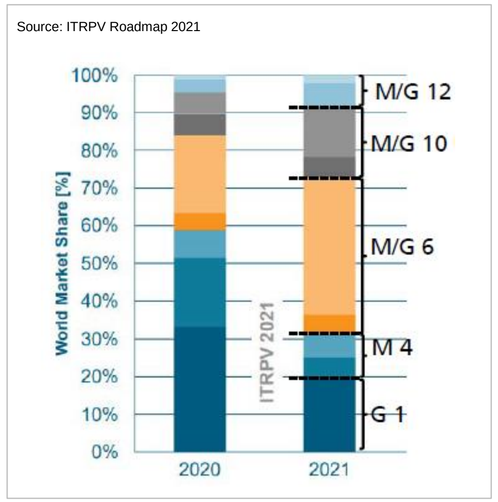
- Low sputtering damage
- Temperature Uniformity (below 200°C)
- Layer Thickness uniformity
- **Less breakage**
- Compatible wafer format and High Throughput

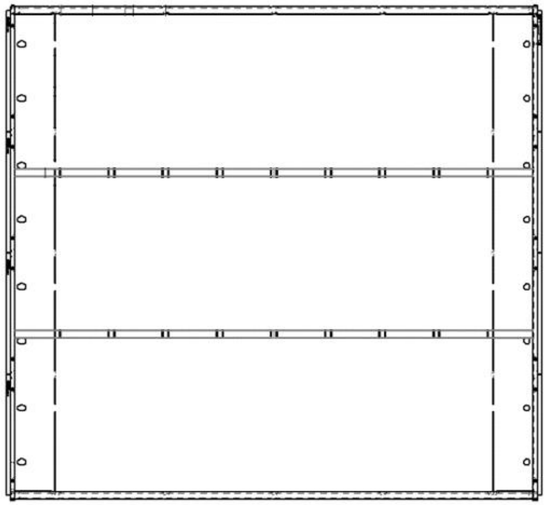


Patented Soft Pumping and Venting Cycles at the GENERIS PVD ensure no wafer movement and minimized wafer breakage

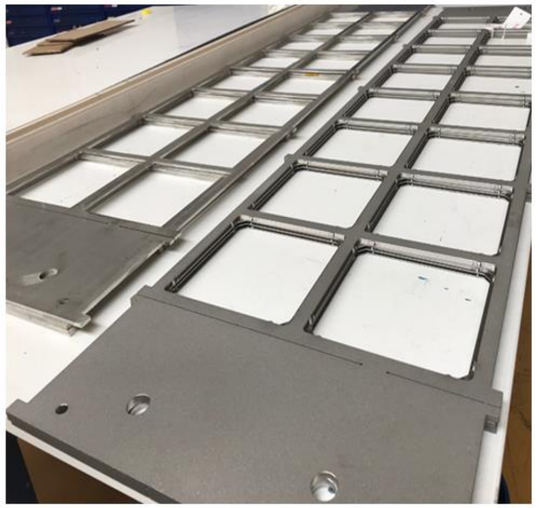
GENERIS High Volume Inline PVD System

PVD Key Requirements of TCO Deposition - Flexible on Wafer Formats and High Throughput

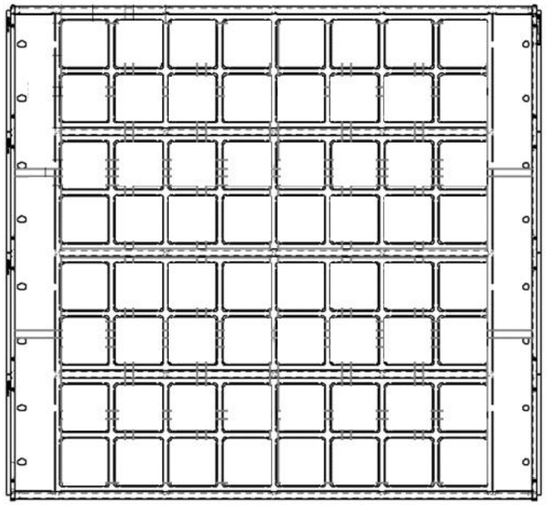




Carrier-Frame (empty)



Carrier-Inlets (flex on wafer size)



Carrier with inlet

	M6	M10	M12
Wafer per Carrier	80	56	48
Throughput GENERIS PVD 10000	**10.000**	**7.100**	**6300**

Wafer Size M2-M12 (incl. half cut) and up to 10.000 wph (gross – M6)

Easy switch of wafer format sizes – Adaption of automatically load/unload system required

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GENERIS High Volume Inline PECVD System

GENERIS PECVD System

Features

- Horizontal **High Volume Inline PECVD Sputter System**
- High throughput performance, **up to 6.000 wph (M6)**
- **High rate linear ICP plasma source**, with **dynamic deposition rates up to 120 nm m/min** (depending on layer)
- Total coating width approx. 1.4 m
- Heaters for temperature control before and during deposition, **typical substrate temperature during process 180°C to 550 °C**
- Economic gas consumption and utilization (> 70 % conversion rate)
- Chamber and tray design to minimize parasitic deposition
- **Compatible for wafer size up to M12**, via special designed carriers (CFC carriers), **Wafer Thickness 120 – 200 µm**
- High-Speed automatization for carrier tray loading- and unloading

GENERIS High Volume Inline PECVD System

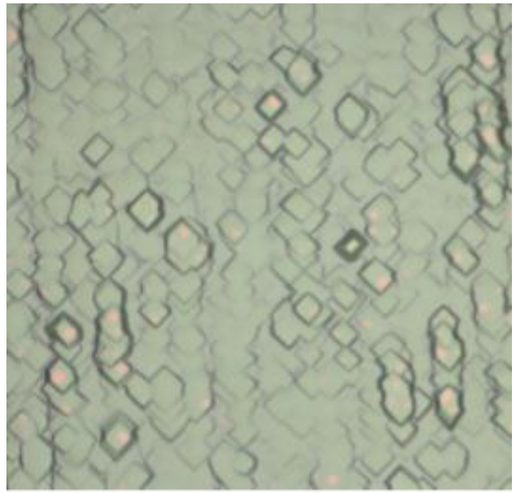
GENERIS PVD – Example of Film Performance

- Poly-Si-Layer for TOPCon
  - **No blistering (even for 180 nm thick poly-Si layers)**
  - **Very good passivation quality**
  - **Extremely low wrap-around**

SINGULUS PECVD Layer
No wrap around

Other's LPCVD Layer
Strong wrap around

SINGULUS PECVD Layer
No blistering



Blistering sample
(pink dots)

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From R&D to High Volume Manufacturing

Close support to the Customer – From R&D to High Volume Production

R&D — PILOT — FAB

Customer RFQ
→ Requirements

R&D Tool set and Proof of Concept
→ Small Scale Substrate

Transfer to Pilot Line
→ Origin Substrate Size

Transfer to MP Tool Set
→ **Gen 1 MP System**

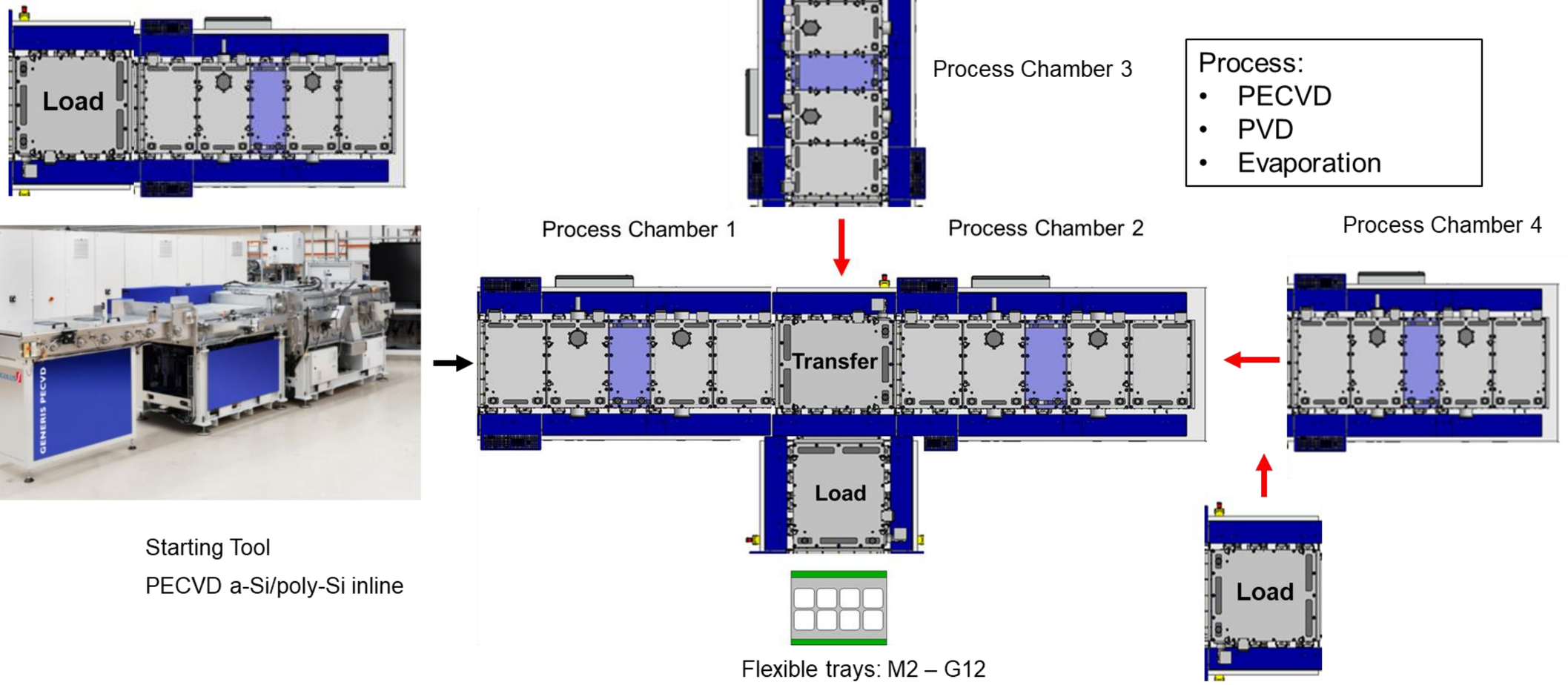
Customer Input and Results
→ **Gen 2 MP System**
→ Increase throughput, decrease Capex

From R&D to High Volume Manufacturing

GENERIS Lab – Example of a Inline Cluster System for Tandem Cell Evaluation

Starting Tool

PECVD a-Si/poly-Si inline



Flexible trays: M2 – G12

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Summary

- ✓ **Inline Horizontal Deposition for PVD and PECVD**
- ✓ Flexible Wafer size: **M2, M4, M6 to M12**
- ✓ High Throughput, up to 10.000 wph (PVD, M6)
- ✓ Excellent Layer uniformities

- ✓ **GENERIS PVD** is an **industrially proven machine**, the production line average SHJ cell efficiency has been over 24.2% with **high quality ITO layers**, which can also provide **good poly-Si layer** for TOPCon cells.
- ✓ **GENERIS PECVD** provide **inline deposition** solution for **SiOx, SiNx, AlOx, i-a-Si & poly-Si for PERx and TOPCon cells** with **uniform & high deposition rate** under **linear ICP source and CCP source**.

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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.