INNOVATIVE PRODUCTION EQUIPMENT

for PV Solar Cell like
PERC – HJT – IBC –
TOPCon – Tandem & more
SINGULUS TECHNOLOGIES builds innovative machines and systems for efficient and resource-friendly production processes. SINGULUS TECHNOLOGIES’ strategy is to take advantage of its existing core competencies and to expand these further.

The core competencies include vacuum coating, surface processing, wet-chemical and thermal production processes. The company offers machines, which are used worldwide in the solar, semiconductor, medical technology, consumer goods and data storage sectors. For all of the machines, processes and applications SINGULUS TECHNOLOGIES harnesses its automation and process technology expertise.

The question how mankind can generate energy in an intelligent and efficient manner is today’s challenge for the future. Solar power is at the forefront of being one pillar for sustainable energy supply. Intelligent energy transition towards renewables represents both an opportunity and a challenge for power generation. Highly efficient photovoltaic cells will pave the road to this destination. Modern storage and battery technologies will sharply increase the use of environmentally-friendly energy.

### Innovative Technology for Photovoltaics

With our production equipment we improve cell efficiency and reduce manufacturing costs. Take a closer look at the production machines for thin-film solar cells (CIGS & CdTe), and high-performance crystalline solar cells (PERC, HJT, IBC, HBC, TOPCon) and tandem solar cells:

- Advanced vacuum thin-film coating (sputtering, evaporation, PECVD)
- Wet chemical processes
- Thermal processing (selenization, sulphurization)
- Combination of thin-film and wafer technologies for the fabrication of top cells in crystalline tandem solar cells
Future Cell Concepts:

**Photovoltaic Technology**

<table>
<thead>
<tr>
<th>Crystalline Silicon</th>
<th>Thin-film</th>
<th>Emerging PV</th>
<th>III/V Cells</th>
<th>Multi Junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocrystalline</td>
<td>CdTe</td>
<td>Perovskite</td>
<td>GaAs</td>
<td>Tandem (Two Junctions)</td>
</tr>
<tr>
<td>Multicrystalline</td>
<td>CIGS</td>
<td>Organic PV</td>
<td></td>
<td>Triple Junction</td>
</tr>
<tr>
<td>Heterojunction Strucures</td>
<td></td>
<td>Dye Sensitized</td>
<td></td>
<td>Four Junctions</td>
</tr>
<tr>
<td>Passivated Contacts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Future Cell Concepts:**

**Charge Carrier Selective Passivated Contacts**

The concept of charge carrier selective passivated contacts, for example heterojunction or TOPCon solar cells, is the next logical step to increase conversion efficiency. Now by reducing or almost eliminating recombination losses of electrons and holes at the contacts (reducing rear side losses by introducing PERC brought cell efficiency already to the level of 21.5%).

Reducing recombination at the contacts is achieved by introducing window layers that transport only one sort of carrier (+ or -) to it’s respective contact and keeping the other sort away. Those selective transport layers are typically realized by doped Si layers.

**Future Cell Concepts:**

**Crystalline Heterojunction Technology (HJT)**

Silicon-based heterojunction solar cells are a hot topic within crystalline silicon photovoltaic as it allows for solar cells with record-efficiency energy conversion above 23 %.

→ Junction formation and BSF by deposition of doped thin a-Si layer
→ Excellent passivation by high purity intrinsic a-Si layers → high $V_{oc}$
→ Better temperature coefficient $T_c$ compared to standard cells → higher energy yield
Future Cell Concepts

Future Cell Concepts:
TOPCon Solar Cells

Tunnel oxide passivated contacts (TOPCon Solar Cells) are based on an ultrathin tunnel oxide capped by a doped Si film exhibiting excellent passivation and contact properties. This cell design has so far resulted in efficiencies of up to 25.7 %.

- Carrier selective, thin SiO$_x$ tunnel oxide to passivate rear contact
- Heavily doped pseudocrystalline Si transport layer
- No rear side patterning required
- Low contact resistance, high FF
- One-dimensional flow of charge carriers
- Tolerant to elevated temperatures during processing (no a-Si layers)

<table>
<thead>
<tr>
<th>Year</th>
<th>$\eta$ [%]</th>
<th>$U_{oc}$ [mV]</th>
<th>$J_{sc}$ [mA/cm$^2$]</th>
<th>FF [%]</th>
<th>Cell area [cm$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-type Cz</td>
<td>2017</td>
<td>25.7</td>
<td>725</td>
<td>42.5</td>
<td>83.3</td>
</tr>
<tr>
<td>n-type HPM</td>
<td>2017</td>
<td>21.9</td>
<td>673</td>
<td>40.8</td>
<td>79.7</td>
</tr>
<tr>
<td>n-type Cz</td>
<td>2017</td>
<td>24.5</td>
<td>713</td>
<td>41.4</td>
<td>83.1</td>
</tr>
</tbody>
</table>

Future Cell Concepts:
IBC Solar Cells

Interdigitated back contact solar cells (IBC) or more general back contact/back junction solar cells (BJBC) are a sophisticated approach to avoid any front shading by relocating both, emitter and emitter contacts to the cell’s rear.

- Both electrodes at rear side, no shading
- High demands on material quality: Carriers must travel through complete wafer thickness
- Excellent passivation required: Low front surface recombination velocity
- Challenge: Defining and separating both polarities on same side

IBC solar cells rely mostly on traditional production methods and offer the potential to boost conversion efficiency to the level of 25 %.

Finally, combining the advantages of HJT (high Voc) and IBC (high Jsc) in Heterojunction Back Contact Cells (HBC), results in record high conversion efficiencies of 26.6 % for single junction c-Si based technologies.
Future Cell Concepts:  
**Tandem Solar Cells comprising Perovskite Top Cell**

A perovskite solar cell includes a perovskite structured compound, most commonly a hybrid organic-inorganic material, as the light-harvesting active layer. Perovskite materials are cheap to produce and simple to manufacture. Perovskites possess intrinsic properties like broad absorption spectrum, fast charge separation, long transport distance of electrons and holes, long carrier separation lifetime, and more, that make them a potential technology as the top cell in tandem solar cells to overcome the Shockley-Queisser limit of 30% efficiency for single junction solar cells based on crystalline Si.

- High absorption coefficient: thin (few μm) photoactive absorbers are sufficient, i.e. less material consumption
- Very low losses
- Good Voc/bandgap ratio on high level
- Low non-radiative recombination rates
- Bandgap tuneable

Tandem solar cells require a crystalline Si bottom cell, for example today’s broad installed base of PERC production which becomes upgradeable to tandem architecture by adding the process steps required for perovskites, i.e. co-evaporation of the photoactive layer and sputtering of transparent conductive oxide layers for the front electrode.
SILEX II
Modular, Automated Wet Processing System for Batch Cleaning and Etching for Solar Cells

SINGULUS TECHNOLOGIES provides complete automated dry-in/dry-out solutions for wet-chemical treatments of Si-wafers in standard and high-efficiency cell lines. The modular SILEX II batch system offers a wide range of process options. With respect to highest flexibility in configuration, the SILEX II machine is characterized by a clear modular design and a compact footprint. The SILEX II machine concept fulfills current and future requirements of capacity, flexibility and reliability for mass production.

The SILEX II 8000 system achieves an output of up to 8000 wph. The SILEX II 4000 system with a reduced batch size will cover a tool capacity of up to 4000 wph for smaller volume production. Both SILEX II systems are running with very low scrap rates down to 0.01 % and a high process yield.

SILEX II Batch Wet Processing Equipment

The SILEX II ALTEX machine is designed to apply IPA-free texturing processes, offering substantial cost advantages compared to traditional etching systems. This texturing process can be adjusted to the individual requirements of standard and advanced cell technologies.

The SILEX II CLEANTEX combines common etching and cleaning steps of monocrystalline Si with advanced cleaning and conditioning processes. Efficient cleaning steps are an indispensable requirement to improve cell efficiencies and reduce operation costs. Ozone-based cleaning operations, applied on SILEX II wet bench, combine efficient organic and metal removal with an appropriate surface conditioning. Due to low
Common and Advanced Process Applications

Typical Features

- High throughput performance up to 8000 wph
- High uptime up to 95% 
- Low breakage rate down to 0.01%
- Wafer thickness down to 120 µm
  (≥120 µm on request)
- Individual, flexible process sequencing
- Onboard scheduler software for throughput tuning
- Onboard performance analyzer software
- Ozone-enhanced cleaning and etching processes
- Short and stable IPA-free texturing process
- Appropriate and effective rinsing and drying

chemical costs and consumption, simple process control and high metal removal efficiency, ozonized cleaning baths are the perfect substitute for traditional, expensive multi-step RCA cleanings, known from the solar and semiconductor industry.

The SILEX II CLEAN is provided to run dedicated cleaning sequences for pre- or post-deposition processes. Depending on cell process flow and requirement the configuration can be designed individually, involving RCA or Ozone based cleanings as well as slight etching steps.
LINEX
Inline Wet Process Equipment for Cleaning, Alkaline & Acidic Etching, Single Side Treatment, Polish Etch & PSG Removal & Inline Ozone Applications

In addition to proven processes, the focus is on new applications such as single side treatment, polish etching, emitter etching and ozone applications. The highly integrated design, high throughput, high availability and low breakage rates make LINEX very attractive for solar cell manufacturers worldwide.

**Future Cell Concepts: TOPCon Solar Cells**
Tunnel oxide passivated contacts (TOPCon Solar Cells) are based on an ultrathin tunnel oxide capped by a doped Si film exhibiting excellent passivation and contact properties. This cell design has so far resulted in efficiencies of up to 25.7%.

SINGULUS TECHNOLOGIES provides for the production of TOPCon high performances solar cells the important manufacturing steps: inline wet process and vacuum deposition (PVD & PECVD).
LINEX Process Applications

Final Clean (Mono & Multi):
Wafer cleaning after separation, with ultrasonic & additives

Alkaline Texture (Mono):
Ultra short process time, superior aesthetics

Single Side Etching:
Single side etching of a-Si for TOPCon applications

Single Side Polish (Mono & Multi):
Acidic or alkaline rear side polishing up to 5 µm

Ozone:
Advanced cleaning technology

Typical Performance Characteristics

→ Inline from R & D tool to the fully integrated 10 lane system
→ Alkaline process up to 90 °C possible in 5 or 10 lane systems
→ Polish etch up to 10 µm
→ Integration of ozone
→ Uniform media flow on wafer surface
→ Consistent flow conditions from lane to lane
→ Easy integration of new or additional process options
→ High uptime up to 98 %
→ High throughput and best performance
→ Low cost of ownership
→ Low breakage rate down to 0.01 %
→ Best footprint
→ SSE application up to 5 µm.

Controlled – Precise – Intelligent

→ Fully automated inline wet process equipment with integrated process control
→ Compact process modules with innovative media and process management
→ Simple and robust wafer transport system
→ Shadow-free contact of the wafer top surface with the process media
→ Wafer tracking and wafer thickness measurement

Safe – Clean – User Friendly

→ Safe for operators, environment and for reliable processing
→ Cleanroom compatible design according to ISO and SEMI standards
→ Gentle wafer transport through the process media
→ Excellent accessibility of the process modules from all sides
Sputtering Competence

For all processes and applications, SINGULUS TECHNOLOGIES uses its know-how in automation and process technologies as well as the integration of production steps and works on transferring these solutions to additional areas of application.

One main focus during the solar cell production is the efficiency. Heterojunction cell technology (HJT) achieves conversion efficiencies of more than 23 % as well as reduced manufacturing costs. The newly developed GENERIS PVD system is a horizontal inline sputter tool designed for the special requirements in photovoltaic high efficiency cell production.

Heterojunction cells are coated on both sides with transparent conductive oxide (TCO) layers by PVD (physical vapor deposition). The GENERIS PVD is ideally suited for challenging layer stacks i.e. TCO layers like ITO and AZO providing maximum optical transmittance, matched refractive index, optimum electrical conductivity as well as charge carrier mobility, which are key-parameters in heterojunction cell technology. Sputter damage to the amorphous silicon layer stack does not occur. A full substrate temperature control during the whole process enables optimum layer performance at temperatures ≤ 200 °C.

With the GENERIS PVD sputtering system, contact layers can be deposited on the front and rear of the Si wafers without the need to turn the wafers between coating processes and without vacuum interruption. Annealing of sputtered layers is integrated optionally. Also full area metal coatings, e.g. Ag can be deposited within the same system. By using rotatable sputtering magnetrons, highest target utilization is achieved and offers lowest production costs.
Other typical applications include anti-reflection layers, barrier layers and precursor layers but also different metallic layers such as Al, Cu, NiV, etc. The GENERIS PVD is using an inline process in which the substrates are transported on specially designed carriers, providing edge isolation simultaneously. The carrier return system is located below the machine under clean environmental conditions. Different automation options for loading and unloading are available.

**Typical Performance Characteristics**

**GENERIS PVD**

- Sputtering materials: ITO, AZO and metals like Ag, NiV, Cu, Al etc.
- Parallel processing of several substrates (Si wafers)
- Available in 3 versions:
  - GENERIS LAB
  - GENERIS PVD 3000 for approx. 3000 wph
  - GENERIS PVD 6000 for approx. 6000 wph
- Modular configuration
- Low cost of ownership and high uptime
- Top down and bottom up sputtering configurable
- Sputter sequence configurable
- Full temperature control throughout the whole process
- Rotatable cylindrical magnetrons for highest utilization of target material
- Single end and double end version selectable
- Manual or semi-automated lab versions on request

**The Modularity of the GENERIS PVD System Allows a High Degree of Flexibility**
One main focus during solar cell production is on cost per Wp. Passivated emitter and rear cell technology (PERC) is a comparatively low-cost approach to achieve conversion efficiencies over 22%. The newly developed GENERIS PECVD system is a horizontal inline tool designed for the special needs in photovoltaic mass production.

PERC solar cells are coated on both sides with dielectric passivation layers. Rear side passivation is achieved by deposition of a thin AlOx-layer capped by SiNy. On the front side, a layer of SiNx serves for both, passivation and anti-reflective coating (ARC). The system is ideally suited for cost effective mass production with high uptime, short cleaning interruptions and maximum utilization of raw materials. Full substrate temperature control during the whole process enables optimum layer performance at temperatures in the range of 450 °C.

The GENERIS PECVD system allows for deposition on both sides of the wafer without vacuum interruption. The usage of both the processes of AlOx and SiNy, are realized by a gas separation chamber. Thus GENERIS PECVD can be configured to individual needs:

- AlOx + SiNy, on rear and SiN, on front for the complete PERC process
- AlOx + SiNy, for PERC rear side passivation
- SiN, on front and/or rear for ARC and/or rear capping layer only

Especially the first configuration in which all PECVD layers are deposited in one tool represents a cost attractive straight forward solution for newly installed PERC fabs.

The system is using an inline process in which the substrates are transported on specially designed carriers for wafer size up to M4. The carrier return system is located below the machine under clean environmental conditions. Different automation options for loading and unloading are available.

For the future, GENERIS PECVD is as well ready to serve in the production of more advanced and ultra high efficiency cell architectures like PERT, IBC, TOPCon/POLO for example by single-side deposition of doped a-Si layers.
**Inductively Coupled Linear Plasma Sources (ICP)**

- Mild coating process, no damage to emitter or interfaces
- High dynamic deposition rates for both AlOx and SiNx, thus reduced number of plasma sources, reduced power consumption
- Economic gas consumption and usage
- Shortest cleaning and maintenance interruption

**Summary GENERIS PECVD:**

- Adaptable to every solar cell architecture
- Throughput scalable, number and sequence of process modules configurable
- IC-PECVD guarantees mild coating process, no damage to emitter or interfaces
- Full control on wafer temperature during the whole process sequence
- Complete PECVD sequence without vacuum interruption
- Economic gas consumption and utilization
- For wafer size up to M4
- Chamber and tray design to minimize parasitic deposition
- Tray return system under clean atmosphere
- 8000 wafer/h, uptime ≈ 97%
- Ready for future cell architectures, e.g. passivated contacts

**GENERIS PECVD Typical Performance Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wafer/tray</td>
<td>64 (8 x 8)</td>
</tr>
<tr>
<td>Cycle time</td>
<td>28.8 s/tray</td>
</tr>
<tr>
<td>Gross throughput</td>
<td>8000 wafer/h</td>
</tr>
<tr>
<td>Uptime</td>
<td>≈ 97 %</td>
</tr>
<tr>
<td>Scheduled downtime</td>
<td>≈ 2.5 %</td>
</tr>
<tr>
<td>MTBM</td>
<td>240 h</td>
</tr>
<tr>
<td>MTTM</td>
<td>4-8 h</td>
</tr>
</tbody>
</table>

![Diagram of GENERIS PECVD system]
Consulting and Planning
→ Site evaluation & selection
→ Feasibility studies
→ Site master planning
→ Programming and concept design studies
→ General studies & simulations
→ Process technology and equipment evaluation
→ Sustainability analyses and energy efficiency audits
→ Costs and schedule models
→ CoO calculations

Design and Engineering
→ Basic, preliminary and detailed design in all engineering disciplines
→ Facility system integration
→ Space management
→ Building information modeling
→ Permits, code & environmental compliance
→ Value engineering & cost optimization
→ Early package development
→ Support getting licenses
→ Engineering, construction and general contracting (EPCM & EPC)
Solutions for High Infrastructure

(Pre) Construction and Project Management
- Commercial management
- Design management
- Space management
- Construction management
- Contractor supervision
- Start-up & commissioning
- As-built documentation
- Warranty management
- Engineering, construction and general contracting (EPCM & EPC)

Installation, Services, Maintenance
- Process equipment services
- Sustaining infrastructural services
- Facility system optimization & benchmarking
- Work package installations
- Technical staffing
- Engineering, construction and general contracting (EPCM & EPC)
SINGULUS TECHNOLOGIES – Innovations for New Technologies

SINGULUS TECHNOLOGIES develops and assembles innovative machines and systems for efficient and resource-saving production processes, which are used worldwide in the solar, semiconductor, medical technology, consumer goods and data storage.

The company’s core competencies include various processes of coating technology, surface treatment and wet-chemical and thermal production processes.