SINGULUS TECHNOLOGIES
Innovations for New Cell Concepts

Best Research-Cell Efficiencies

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, HIT, 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:

**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 SiOx tunneloxide 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)

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.
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.

Future Cell Concepts:

Tandem Solar Cells comprising Perovskite Top Cell

- 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

SILEX II Batch Wet Processing Equipment

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.

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 chemical costs and consumption, simple process control and high metal removal efficiency, ozonized
### Typical Features

- High throughput performance up to 8,000 wph (wafer size M6)
- High uptime up to 95%
- Low breakage rate down to 0.01%
- Wafer thickness down to 120 µm (wafer size M6) (<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

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 Treatment of High Efficiency Solar Cells like PERC, TOPCon and Laser Doped Selective Emitter

PV Technology Powers the World
SINGULUS TECHNOLOGIES provides technology solutions for both crystalline and thin-film high-performance solar cell platforms. SINGULUS TECHNOLOGIES is an established equipment supplier with customers producing crystalline and CIGS/CdTe solar cells as well as future formats. Evolutionary improvement in cell concepts like PERC – TOPCon – LDSE PERC will drive the future of crystalline solar. SINGULUS TECHNOLOGIES’ expertise includes wet chemical processes, physical-enhanced chemical vapor deposition (PECVD, physical vapor deposition (PVD), evaporation), surface engineering and thermal processing.

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 performance solar cells the important manufacturing steps: inline wet processing and vacuum deposition (PVD & PECVD).
LINEX Applications for High Efficiency Cell Concepts*

Poly-Si Removal:
Single side removal of Poly-Si wrap-around for TopCon applications

WetTO Application:
Tunnel-oxide formation for TOPCon applications

Alkaline Chemical Edge Isolation:
Electrical isolation for TOPCon, PERC, LD SE PERC

Alkaline Texture:
Ultra-short process time, superior aesthetics

Ozone:
Advanced cleaning technology

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
→ Fully automated airflow control flaps for optimal process conditions available
→ Virtual wafer tracking on each lane
→ Inline wafer thickness measurement and reflectivity measurement on request

Safe – Clean – User Friendly
→ Safe for operators, environment and for reliable processing
→ Cleanroom compatible design according to ISO standards
→ UL, SEMI and other standards on request
→ Gentle wafer transport through the process media
→ Excellent accessibility of the process modules from all sides

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
→ Single side Alkaline etch up to 5 µm
→ NOx-free edge isolation
→ Integration of ozone for oxidation and cleaning sequences, up to 50 ppm per bath achievable
→ Uniform and consistent media flow on wafer surface from lane to lane
→ Easy integration of new or additional process options
→ High uptime up to 99 %
→ Low cost of ownership
→ Low breakage rate down to 0.01 %
→ Best footprint, up to 40 % footprint savings in comparison to competitor equipment
→ High flexibility in wafer/substrate dimensions
→ Wafer size change possible within 10 min
→ Wafer thickness from 80 µm up to 210 µm possible
→ Temperature range for drying from room temperature up to 60°C

* Other applications also available
GENERIS PVD
Inline Sputtering System for Heterojunction Solar Cells

Sputtering Technology for High Performance Solar Cells e.g. Heterojunction Cells

The SINGULUS TECHNOLOGIES GENERIS PVD has been especially designed for very thin substrates such as silicon wafers for the manufacturing of HJT solar cells. To generate and supply electric energy, thin-films of different electronic properties are deposited on the n-doped crystalline silicon wafer. The heterojunction and passivating structures are formed by dual-sided thin layers of intrinsic and doped amorphous silicon. On top of these silicon structures, thin and transparent conductive oxide films (TCO) are applied by a sputtering process as contact layers to conduct the generated electricity out of the cell.

Numerous SINGULUS TECHNOLOGIES vacuum sputtering machines are in operation in the solar industry, where SINGULUS TECHNOLOGIES provides the GENERIS PVD as a high throughput inline sputtering system platform with horizontal substrate transport. The GENERIS PVD is engineered for the specific requirements of the production of high-performance HJT solar cells. The GENERIS PVD ideally meets the key requirements of the heterojunction cell technology with respect to sophisticated transparent conductive oxide layers (TCO) such as ITO (Indium Tin Oxide) and AZO (Aluminum doped Zinc Oxide). The solar cells are
automatically transported through the process chambers of the GENERIS PVD, following the inline principle and applying coatings on both sides. The sputtering system safeguards a high level of layer thickness uniformity with high layer reproducibility, high productivity and at the same time very low operating expenses (OPEX).

A full substrate temperature control during the whole process section enables optimum layer performance at temperatures ≤ 200 °C. Compared to conventional alternative processes like Reactive Plasma Deposition (RPD), a vacuum inline sputtering system offers a number of clear advantages. Based on the calculation for a 1 GW production fab for HJT solar cells, the CAPEX for using a reduced number of high-throughput sputtering systems from SINGULUS TECHNOLOGIES with a max. capacity of 10,000 wafers per hour (wph) is by far lower compared to RPD systems with a capacity of only 2,500 wph. With the latest system generation GENERIS PVD 10000, SINGULUS TECHNOLOGIES can assure capacities up to 10,000 wph leading to an annual equipment output of about 500 MW. There are further savings due to the smaller footprint of the equipment and related smaller building and cleanroom space requirements. In addition, RPD systems offer only bottom up, single-sided processes requiring a wafer flip which causes additional, unnecessary wafer handling. In comparison, the dual-sided processes of the GENERIS PVD require less wafer handling resulting in reduced wafer breakage, wafer damage and wafer marks. SINGULUS TECHNOLOGIES offers the GENERIS PVD with different throughput ranges of 3,000, 6,000 and up to 10,000 wafer per hour.

**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 4 versions:
  - GENERIS LAB
  - GENERIS PVD 3000 for approx. 3,000 wph
  - GENERIS PVD 6000 for approx. 6,000 wph
  - GENERIS PVD 10000 for approx. 10,000 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
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.