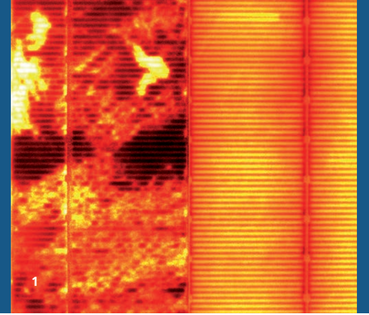

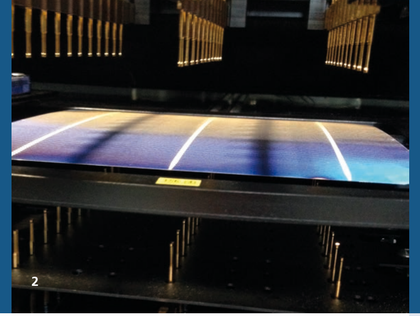

Characterization and Material Evaluation

The technological work is accompanied by comprehensive analysis and qualification of silicon materials and solar cells which enable efficiency-limiting mechanisms to be identified and material, processes and cell concepts to be systematically improved. Using a large variety of state-of-the-art offline and inline metrology systems, we are able to measure all relevant quality parameters on starting wafers, solar cell precursors and finished solar cells on a statistically relevant basis. Metrology systems with high spatial resolution allow loss mechanisms of cells to be analyzed in depth. A well-equipped wet-chemistry analysis laboratory allows inline-monitoring of chemical baths.

Metrology Evaluation
PV-TEC provides excellent conditions for qualifying new measuring instruments from manufacturers for use in PV industry. Measurement suitability testing can be performed on any form of test samples, measurement accuracy can be determined by numerous reference methods and reliability and reproducibility may be tested by temporarily incorporating inline measuring systems into automatic measuring stations.

Metrology Development, Data Analysis and Simulation
We develop metrology, data analysis and simulation tools in various areas, both independently and with partners. A major focal point lies in electro- and photoluminescence imaging where we develop inline-capable image recording methods for contrast differentiation and quantitative determination of physical parameters, image processing algorithms for automated identification of process and material defects and complete wafer rating models for a performance prediction based on raw-wafer data, which can be adapted to customer processes. Finally, we also develop simulation tools to analyze efficiency potential and loss mechanisms of the developed cell concepts as well as their sensitivity towards process variations.

Characterization of New Silicon Materials
We analyze all wafer-based silicon materials from standard and alternative feedstock such as upgraded metallurgical grade and compensated silicon, standard and high-performance multi- and monocrystalline silicon, with respect to the efficiency-limiting electrical characteristics such as recombination lifetime, impurity content and crystallographic structure taking into account block position. We develop adapted processes for material improvement and determine the efficiency potential on adequate statistical basis.

1 *Quantitative photoluminescence imaging of solar cells: dark saturation current image (left) and series resistance image (right).*
2 *Automated IV-curve, electroluminescence and thermography measurement at PV-TEC.*

Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstrasse 2
79110 Freiburg
Germany
Phone +49 761 4588-0
Fax +49 761 4588-9000
www.ise.fraunhofer.de

PV-TEC – Photovoltaic Technology Evaluation Center
Dr. Ralf Preu
Phone +49 761 4588-5260
info@pvtec.de

Front End Technology
Dr. Jochen Rentsch
Phone +49 761 4588-5199

Back End Technology
Dr. Florian Clement
Phone +49 761 4588-5050

Inline Characterization
Dr. Stefan Rein
Phone +49 761 4588-5271

www.pvtec.de

Cover photo: PV-TEC back end overview.

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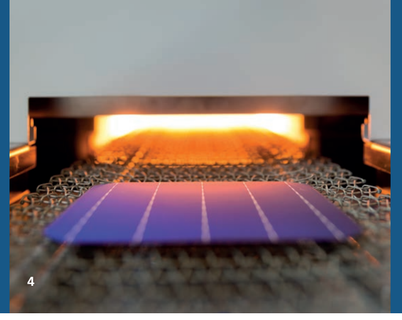

Production Technology Research

Since its foundation in 1981 Fraunhofer ISE conducts R&D in the field of photovoltaics (PV) and since 1996 in the field of PV production technology. The main objectives are an increase of efficiency and a reduction of process cost based on advanced cell concepts, highly productive processes and materials and a more efficient use of resources.

In 2005 PV-TEC – Photovoltaic Technology Evaluation Center was set up with a basic investment of 12 Mio. Euro mainly covered by the German Ministry of the Environment to support the German / European PV industry, enabling solar cell processing and characterization on a level of several 100 wafers/hour. Inaugurated in 2006, our PV-TEC – Photovoltaic Technology Evaluation Center was the first non-profit R&D laboratory in the field of crystalline silicon solar cells based on large-scale and mostly automated equipment. Since then more than 4000 extensive experiments have been conducted and the infrastructure has been continuously improved to match the demand on cutting-edge pilot technology.

Since the beginning of 2018, lab restructuring resulted in the opening of two separated large area laboratories, the PV-TEC front and PV-TEC back end. Both laboratories offer areas with high cleanliness (cleanroom class 1000) and therefore enable large-scale research and development targeting highest conversion efficiency.

We offer customized services to:

- solar cell, module and silicon wafer manufacturers
- equipment vendors
- process material suppliers

AREAS OF SERVICE

- development and evaluation of processes and characterization as well as equipment thereof, including technical and economic parameters
- design and realization of advanced solar cell structures
- characterization and evaluation of materials and cells
- technology assessment
- evaluation and improvement of production lines
- training for PV companies
- process transfer / in-house support

PATENTS AND LICENCES

We hold and file patents on our research, thus protecting the generated intellectual property (IP) together with our patent experts. Licenses can be granted for various patents to allow a safe market entry.

CONFIDENTIALITY

A very high degree of confidentiality is of paramount importance. On request, all correspondence and cooperation results can be covered by NDAs to protect customer interests.

Process Transfer

Beside the in-house development, we also offer to transfer individual PV-TEC processes or complete process sequences into the industrial process lines of our customers. The transfers are accomplished by detailed process descriptions and customer site support during process start-up.

Development and Evaluation of Processes and Equipment

PV-TEC features industrially relevant production technology needed for advanced solar cell processing of silicon wafers of standard and specific sizes (on request) including:

- wet-chemical etching, cleaning and conditioning (texturing, single side etching, industrial cleaning sequences, tunnel oxide formation); Inline and batch systems on industrial scale but also smaller wet benches
- thermal diffusion, oxidation and annealing: POCl3 and BBr3 tube furnace diffusion, dry and wet thermal oxidation and annealing (crystallization, pre-gettering, post-implantation)
- LPCVD (low pressure chemical vapor deposition) tube furnace
- printing technology: screen, stencil, inkjet and rotational (flexographic, rotary screen) printing as well as single- and multi-nozzle dispensing; application/evaluation of metal, polymer, dielectric, dopant, semiconductor, isolator and etchant pastes; high precision automated and semi-automated printing and dispensing tools and platforms
- dry conditioning and etching: plasma and atmospheric processing and tools
- PVD (Physical Vapor Deposition): sputtering of dielectric and transparent conductive oxide layers, inline sputtering and evaporation of metal layers and metal stacks both for front and rear contacts of solar cells
- sinter and curing technology: inline furnaces for contact sintering and curing (temperature range up to 900°C); photonic sintering; thermal annealing processes
- PECVD (Plasma Enhanced Chemical Vapor Deposition): coating with various AR (anti-reflection) and passivation layers in automated and direct and remote plasma systems
- laser processing: ablation (local contact opening LCO), doping (selective emitter formation), alloying (laser fired contacts LFC, foil metallization) laser-assisted transfer of metals and dopants, annealing and regeneration; various high quality automated and manual laser workstations, optical bench for laser testing

In all areas of technology, we offer computer-aided modeling for fast and efficient development and optimization of process and equipment components.

We develop and offer technology to process a wide range of advanced cell structures. Additionally we use and offer support for the modelling of such cell structures and structural elements based on single and multi-dimensional finite element simulation and analytic calculation tools.

1 *PV-TEC front end: wet-chemical bench for cleaning.*
2 *PV-TEC back end: inline fast-firing furnace.*

Design and Evaluation of Advanced Solar Cell Structures

Passivated Emitter and Rear Solar Cells

For the development of p- and n-type solar cells with passivated surfaces and localized contacts we develop both individual technological components and completed process sequences:

- single side treatment processes for cleaning and passivation
- laser treatment for locally contacted rear surface
- advanced junction formation and selective doping structures, co-diffusion for simultaneous p- and n-doping
- passivation based on vacuum deposition (aluminum oxide, silicon nitride and customized stacks)
- passivation based thermal oxidation (wet and dry processes)
- metallization for advanced front and rear contacts
- process and concept developments for bifacial application
- regeneration processes to eliminate light-induced degradation in Cz-Si and mc-Si
- process developments suitable for thin wafers

Back-Contact Solar Cells

Back-contact solar cell structures enable increased efficiency and module design. We develop and transfer technology for

- standard size metal wrap through (MWT) cells which can be combined with passivated surfaces
- modular MWT cell design (all-purpose MWT) for low concentration application (around 10x) but also for low light applications (indoor etc.)
- back-contact back-junction (BC-BJ) without any front contacts which allow very high efficiencies

Carrier Selective Solar Cell Structures

We conduct process and equipment evaluation as well as material characterization to optimize solar cells with carrier selective surfaces (i.e. heterojunction (HJT), poly-Si based structures) in order to reduce the production cost of these high-efficiency cell structures. We feature very low contamination conditions for front end processes in PV-TEC (clean room class 1000):

- simplified cleaning and surface conditioning prior to intrinsic amorphous silicon deposition
- inline deposition of intrinsic and doped a-Si layers on various technology platforms
- tunnel oxide formation
- LPCVD (low pressure chemical vapor deposition) of intrinsic and doped poly-Si layers
- alternative TCO deposition techniques and materials
- fine line metallization of low temperature pastes based on screen printing, dispensing and inkjet techniques
- inline PVD deposition of metal stacks for rear side metallization

Further cell structures are under development.

3 *High speed laser drilling process.*
4 *PV-TEC back end: wafer in firing furnace.*