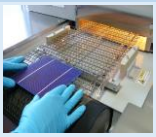
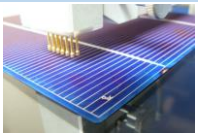
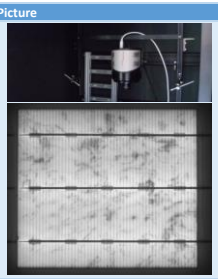
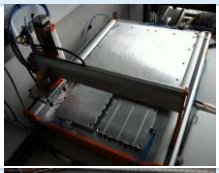
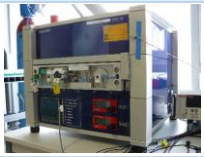
Equipment	Picture	Application	Properties
several fume hoods		- preparation of samples	- with or without gas-washer - 1200 mm width
Screen printer line (Asys Group)	 	- Screen printing (Metallization) - Drying - Wafer loading and unloading	- Automatic screen printer -Loader + Ekra printer + Interconnection unit + Dryer + Unloader (7100 mm x 1662 mm x 1550 mm) (length x wide x height) - Wafer format: 156.75 x 156.75 mm² - Alignment with automatic moving camera system - Highly precise fiducial alignment for dual print, double print, print on print or print on laser structure - High fiducial matching system - Printing under N2 atmosphere possible - Pressure controlled squeegee head for homogeneous print results -IR conveyor drying
dryer (Binder)		- paste dryer	- up to 300°C - for up to 200 cells
UV belt dryer (Bochonow)		- cure UV paste, such as UV paste designed as insulation layer	- belt furnace - format: up to 300x300 mm² - belt length: 1.4 m - max UV lamp power: 6 kW (200 W/cm); the intensity can be adjusted in the range to 40-100 % of the maximum intensity - the process time can be adjusted by tuning the belt speed from 2-20 m/min
boat etcher (Singulus)		- etch back of SiNx boats (graphite) - etch back of dummies (SiOx, SiNx)	- for vertical and horizontal graphite boats (125x125 mm² or 156x156 mm²) - up to 6 wafers (156 mm) long plates - place for 2 boats
Software (CAD)		- screens design - chucks design - PCB design - simulations	3D design (Solidworks) 2D design (Draftsight) PCB design (Altium)
chemicals		- different chemicals	- HCl (32 %) (hydrochloric acid) - HF (5 % and 50 %) (hydrofluoric acid) - H_2O_2 (30 %) (hydrogen peroxide) - NaOH (pellets) (sodium hydroxide) - KOH (50 %) (potassium hydroxide) - HNO_3 (65 %) (nitric acid) - H_2SO_4 (95-97 %) (sulphuric acid) - 2-Propanol (IPA)
ECV (Centrotherm)		- Electrochemical capacitance-voltage (ECV) profile allows the extraction of the active doping concentration of doped semiconductors. - ECV use in R&D PV industry to measure the phosphorus or boron doping profile of silicon wafer solar cells and silicon thin-film solar cells.	- Active dopant densities in the range of 1012 - 1021 cm-3 can be detected with a depth resolution of 1 nm.
diffusion furnace (Centrotherm)	 	- POCl3 diffusion - BBr3 diffusion - LP POCl diffusion (single or half pitch loading) - LP BBr3 diffusion (single or half pitch loading)	- format: 50x50 to 156.75x156.75 mm² - up to 200 wafers (400 wafers back to back)
PECVD furnace (Centrotherm)		- PECVD - LPCVD - thermal and wet oxidation	- standard industrial system - wafer format: any size up to 160x160 mm² - PECVD gases: SiH_4, NH_3, N_2, H_2, N_2O, CH4, TMA, free line for e.g. doping gas - PECVD graphite boats for up to 196 wafers (Standard verticalboat: for 144 Wafers (156x156 mm²)) - LPCVD gases: N_2, SiH_4, SiH_4/PH_3, SiH_4/B_2H_6
belt-furnace (Centrotherm)		- firing of metalized samples	- metal belt furnace - format: 50x50 to 210x210 mm² - 7 m long - 6 heating zones - up to 1000 °C - approx. 1.5 min per process (with std. parameters)

Equipment	Picture	Application	Properties
data logger (DataPaq)		- Thermal Barrier Model TB2038B - Measurement of temperature by thermocouples directly in the processing chamber: -- Laminator -- Firing furnace -- Drying oven -- Hot plate -- Stringer	Up to six measurement channels Separate software for data analysis included Internal reference temperature measurement Measurement intervall up to 50 ms Triggered measurement start possible
data logger			
degradation measuring stand (ISC Konstanz)		- Light induced degradation test - Solar cell regeneration & annealing - In-situ VOC measurement	- capable of four solar cells in one run - chuck with controllable temperature (10-230 °C, active heating & cooling) - 1000 W/m² halogen light source - UV light source available - Individual programmable recipes for free experiment configuration - Data logging in text file
cell flasher add-on (Pasan)		contact solar cells without busbars	base PCB can be changed to contact bifacial solar cells, eventually IBC solar cells (PCB not available yet).
High Potential (Voltage) Tester (ETL-Prüftechnik)		- IEC 61215 (MQT 03) - For Insulation Test , To measure the PV modules for high-voltage resistance after production - IEC 61215 (MQT 15) - Wet leakage current test	- For the measurement, the module does not necessarily have to be framed (one simulates this by packing the module in an Al foil) (- in IEC 61730 (MST-14, MST-15 und MST-16) this device can be used too)
climatic chamber (Vötsch)		- Environmental testing of solar module samples - Damp heat testing - Humidity freeze testing - Thermo-cycling	- Chamber size for up to 160 one-cell mini modules or 30 two-cell modules - Climatic testing recipe with option to program temperature and humidity ramps - Full humidity control (up to 100 % humidity) and temperature control (-40 °C up to 90 °C) - Access from outside to testing chamber allows for example measurement of contact resistances or application of current to modules during test
laminator (Phototrade - P. Energy)		- Module lamination	- lamination of mini-modules (1 cell) up to 60 cell modules: glass-foil and glass-glass - classical lamella laminator with pins - lamella pressure adaptable vial control of vacuum level in upper chamber - top lamella up to 90 °C - hot plate up to 200 °C - free design of lamination recipe - log of temperature + pressure profile possible I67
soldering Station		hand soldering	
4-point tester (GP-Solar)		measurement of: - wafer resistivity - sheet-resistance - line resistance - contact resistance	- exchangeable measuring-heads - measurement of wafer, half processed cell and cell properties - contact resistance for finger spacing of about 2.6 mm
4-point tester (PV-Tools)		measurement of: - wafer resistivity (automatic maping) - sheet-resistance (automatic maping)	- exchangeable measuring-heads - measurement of wafer, half processed cell
peel tester (Zwick Roell)		- Peel tester for simultaneous peel testing of up to 3 interconnected ribbon to determine the adhesion between ribbon and solar cell - Mechanical measurement and evaluation module integrated to determine mechanical properties of solar ribbon (e.g. max. elongation and yield strength)	- Measures tensile and comprsive forces up to 500 N - Highly sensitive force sensors to determine peel force with accuracy in mNewton range - Force-displacement measurement - High accuracy yield strength determination of solar ribbon - 3 and 4 point bending test fixture - Custom shear force test fixture for cell-celll interconnects
Corescan Multi BusbBar (Sunlab)		- Corescan - Shuntscan - Voc scan	- Mapping of metal grid contact resistance for the whole cell area - Locate shunts on solar cells and find out about their nature - Find the locations of increased recombination (on research cells without front side metallization).
differential scanning calorimetry (Netsch)			- measurements in temperature range -70°C + 600°C - heating /cooling ramps 0.001 up to 500 K/min

Equipment	Picture	Application	Properties
EL, PL (ISC Konstanz)		- imaging of recombination in as-textured wafers - analysis of gettering/hydrogenation in mc-Si material - imaging of surface recombination - series resistance imaging, particularly useful for firing optimization/paste evaluation - shunt imaging - detection of processing induced issues like tweezers marks, finger prints etc - detection of cracks during module fabrication	- non-destructive characterization of solar cells in all process-stages - very fast measurement, ca 1 second per image
EL handheld camera (Optic Makario / Nikon)		-Nikon D7200 (rebuilt with electroluminescence sensor)	- for taking pictures of energized modules in the dark
spectroscopic ellipsometer (Sentech)		- Optical and dielectric layer properties (thickness, refractive index) - Ellipsometry is a very sensitive measurement technique that uses polarized light to characterize thin films, surfaces, and material microstructure. Usually the polarization of light changes upon reflection. These changes are measured by an ellipsometer and interpreted on the basis of model calculations. The change in the state of polarization is the direct consequence of the interference within the layer system, that is captured by the so called ellipsometry angles Δ and Ψ and results by modelling for example in optical n(λ), k(λ) and dielectric properties expressed by ε1, ε2.	- UV-Vis wavelength range (280-920 nm) - default wavelength window: λ 300-850 nm - standard sample size few mm < x < 20 cm - fast measurement (< 1 min) - thickness measurement down to 0.5 nm - double-layer evaluation - large number of fitting models available Development or adaption of fitting models to layer structures and internal materials structure and morphology (e. g. heterogeneous material structure) possible - measurements of flat, polished and also on textured surfaces of mono- and multi-crystalline samples (e.g. random pyramids, iso-texture) - X-Y table with scanning area of 200x200 mm²
Fourier Transform Infrared Spectrometer (Thermo Fischer)		- Detection of molecular bonds, e.g. for measurement of Hydrogen content in a-Si layers	- Transmission or attenuated total reflection (ATR) measurement - Spectral resolution Better than 0.25 cm -1 - Spectral range: 7,800-350 cm -1
cell flasher (Halm)		- Illuminated and dark IV measurement at room temperature - Suitable for bifacial cells - Suitable for mini-modules (single cell) - Reconfigurable for measuring IBC solar cells (e.g. Zebra)	- Lamp AM 1.5 G (0.2 – 1.2 Suns) - Flash pulse 120 ms - Cell load & measurement time < 30 s - Temperature and irradiance corrections - Built-in modules for cell parameters extraction (series and shunt resistances, power, grid resistance, pseudo fill factor, etc)
module flasher (Halm)		- Illuminated and dark IV measurement at room temperature - Suitable for modules of different sizes, up 210x140 cm²	- Lamp AM 1.5 G (0.2 – 1.2 Suns) - Flash pulse 100 ms - Flexibility in contacting - Temperature and irradiance corrections - Advanced measuring and analysis methods - High precision measuring
Infrared handheld camera (Jenoptik / InfraTec)		- Thermography images of single solar cells up to large PV installations	- Mobile hand camera system - Uncooled microbolometer detector - Resolution 384 px x 288 px - Thermal resolution < 0,04 K, precision +/- 1.5 K - Power supply up to 60 V / 15 A
modul EL (MBJ)		- electroluminescence imaging of solar modules up to the size of 6 x 12 = 72 cells (6 inch) - measurement of half-cell modules - measurement of low current EL images (0.5 A)	- 3 cameras - single cell measurement - resolution ~200 µm/pixel = ~1 MP/cell - excitation current 0...25 A (0...220 V) - typ. measurement
Potential Induced Degradation (Weiss)		- PID-s und PID-p test	- capacity: up to 10 lifetime samples, cells or minimodules - bias: up to -/+ 1000 V - temperature: max. 85 °C
PV2000 (Semilab)		-diffusion length mapping via surface photo voltage method -Fe concentration and B-O distribution mapping using internal accelerated-LID chuck -QSS-uPCD for minority charge carrier lifetime mapping @ defined injection levels -corona charging for evaluation of passivating layers	-fully automated measurement of up to 100 wafers/cells -measurement of wafers at various production stages
QssPC + suns VOC (Sinton)		- injection level resolved minority charge carrier lifetime - illumination-dependent Voc measurements - contactless resistivity measurement	- fast lifetime measurements - Voc for metalized and non-front-side- metalized cells - Voc for a broad range of illumination

Equipment	Picture	Application	Properties
spectral photometer (Perkin Elmer)		- Measurement of the diffuse as well as directed optical reflectivity R and the transmission T vs. wave length; calculation of absorption A=100-R-T	- standard sample size about 1cm < x < 15cm, but larger ones possible by adaption - size of illuminated spot from 0.5x3 cm down to 0.1x0.1 cm - wave length window: λ=180–3200 nm - adaption of measurement set-up and proceeding is straight forward possible - sample sizes ranging from 2cm in diameter up to the size of large modules (im R-mode)
spectral response (PV-Tools)		- EQE, reflexion measurements on solar cells - Measurement of finger widths and calculation of metal fraction of solar cells - Automated wafer thickness measurement - Quantum efficiency mapping	- spot size can be changed - scanning of the entire surface of the solar cell - loss analysis
Viscometer (Brookfield)		- Determination of rheological properties of pastes and liquids	- Variety of probes, heads, and vessels - Temperature control 0 - 135 °C
screen printer (Micro-Tec)		- Front side metallization	- Semiautomatic screen printer - Wafer format: 125x125 or 156.75 x 156.75 mm² - Alignment with two freely adjustable cameras - Highly precise fiducial alignment for dual print, double print, print on print or print on laser structure - Printing under N2 atmosphere possible - Pressure controlled squeegee head for homogeneous print results
back contact mini modul line (Stepcraft)		- Semi automated assembly of back contact modules (one to four cells) - Dispensing of ECA or similar materials on solar cells (both sides possible)	- Dispensing unit can execute custom made CAD dispenser layouts - Pick and place of solar cells - Operating space 40x60 cm - Alignment pins for placement of conductive backsheet and rear encapsulation - Xyz-stepper motors with +- 50 micron accuracy
module measuring system (ISC Konstanz)		- outside testing field for 16 modules	- outside IV-measurement for up to 16 modules (configuration may be one-cell up to four-cell mini modules) - measurement interval flexible (smallest step is every 1 minute) - light intensity measurement with pyranometer - temperature tracking with thermocouple
transportable wet bench (Exateq)		- NaOS (Nitric acid oxidation of Si)	- mobile wet bench, transportable by plane - format: 50x50 to 156.75x156.75 mm² - diluted HCl bath - conc. HNO3 bath (heating up to 60°C) - 2 deionised water rinse with N2-bubbling
PID chamber modules (ISC Konstanz)		- for 60 cell modules PID test´s	- without huminity - 65°C - max. 3 modules at same time
process gases		- 13 process gases	- N_2, H_2, O_2 (technical and high purity) - C_3H_8, CH_4, CO_2 - Ar, N_20, NF_3 - SiH_4, NH_3, SiH_4/PH_3, SiH_4/B_2H_6
3D Microscope (Olympus)		- determination of width and height of screen printed finger-grid - characterization of isotropic and anisotropic textures - roughness analysis	- 5fold, 10fold, 20fold, 50fold and 100fold objective - resolution down to 120 nm (x/y-direction) and 10 nm (z-direction) - slope detection capability up to 85° - motor-driven - programmable optical table
wet-bench (Rena)		- suitable for beaker experiments (e.g., alkaline texture)	- for 100x100 to 156.75x156.75 mm² (also M2) - max. for 25 Wafers - 1 deionised water rinse (N2 bubbling can be possible)

Equipment	Picture	Application	Properties
batch wet-bench (RENA)		- alkaline texture - KOH + RENA monoTEX texture - HF/O3 wafer cleaning - KOH/H2O2-cleaning - HF/HCl-cleaning - HF/O3 emitter etch back	- semi-automatic - wafer-format: 100 mm to 156.75 mm and 166 mm - 50 wafers per batch - (wafer-format 100 mm_25 wafers per batch)
indus batch wet-bench (RENA)	 	- alkaline etching - industrial cleaning - piranha cleaning - drying	- format: 50x50 to 156.75x156.75 mm and 166 x166mm - alkaline bath with heating - HF/HCl bath - HF bath - different deionised water cascades for rinsing - piranha bath - oven for drying
Acid Bath (HF)		2 Baths for 25Wafer per Batch	- 156 and 156,75 and 166mm waferformat - SiNx etchback in 8%HF (without metal) - SiNx etchback in 5%HF (with metal, fired)
inline wet-bench (RENA)		- inline etching and cleaning of silicon wafers - single side treatment (with protection of front side) for polishing (edge isolation, PERC) - double sided treatment (acidic texturing) - several post-etch treatments possible (KOH, HCl, HF, ozone)	- semi-automatic - industrial size - 125-165 mm² wafers - 3 different etching baths in stock
ribbon cutter (Rotte)		- Busing (Strings) - cell connector	- Busing (strings, Wide: max 6 mm, Length: max 75 cm) - Ribbonslength from 3-30 cm with stretching from 0.3-3 % (more is possible, depends on material)
laser (Rofin)		- numbering - cutting - edge isolation - cell repair (isolate shunts)	- diode pumped fiber laser (Yb) with 1064 nm - single cell processing (50x50 to 156x156 mm²) - frequency: 20-100 kHz - pulse width: 100 ns @ 20 kHz - power: 14 W - spot size: 40-60 µm
laser (Rofin)		- numbering - cutting - edge isolation - fine lines opening on dielectric layers (application for PERC)	- ND: YV04 green laser for class 1 operation - easy touch pad software, automatic door security - wave length: 532 nm - frequency: 15-200 kHz - power: 18 W - fine lines of 50 µm width
laser (Rofin)		- Ablation of dielectrics - Large area Ablation for ZEBRA	- Nd:YAG laser with SHG module for 532 nm - dual rotary table for fast processing - 156x156 mm² wafer - frequency: 6-50 kHz - pulse width: 120 ns @ 10 kHz - power: 200 W - rectangular spot with 300x600 µm - 8-point automatic wafer alignment
laser (Rofin)		- cutting (without aperture) - damage free dot or line opening on dielectric layers - Alignment on existing structures by camera	- PHAROS (Lightconversion) femtosecond laser - directly diode-pumped Yb:KGW - wave length: 343, 514 and 1028 nm - pulse repetition rate: 250 fs up to 10 ps - power: 6 W - High accuracy due to moving table - Camera alignment
RTP oven		- Thermal processing for single solar cells - In-situ measurement of temperature and resistance (developed at ISC Konstanz)	- up to 156x156 mm² wafers - up to 1000°C - heating with 75 K/s - cooling with up to 100 K/s (>700 °C) - Gas inlet for forming gas, N2, O2, air - water cooled - custom software for data collection available
Software (Fraunhofer ISE)		- Simulation of CTM losses in PV modules	- Simulates both optical and electrical losses - Apsorption losses by materials in module stack - Reflections at interfaces in layer stack and from busbars etc - Electrical losses in busbars, interconnects, cabling, junction box - Custom material data input possible

Equipment	Picture	Application	Properties
stringer (Teamtechnik)		Interconnection of solar cell to cell strings	- automatic, semiautomatic and manual IR soldering of ribbons to cell busbars - semiautomatic and manual curing of ECA glued ribbons to cell busbars - processing of full and half cells in automatic mode with 4 or 5 busbars per polarity - processing of cell wafer dimmension M2 (156.75 x 156.75mm) and G1 (158.75 x 158.75mm) - max. number of cells per string: full cells = 12/ half cells = 24 - min. number of cells per string: full cells = 1 / half cells = 1 - automatic processing of cell connectors with 1,0 mm and 1,5 mm width
PTP printer (Utilight)		Finger metallization	Laser deposition roll to roll principal up to 2000 Wafers/h optical allignment with 8 cameras for edge & fiducial alignment Format: M0 - M2 Power: 200-700 W Fingerwidth: <25 µm (after firing)
UV-Chamber (PI-Berlin)		For: - 1x 60 cell module - 4x 4 cell mini-modules - 24x 1 cell mini-modules	- IEC-Norm 61215 / IEC-Norm 61646 - Test Area 1x2 m (with 15 % inhomogeneity, 100-150 W/m²) - UVB 280-320 nm (4,5 % UVB) - UVA 320-385 nm - Irradiation values can be determined - large modules can be energized to the Maximum Power Point (MPP)
PECVD furnace (Von Ardenne)		- a-Si n-doped - a-Si undoped (- a-Si p-doped)	- prototype system - wafer format: M2 (156,75x156,75mm), 8 wafer per deposition - single layer poly-Si deposition - Gases: N2, SiH4, SiH4/PH3, H2, Ar, SiH4/B2H6, N2O, NH3, NF3, CO2
3D-Printer (CreatBot)		CreatBot PEEK-300	- Build Volume 300*300*400mm - Print Resolution 0.04mm-0.4mm - Filament Diameter 1.75mm - Dual Extruder - Print Speed 10-150mm/s - Nozzle Diameter 0.4mm (0.3~1.0mm optional) - Filament Compatibility Engineering Plastics: PLA, TPU, PC, ABS, PA6, PETG, PVDF, TPU - High temperature Material: PPSU, PEI (ULTEM), PA12, PSU, PPS, PA-CF, POM, PP - Ultra-performance material: Medical grade PEEK, PEEK, PEKK, CF-PEEK (Carbon fiber), GF-PEEK (glass fiber), etc.
portable multigas FTIR gas analyser (Protea atmosFIRt)		for emission monitoring	Detectable emission gases and calibration ranges: - HF, NO2, NO, SiF4, O3 (0-200 ppm) - SO2 (0-100 ppm) - N2O (0-50 ppm) - H2O (0-11 %vol)