# Electrical Characterization

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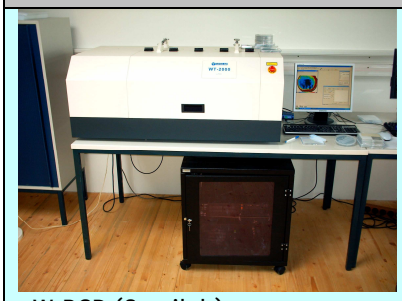
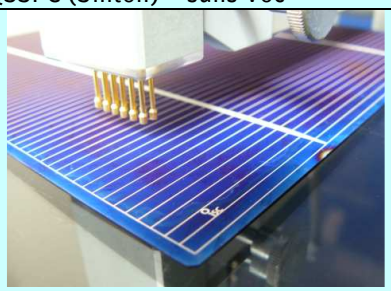
|  <br>µW-PCD (Semilab) | - spatially resolved minority charge carrier lifetime | - wafer size up to 210 x 210 $mm^2$<br>- as-cut measurement of bricks<br>- high resolution lifetime maps (62.5 µm)<br>- SHR (sheet resistance mapping)<br>- LBIC (current, IQE mapping)<br>- Eddy current resistivity mapping of wafers and bricks |
| <br>PV2000 (Semilab) | -diffusion length mapping via surface photo voltage method<br>-Fe concentration and B-O distribution mapping using internal accelerated-LID chuck<br>-QSS-uPCD for minority charge carrier lifetime mapping @ defined injection levels<br>-corona charging for evaluation of passivating layers | -fully automated measurement of up to 100 wafers/cells<br>-measurement of wafers at various production stages<br>- |
| <br>QSSPC (Sinton) + suns Voc | - injection level resolved minority charge carrier lifetime<br>- illumination-dependent Voc measurements<br>- contactless resistivity measurement | - fast lifetime measurements<br>- Voc for metalized and non-front-side-metalized cells<br>- Voc for a broad range of illumination |
|  <br>4-point tester (GP-solar) | measurement of:<br>- wafer resistivity<br>- sheet-resistance<br>- line resistance<br>- contact resistance | - exchangeable measuring-heads<br>- measurement of wafer, half processed cell and cell properties<br>- contact resistance for finger spacing of about 2,6mm |
| <br>ECV (Accent) | - measurement of carrier density depth profile | - measurement time:<br>about 2 hours for standard emitter<br>up to 10 hours for Al-BSF<br>- two measuring spot sizes: 0.9 / 3.4 mm<br>- depth resolution down to 5nm<br>- precise measurement on polished surfaces only! |
| <br>Corre-Scan | - spatially resolved losses / contact resistance / voltage | - Core Scan<br>Series resistance detection of short circuited cell by potential difference measurement while local illumination<br>- Shunt Scan<br>Applying a bias across the cell without illumination<br>- Voc Scan<br>Potential probe is illuminated under open circuit condition without front contact<br>- LIBC Scan |

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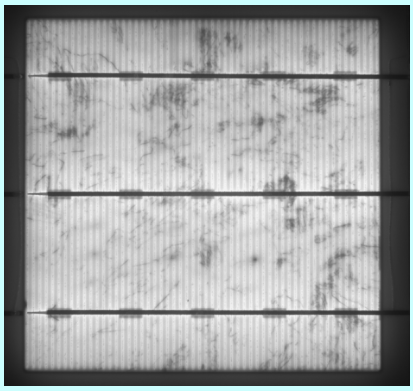
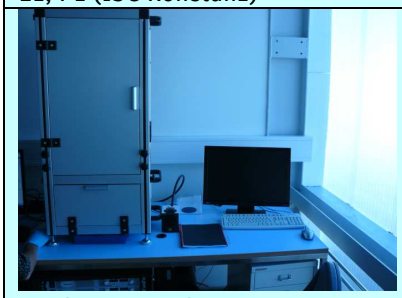
| <br>degradation stand (ISC Konstanz) | - degradation of cells and wafers | – degradation of up to 24 solar cells or wafers<br>– illumination at ca. 1 sun and temperature of about 50°C |
| <br>LID measuring syst. (ISC Konstanz) | – LID with temperatures between 10 and 220°C<br>– Annealing<br>– Regeneration<br>– Measure $V_{oc}(T)$ dependence<br>– illumination with up to 1 sun<br>– Handling of up to four cells | – Degradation, annealing and regeneration for up to four cells<br>– In situ measurement of VOC, temperatures and light intensity<br>– Very precise measurements<br>– recipe control for automized experiments<br>– Data logged in Excel compatible format |
| <br>module measuring syst. (ISC Konstanz) | - outside testing field for 16 modules | - outside IV-measurements for 16 modules<br>- measurement every 10 minutes<br>- light intensity measurement with pyranometer<br>- temperature tracking with thermocouple |
| <br>  <br>EL, PL (ISC Konstanz) | - imaging of recombination in as-textured wafers<br>- analysis of gettering/hydrogenation in mc-Si material<br>- imaging of surface recombination<br>- series resistance imaging, particularly useful for firing optimization/paste evaluation<br>- shunt imaging<br>- detection of processing induced issues like tweezers marks, finger prints etc<br>- detection of cracks during module fabrication | - non-destructive characterization of solar cells in all process-stages<br>- very fast measurement, ca 10 seconds per image |
|  <br>IR-Thermography | - spatially resolved shunt detection | - measurement of spatial resolved temperature distribution with IR camera<br>- localisation of shunts<br>- VOMO Lit or LIMO Lit measurements possible |
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# Optical Characterization

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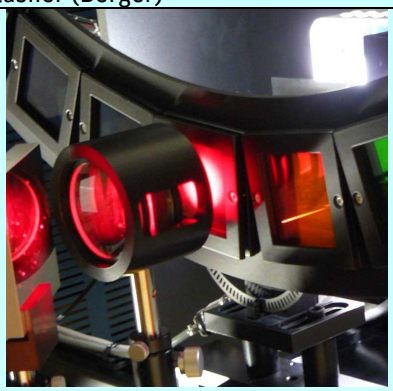
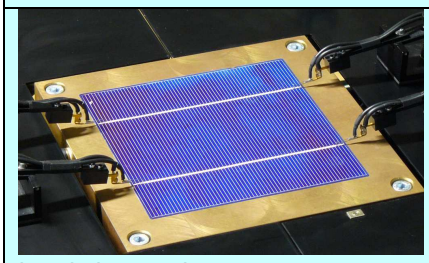
| <br>sun simulator (ISC Konstanz) | - measurement of IV-characteristics | - illuminated and dark IV-measurement<br>- format: 50 x 50 $mm^2$ to 210 x 210 $mm^2$<br>- chuck temperature 0°C to 80°C<br>- Xenon lamp, AM 1,5G (700 to 1200 $W/m^2$) |
| <br>flasher (Berger) | - Illuminated and dark IV measurement at RT<br>- Suitable for bifacial cells<br>- Suitable for mini-modules<br>- Reconfigurable depending on busbar positions | - Lamp AM 1.5G (0.2 – 1 Suns)<br>- Flash pulse 18 ms<br>- Cell load & measurement time < 30 s<br>- Temperature and irradiance corrections<br>- Built-in module for cell parameters extraction (series and shunt resistances, power) |
|  <br>spectral response (ISC Konstanz) | - Measurement of EQE and Reflectance to calculate IQE<br>- Illuminated and dark IV characteristics<br>- Weak light performance and linearity tests<br>- Temperature coefficients | - Fast and full area determination of Quantum Efficiencies<br>- Sample sizes ranging from 10 x 10 $mm^2$ up to 210 x 210 $mm^2$<br>- Filter-Monochromator with 29 interference filters and 10 - 15 nm FWHM<br>- Class AAA Sun Simulator for bias illumination and IV curve determination with variable intensity between 0 and 1,2 Suns<br>- Spatial homogeneity of spectral as well as bias illumination within ± 2%<br>- Temperature controlled Brass probe holder (10°C - 200°C) with different available coatings (e.g. black, conductive) and vacuum sucking<br>- Possibility to measure under up to 500x concentrated sun light<br>- Adaption of Sun Simulator to other spectral distributions possible (eg. AM0, AM1, AM1.5 Direct, AM2 |
|  <br>break down voltage set-up | - Measurement of reverse characteristics of Solar Cells<br>- Determination of temperature coefficients for different breakdown mechanisms | - Determination of Current - Voltage Curves with 4 - quadrant power supply between ± 50 V and ± 16 A<br>- Temperature range 10°C - 200°C<br>- Extraction of Breakdown Voltage<br>- Various fitting possibilities |
| <br>spectroscopic ellipsometer | - Optical and dielectric layer properties (thickness, refractive index)<br>- 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 | - UV-Vis wavelength range (280-920 nm)<br>- default wavelength window: □□□□300 – 850nm<br>- standard sample size few mm < □ < 20cm<br><br>- fast measurement (< 1 min)<br>- thickness measurement down to 0.5 nm<br>- double-layer evaluation<br>- large number of fitting models available Development or adaption of fitting models |

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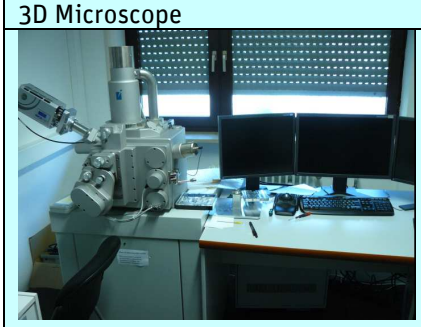
| | changes are measured by an ellipsometer and interpreted on the basis of model calculations. The change in the state of polarization is the direct consequence of the interference within the layer system, that is captured by the so called ellipsometric angles □ and □ and results by modelling for example in optical n(□), k(□) and dielectric properties expressed by $□_1$, $□_2$. | to layer structures and internal materials structure and morphology (e. g. heterogeneous material structure) possible<br>- measurements of flat, polished and also on textured surfaces of mono- and multi-crystalline samples (e.g. random pyramids, iso-texture) |
| <br>spectral photometer | - 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 < □ < 15cm, but larger ones possible by adaption<br>Size of illuminated spot from 0.5cmx3cm down to 0.1cmx0.1cm<br>- wave length window: □=180nm – 3200nm<br>- adaption of measurement set-up and proceeding is straight forward possible<br>- Sample sizes ranging from 2cm in diameter up to the size of large modules<br>- X-Y table with scanning area of 200 x 200 mm² |
| <br>3D Microscope | - determination of width and height of screen printed finger-grid<br>- characterization of isotropic and anisotropic textures<br>- roughness analysis | - 5fold, 10fold, 20fold, 50fold and 100fold objective<br>- resolution down to 120nm (x/y-direction) and 10 nm (z-direction)<br>- slope detection capability up to 85°<br>- motor-driven<br>- programmable optical table |
|  <br>SEM and EDX | - surface morphology<br>- analysis of cross sections<br>- chemical analysis (EDX) | - acceleration voltage: 5-30kV<br>- resolution <1µm<br>- backscatter and secondary e- detector<br>- EDX<br>- BES, eutectic analysis |
| <br>optical microscopes | - 3D pictures of surface | - 3D fingers pictures (high and width) |
| FTIR<br>spectral Photometer<br>SIMS | Collaboration contract with IPE of University of Stuttgart | |