Solar Cell Calibration and Measurement Procedures at Fraunhofer ISE CalLab PV Cells

Fraunhofer ISE CalLab PV Cells has been accredited as a calibration lab with the "Deutsche Akkreditierungsstelle GmbH" DAkkS (Registration number: D-K-11140-01-00), according to ISO 17025 since 2008 (former DKD). The subjects of the accreditation are the measurements of spectral response curves and IV-curve parameters, for which approved measurement uncertainty calculations apply. Thus, calibration services are available for nearly all kinds of PV-devices; including wafer-based standard silicon solar cells in lab and industrial formats, as well as thin-film devices from various materials.

CalLab PV Cells continues to develop additional calibration experience, allowing for measurements which do not (yet) fall under the accreditation. These calibrations and measurements are performed with the same equipment and reference standards as accredited calibrations. If uncertainty margins can be given, calibrations on such devices are offered as a "Propriety calibration". A "Measurement report" is issued if no uncertainty margins can be stated for a measurement. This last case occurs due to specific properties of a measurement object, or if no spectral response measurement is done. Thus, the regular and most prominent service is the "Calibration of a PV device" described in section I. Sections II and III describe additional service offers. An overview of the respective procedures and documents issued is given in Fig. 1.

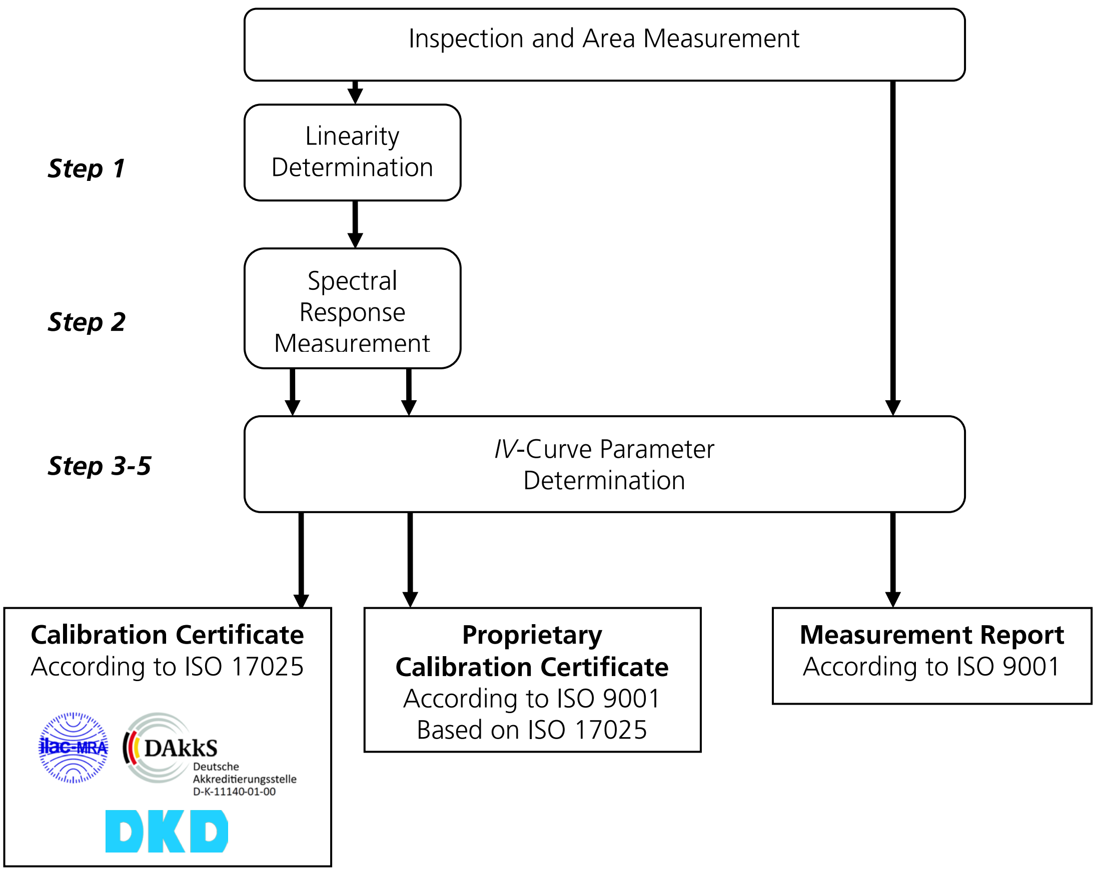

Figure 1: Calibration and measurement procedures

I) Calibration of a PV device

The calibrated measurements of the *IV*-curve parameters and the spectral response curves of solar cells constitute our standard services as an ISO 17025 accredited lab. Calibrations are performed under standard testing conditions (STC), as defined in the IEC 60904 series of standards. Consequently, calibrated measurements are only possible if the device fulfills all requirements which allow us to establish and control STC conditions (e.g. thermal contact, temperature control, possibility to measure current without shunt resistor). We do not do any tests to determine the temporal stability of a device, but regard it as the responsibility of the customer to select and/or precondition cells to be suitable as stable references.

For a calibrated measurement:

- The traceability to SI-units is established. This is realized by reference devices traceable to the PTB (Physikalisch-Technische Bundesanstalt), the NMI (National Metrological Institute) of Germany or to other accredited institutions.
- Measurement uncertainties of the solar cell parameters can be stated.
- A calibration certificate is issued.

Solar cells with calibration certificates may be used as references to, for example, establish traceability of production line output. The determination of the spectral response of a device is always necessary if a device is to be calibrated.

The calibration procedure is as follows:

Step 1: Determination of linearity of short circuit current
First, we must always determine the linearity of the short circuit current of the device with irradiation using the White-Light-Response (WLR) technique (see [1]).

Step 2: Measurement of spectral response curve (SR(λ))
In the second step, the results of *Step 1* allow us to set the constant bias irradiation intensity for the measurement of the Differential Spectral Response (DSR) (compare [2]) to the value which results in a DSR equivalent to the correct *SR(λ)* of the device under constant STC irradiation conditions. The *SR(λ)*-measurement is then done in respect to a primary calibrated reference cell.

Step 3: Determination of spectral mismatch factor and irradiance correction procedure
For the *IV*-curve measurement, a simulator with constant irradiation is used. The irradiation spectrum (Class A) is measured on a regular basis with a spectroradiometer, which is calibrated in house against a PTB-calibrated standard lamp. With the known *SR(λ)* (*Step 2*) and the measured simulator spectrum, we select a reference cell (*SR(λ)* and I_{SC}(STC) from PTB) for setting the simulator which leads to a minimal spectral mismatch. We set the simulator irradiance, with this cell to the level which represents an irradiance intensity of 1000W/m² for the test cell, with the calculated spectral mismatch factor. In addition, a correction of the difference in irradiation for the area covered by the small 2x2cm² reference cell compared to the one by the test cell is applied. This correction is calculated from a previous measurement of the lateral irradiation distribution on the measurement plane with 1 cm² resolution (inhomogeneity correction).

The IV-parameters are determined in a two-step procedure. Here we follow the principle that we wish to provide calibrated values for immediate use in industry with the highest reproducibility which we can achieve. Optimal use in industry necessitates the calibration of bare cells without soldered tabs. The use of contacting bars, as is the standard practice for cells with busbars in industry, is prone to introducing an additional uncertainty for the short circuit current due to shading and reflections. The extent of these influences depends on the precision of the necessary alignment to the busbars. These effects vary between different cells, labs and solar simulators. We have therefore decided to use a procedure which avoids the influence of the contacting bars, thus giving short circuit current values which include shading solely from the busbars on the cells. Additionally, we compensate with our contact unit for the serial resistance of the busbars; this leads us to a "busbar-free" measurement.

As we use a steady state (continuous) light source, we have to contact the cells thermally from the back side to keep the cell at 25°C. As a consequence, we contact the cell electrically at the full area from the back side. The rear voltage contact is situated in the center of the base plate. This configuration can result in a different *FF* than measurements which are made with a contact bar configuration on the back side which is the same as that which is used on the front side. For cells with H-pattern-like metallization (3 busbars) on the back side, the FF deviation may reach up to 1 %; whereas for cells with full area low resistivity metallization, the deviation may be minimized to 0%. Before any measurement is done, the cell is vacuum suctioned onto the gold-plated chuck surface, and the temperature under irradiation is set to (25.0±0.5)°C by controlling the temperature of the junction with a tactile temperature sensor from the front. Any fluctuations of the irradiation intensity during the measurement procedure are monitored and corrected automatically.

Step 4: Measurement of short circuit current

Under the irradiation intensity set in step 3, the short circuit current is first determined using Kelvin probes placed from the side onto the busbars with negligible shading. This contacting is sufficient for I_{SC} determination if the serial resistance is not to high and the shunt resistance is not to low [3].

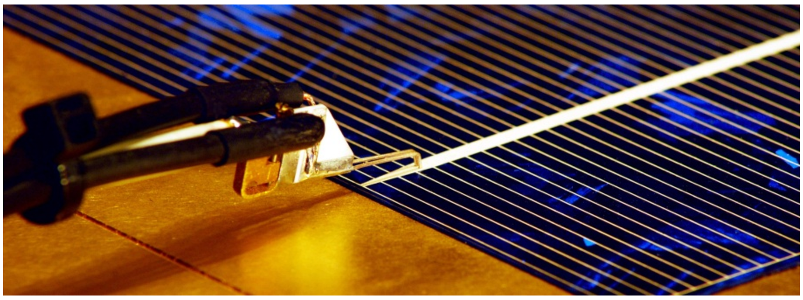

Figure 2: Kelvin probe contacting a busbar of a 6"-solar cell for I_{SC} determination (Step 4).

For solar cells with highly resistive busbar metallization (i.e. non-uniform/non-continuous busbars), additional current pins are used. The additional shadow produced with these pins is determined and corrected by re-adjustment of the irradiation intensity.

Step 5: IV-curve measurement.

Next the cell is contacted at the front with contacting bars suitable for an exact measurement of the complete IV-curve. For details see [3].

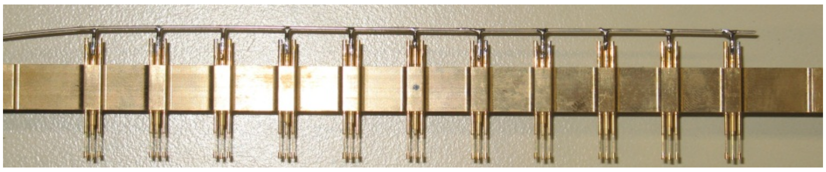

Figure 3: Contacting bar for front side contacting of a 6"-solar cell. This configuration is used for the *IV*-curve determination (Step 5). For solar cells with non-uniform/non-continuous busbars an adapted contact unit is used.

The irradiation intensity is re-adjusted in order to have the shading-free short circuit current, as determined in Step 4, flowing through the cell. Then, the *IV*-curve is measured.

Please note: The shadow free measurement is, in the present procedure, considered standard. For solar cells with interrupted busbars, this has the consequence that the cell to module loss increases

for reduced busbar metallization. This decreases the cell current by about 5%, decreases the V_{OC} by about 0.2% and increases the FF by about 0.1%.!!

II) Uncalibrated IV-curve measurement with spectral mismatch correction

By customer request, we also offer the option to have only *IV*-curves measured on cells which are selected by the customer as being very similar to other cells calibrated in parallel to these cells. For example, a customer may like to have a larger group of equivalent cells for quality control or internal comparison, without the costs of having them all calibrated. A typical recommendation is that these cells should be of the same batch and bin as the respective calibrated ones. This option is available for such cells in addition to a calibration according to the full procedures outlined in section I. The customer himself must insure that the spectral response of the additional cells is as similar as possible to that of the respective calibrated cell. Assuming a suitable selection by the customer, we will use the spectral response of the corresponding calibrated cell for the mismatch correction of those for which only *IV*-curves were measured. The customer must specify the calibrated cell from which the mismatch correction should be used.

The selection of the cells is entirely the responsibility of the customer, and should be part of the customer's quality management system. Since we have no control over the selection criteria and process, traceability according to ISO 17025 is not established. Therefore, we cannot give uncertainty margins and no calibration certificates can be issued for these cells. Instead, they receive measurement reports only. Thus, the additional cells, without indication of measurement uncertainties and certificates, are only for internal use for the customer, but of limited value in discussions within external relations.

III) Uncalibrated *IV*-curve measurement without spectral mismatch correction

On explicit request by a customer, we also do *IV*-measurements without spectral mismatch correction. Please note that the *IV*-parameters stated in the respective measurement reports can only be regarded as qualitative indications compared to a calibrated measurement according to section I. We strongly advise against any communication of the data except for internal use by the customer, since this data may be prone to misperception. We explicitly request for any statement given to the outside by the customer, to cite this data only as uncalibrated, qualitative result.

References:

1. J. Hohl-Ebinger, G. Siefer, and W. Warta, *Non-Linearity of Solar Cells in Spectral Response Measurements*. in *22th European Photovoltaic Solar Energy Conference and Exhibition*. 2007.
2. J. Metzdorf, *Calibration of Solar Cells. 1: The Differential Spectral Responsivity Method.* Applied Optics, 1987. **26**(9): p. 1701-1708.
3. J. Hohl-Ebinger, D. Grote, B. Hund, A. Mette, and W. Warta, *Contacting Bare Solar Cells for STC Measurements*. in *23rd EUPVSEC*. 2008. Valencia Spain.