DEVELOPMENT OF A LARGE AREA REFERENCE CELL BASED ON MODIFIED C-SI-MODULE TECHNOLOGY

Peter Schmitt, Thomas Schmidt, Marco Tranitz, Stefan Brachmann

Fraunhofer-Institute for Solar Energy Systems ISE, Heidenhofstr. 2, 79110 Freiburg, Germany
Corresponding author: Stefan.Brachmann@ise.fraunhofer.de

ABSTRACT: Reference cells are preferably used for the calibration of solar cells, solar modules, solar power plants and solar simulators [1]. Module calibration can take place indoor in measuring laboratories and production facilities, as well as outdoor at the site of the plant. So far, conventional reference cells usually contain small solar cells with dimensions of less than 50 mm x 50 mm. The state-of-the-art reference cell architecture does not necessarily match the cells and materials used in the respective modules. With these two restrictions considerable disadvantages are associated such as limited measurement accuracy and error susceptibility. The Large Area Reference Cell (LARC®)-concept allows the use of the same cell technology with similar module materials as the device under test (DUT) as well as a large active cell area of 156 mm x 156 mm. It thereby omits expensive and error-prone post-processing of measured data and improves the accuracy of the measurements

Keywords: Reference Cell, PV Module, Qualification and Testing

1 INTRODUCTION

The aim of the LARC® is to avoid the disadvantages of typical small-scale (50 mm x 50 mm) reference cells. These reference cells have a different design and also use different materials than standard c-Si PV-modules. This implies that by using an adapted reference solar cell with similar materials like a standard c-Si PV-module [2, 3], a matched spectral range, ideally the entire spectral response range can be measured.

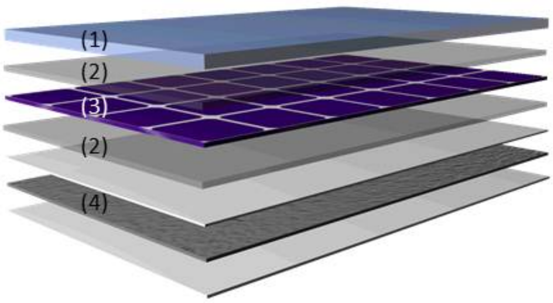

Figure 1: Construction build-up of a standard c-Si PV-module, with glass (1), encapsulant (2), cell matrix (3), encapsulant (2), backsheet composition (4).

Due to the use of similar or identical materials and active cell areas a determination of a correction factor for existing spatial inhomogeneity of the radiation intensity is omitted. Ideally, the spectral mismatch [4] between the LARC® reference cell and the solar cells and materials used in the module to be measured is minimized. Thereby expensive and error-prone corrections are omitted.

Figure 2: Picture of the LARC® consisting of a commercial available standard c-Si BSF-cell with dimensions of 156 mm x 156 mm. The picture shows the reference cell with glass, case and the connection box.

2 CONCEPT OF THE LARC®

Essential for the development of the LARC® is the development of an alternative rear side contact. In typical reference cells, this rear side contact usually is achieved by a full-surface contact between the rear side of the solar cell and the bearing plate. Due to this kind of thermal coupling, a homogeneous and also relatively low thermal resistance between the solar cell and the bearing plate is formed. However, for large-scale solar cells this type of contact is critical due to the CTE mismatch between silicon and the plate material. This can lead to cell damage due to thermo-mechanical stress. We have developed a special method of wiring in which the solar cell rear side is neither electrically nor thermally contacted with the bearing plate. Nevertheless, the solar cell is easily connected thermally to the measuring environment. With this technology, conventional standard silicon solar cells and module materials can be used in our LARC® structure. A frame including a junction box is designed to protect the solar cell and to ensure the connectivity, while the frame has also been optimized with respect to the beam path avoiding shading and reflection. LEMO® connectors are used due to their high reliability and their acceptance in this field [1]. Also a Pt100 temperature sensor (RTD) is thermally connected to the cells' rear side and included in the LARC® to guarantee a precise calibration. The temperature sensor is a class A Pt100 according to DIN EN 60751 [5]. The LARC® is designed for indoor and outdoor usage for reference purposes as well as an irradiance sensor.

The material used in the construction is identical to the material used in standard module technology. A customized use of materials is possible. In the regular LARC® we use a float glass on top with an Ethylen-Vinyl-Acetate (EVA) layer between glass and cell, as well as cell and backsheet. A standard TPT backsheet is usually used in the construction on the rear side, see Table I.

Table I: Materials used in a standard non-customized LARC®.

Material	Type	Thickness
Front glass	Float glass	4 mm
Encapsulant	EVA	460 µm
Backsheet	TPT	320 µm

On the cells' rear side a Pt100 temperature sensor in a four-point configuration is attached to the cell. The sensor is thermally connected to the cell with a special isolation layer to the power connection of the cell. We use a commercially available standard c-Si BSF-cell with the dimensions of 156 mm x 156 mm. The cell is also wired in a four-point configuration to avoid measurement errors due to a higher series resistance of the power connection. Here a system of different layers allows for an isolation of the power connection from emitter to base while the device is optimized in terms of minimal thickness and optimal thermal conductivity.

3 RESULTS

Due to the large active area (cell) a higher accuracy in calibration is possible. The developed case guarantees good protection and mounting of the cell, including a junction box with reliable connectors. This case is made of light-weight, black anodized aluminum. The frame of the case is designed to minimize influences due to beam reflection of the frame.

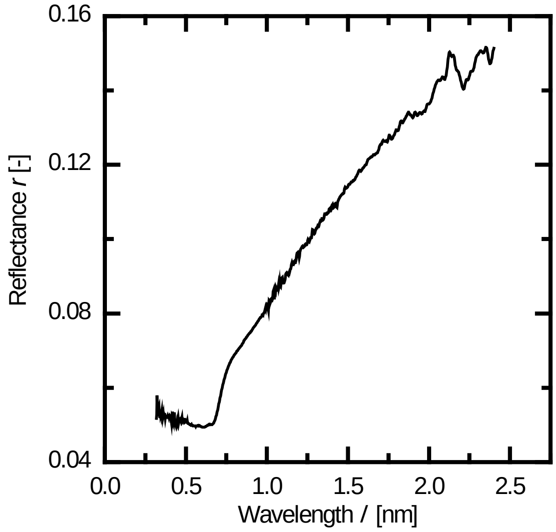

Figure 3: Reflection of the black anodized frame material used in our LARC®. The reflection is under 0.1 for the range from 300 nm to 1200 nm.

Figure 4 shows the external quantum efficiency and spectral response of the LARC® in the setup with a standard Al-BSF-cell. The measurements are according to the corresponding standards [6]. The curves are equal to standard c-Si PV Modules due to the materials used and therefore a determination of a correction factor for existing spatial inhomogeneity of the radiation intensity are omitted. Thus the Mismatch Factor [4] is nearly reduced to zero.

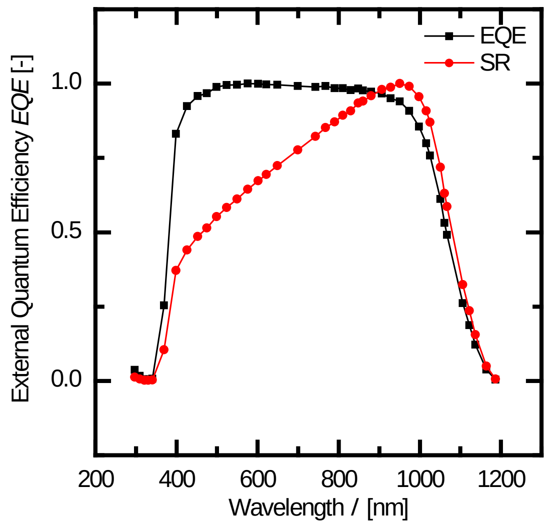

Figure 4: Relative values of the external quantum efficiency (EQE) and spectral response (SR) of the LARC® at different wavelengths.

We conducted a forward ray-tracing simulation, with a non-divergent ray light source to determine the sensitivity and the effect of shading and reflection depending of the angle due to the frame as well as the relative optical efficiency including the cosine losses.

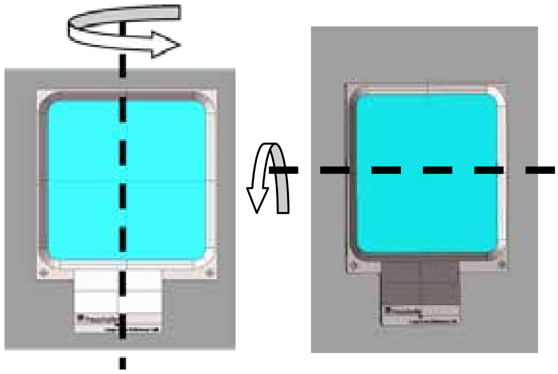

Figure 5: Rotation of the LARC® for the ray-tracing simulation. The rotation is shown around the y-axis (left) and the x-axis (right).

An analysis of the relative optical efficiency at different angles shows no noticeable reflection influences or shading by the black anodized aluminum frame of the case. The dominant effects on the optical efficiency are angle-dependent Fresnel reflection of the glass pane and the cosine losses, shown in figure 6.

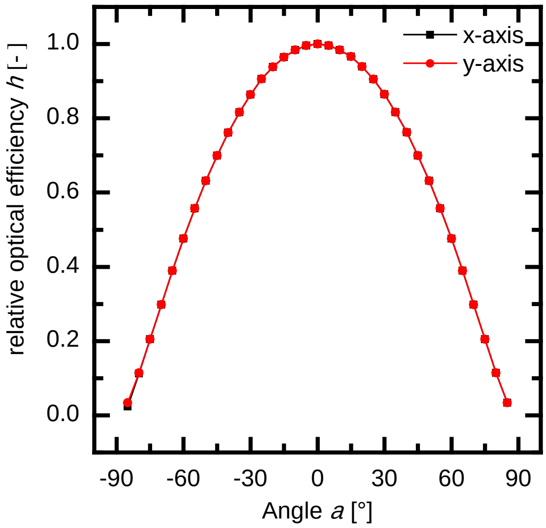

Figure 6: Ray-tracing results of the relative optical efficiency with cosine losses at different angles. The axis of rotation is shown in Figure 5. No noticeable reflection influences from the frame are visible.

Due to the small shading effect, the same simulation was performed without a case. The comparison of both simulations with and without the case is shown in figure 7. At an angle of 0° +/- 80° no shading effects exist. According to IEC 60904-2 [7] an incidence angle range of 160° in both X/Y axes' is allowed.

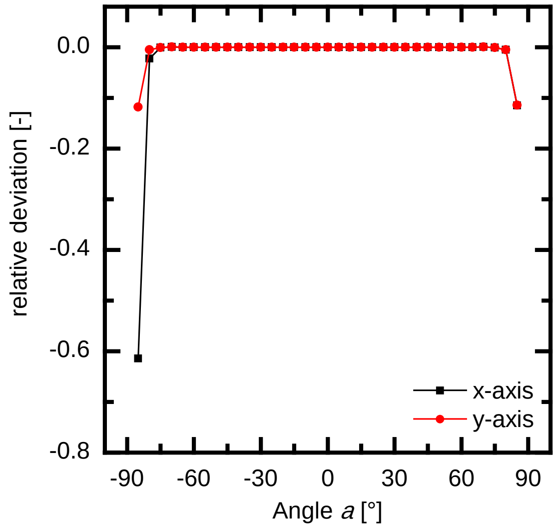

Figure 7: The relative deviation of a LARC® with and without a case shows the shading of the cell due to the frame at different angles rotating around the x- and y-axis.

IV-measurements [8] at irradiations from 100 W/m² to 1000 W/m² show a high linearity [9, 10] with R^2= 0.999 of the short-circuit current (I_{sc}) versus the irradiance.

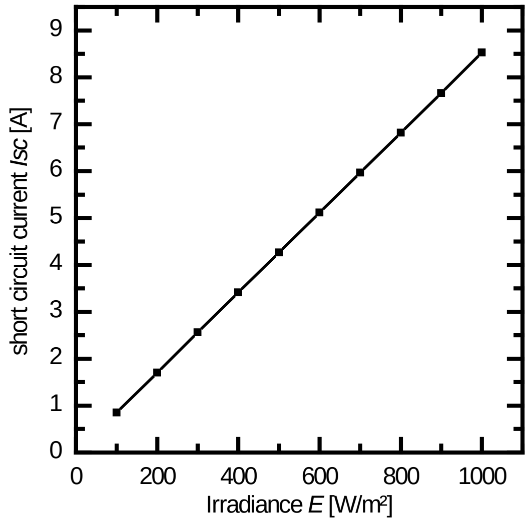

Figure 8: Results of the linearity measurements. The graph shows the short-circuit current (I_{sc}) versus the irradiance from 100 W/m² to 1000 W/m². A coefficient of determination R^2 of 0.999 is reached.

In Table II the values for the short current, the open circuit voltage and the fill factor including standard deviation and measurement uncertainty for the measured values are shown.

Table II: Test results at an Irradiation of 1000.3 W/m² at AM 1.5 global.

	I_{sc} [A]	V_{oc} [V]	FF [%]
Average	8.430	0.622	74.719
Standard deviation	0.002	0.000	0.010
Measurement uncertainty	±1.3%	±0.7%	±2.2%

4 CONCLUSIONS

In this work we present the results of our development of a large area reference cell based on modified c-Si-module technology. This advanced design allows a customized and flexible adjustment of the reference cell to the DUT and therefore omits expensive and error-prone corrections. Our LARC® reduces the spectral mismatch factor and the error resulting from the unequal surface sizes of the reference cell and the sample. Additionally errors caused by inhomogeneous solar simulators are reduced. This improves the accuracy of the measurements and requires less signal corrections. A durable case is engineered to protect the cell from environmental influences. In addition it acts as a mounting and provides a junction box. The case is also optimized to avoid case-induced reflections and shading of the active cell area. At an angle range exceeding +/- 80° no shading effects occur.

This technology with its customized and DUT associated adjustment leads to an improved accuracy of measurements. A patent is pending for this technology.

Comparison measurements of state-of-the-art reference cells versus the LARC® will be done as next steps.

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