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DESIGN AND REALIZATION OF A NEXT GENERATION HIGH ACCURACY PRIMARY CALIBRATION FACILITY FOR SOLAR CELLS AT PTB

S. Winter, T. Fey, I. Kröger, D. Friedrich, K. Ladner, B. Ortel, S. Pendsa, D. Schlüssel

Physikalisch-Technische Bundesanstalt PTB, Bundesallee 100, D-38116 Braunschweig, Germany
Tel.: +49 531 592 4140, Fax: +49 531 592 694140, Email: Stefan.Winter@ptb.de

Abstract: A completely newly designed multi-functional flexible facility for the primary calibration of reference solar cells and the spectral characterization of all solar cell types has been developed and built at PTB. The new facility is based on the successfully applied Differential Spectral Responsivity (DSR) method that allows the determination of the absolute spectral responsivity and nonlinearity of solar cells with the lowest uncertainties. By using a tunable laser system, the new setup avoids the main problem of monochromator-based systems: the low optical power level of the monochromatic beam. Thus it enables a significant reduction of the uncertainty for the short circuit current under standard test conditions I_{STC} of large solar cells.

Keywords: Traceability, Calibration, Tunable Laser, Spectral Responsivity, Solar Cells.

1. INTRODUCTION

Due to the high market volume of solar modules, an uncertainty of 1% in efficiency measurement causes an uncertainty of many 100 millions of Euro per year in the product value. Hence PTB has repeatedly been approached with the request of a lower measurement uncertainty, even though PTB - as a qualified World Photovoltaic Scale (WPVS) laboratory - already belongs to the institutes serving the lowest uncertainty for the primary calibration of reference solar cells worldwide while being traceable to the SI.

In this paper, we will present our realization of a new improved setup for the calibration of solar cells and detectors that meets the needs of industry for decreased uncertainty levels. Because a large number of calibration and testing labs worldwide are customers of PTB, a large proportion of the complete PV community will benefit from these improvements, as the starting point of their PV calibration chain is PTB.

2. APPROACH

A completely new facility for the primary calibration of reference solar cells has been designed and built up at PTB. The new facility bases on the successful Differential Spectral Responsivity method that allows the determination of the absolute spectral responsivity and nonlinearity of the solar cell with lowest uncertainties [1]. By using a tunable laser (see Fig. 1), the new setup avoids the main problem of the old lamp-based system: the low optical power of the monochromatic beam. The higher power of the new setup allows is going to solve the subsequent problems of low monochromatic power like: a bad signal-to-noise ratio for large solar cells at high bias radiation levels, the difficulty to reach a good uniformity, the high bandwidth of the monochromatic beam and the interpolation error when merging absolute and relative measurements.

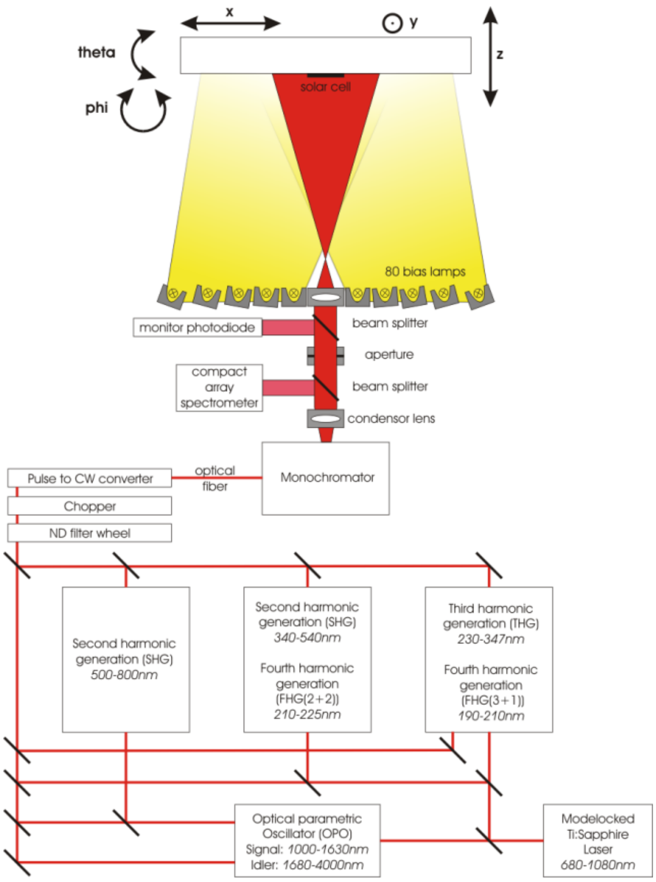

Fig. 1: Schematic diagram of the new Laser-DSR facility. In the lower half the laser setup is shown (see Fig. 3). The beam passes a chopper before it hits an optical fiber (pulse-to-cw converter). The fiber ends at the entrance slit of the monochromator. There the spectral band width of the laser is reduced (s. Fig. 7). The exit optic homogenizes the modulated monochromatic radiation field on the solar cell. To get the same operating point as under natural sun light the solar cells are irradiated by a sun simulator (80 bias lamps).

3. SETUP

The principle of the new setup is identical to the old setup in many ways: A chopped uniform monochromatic beam and sun-like bias lamps irradiate the solar cell under test. The signal of the chopped beam is measured with a lock-in amplifier and is used to determine the absolute spectral responsivity and therewith the current under standard test conditions. The main difference of the new setup is the source of the monochromatic light. Instead of a quartz halogen lamp or a xenon lamp, the new setup uses a tunable laser that is coupled into the monochromator via a quartz fiber (see Fig. 1 and Fig. 2). The laser beam starts at a hands-free widely tunable modelocked Ti:Sapphire laser (Chameleon Ultra II) with a repetition rate of 80 MHz. The pulse duration is about 120 fs. Depending on the wavelength needed, the beam passes an optical parametric oscillator (OPO) and/or a second, third or fourth harmonic generator (SHG, THG, FHG; see Fig. 1 and Fig. 3). Most of the laser components are purpose-built items that have a wider wavelength range, a higher efficiency or are better automated than the actual standard components. The beam routing is done by computer controlled mirror mounts. This enables an automated wavelength selection from 210 nm up to 4000 nm (without automation even from 190 nm).

Before the laser beam is coupled into a fiber it passes through a neutral density filter wheel and a chopper. A monochromator reduces the spectral band width and two lenses create a uniform monochromatic irradiation at the measuring plane. Up to 80 individually switchable bias lamps create a uniform bias irradiation of up to 10.000 W/m². The measurement plane can be tilted from 0° to 90° and rotated from 0° to 360° (see Fig. 5). Thus it can be used as a solar cell goniometer to irradiate the solar cell from any direction to measure a spectrally resolved angular dependence. The temperature of the solar cells is controlled by the combination of water cooling and peltier elements.

Two beam splitters reflect each a small part of the monochromatic radiation behind the monochromator: the first one to a stable high-end array spectroradiometer and the second one to a monitor photodiode. This enables the simultaneous measurement of the centre wavelength between 220 nm and 1600 nm and the irradiance level. The uncertainty of the wavelength measurement is 0.4 nm.

While the peak power of the fs pulses within the laser system must be as high as possible to enable a wide wavelength range with the help of nonlinear effects, for the calibration itself constant radiation power it is necessary to enable quantitative and reproducible results that are not biased by nonlinear saturation effects of the detector. This challenge is solved by a special patent pending fiber design that smoothes the pulsed signal to a cw-like signal (pulse-to-cw converter, see Fig. 4): The beam within the fiber bundle is divided into 100 paths with different lengths respectively. Instead of one large pulse 100 small pulses exit the pulse-to-cw-converter equally distributed during the cycle duration of 12.5 ns. Hence the repetition rate is increased from 80 MHz to 8 GHz. Because in addition each of the 100 pulses is widened within the fiber and the following path through the monochromator the signal at the exit is a cw signal. More details and linearity measurements with and without the use of the pulse-to-cw-converter can be found in Ref. [2].

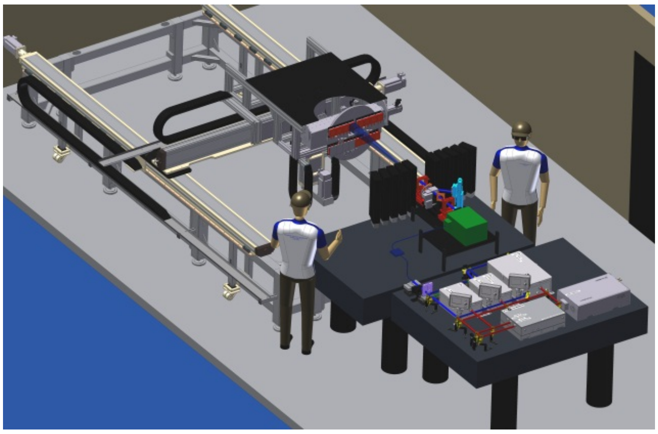

Fig. 2: CAD-drawing of the new DSR facility showing the three major parts of the setup: On the lower right corner the laser setup is shown (see also Fig. 3). The monochromator (green) based optics as well as the bias lamps are located on the second table. The solar cells are mounted on the large x-y-z-table including the goniometer (see Fig. 5).

Fig. 3: Photo of the complete laser setup with the beam routed through the SHG (400nm). All beam paths are aligned to be coupled into the optical fiber (not shown here). During a measurement the laser setup is completely enclosed.

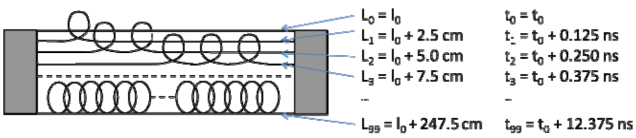

Fig. 4: Schematic diagram of the pulse-to-cw converter: A fiber bundle with 100 multimode fibers, each with an individual length.

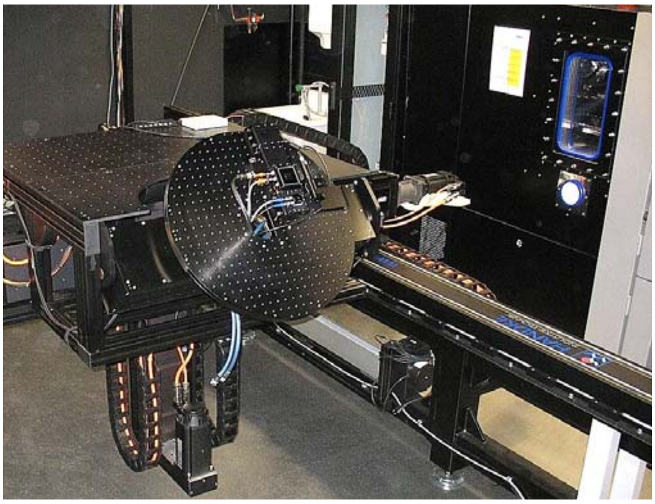

Fig. 5: On the left-hand side the integrated solar cell goniometer can be seen. The quartz glass entrance window of the climate chamber is located in the top right corner of the image. A mirror (not shown here) on the xyz-table will reflect the monochromatic and the bias beam to a solar cell inside the climate chamber.

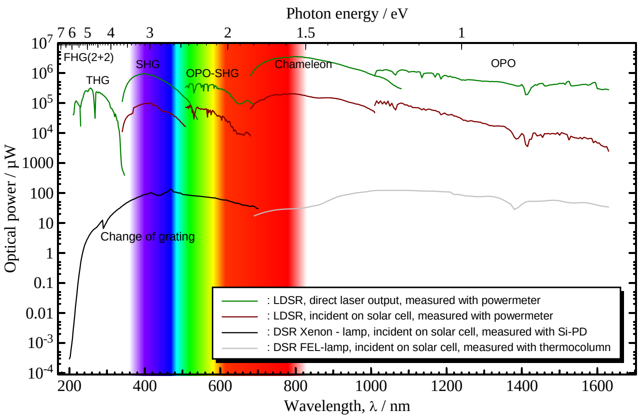

Fig. 6: Optical power in dependence of the wavelength of the laser-based DSR setup and of the traditional lamp-based DSR setup. Both measurements were made behind the monochromator and the lenses. Additional the direct output power of the laser is shown.

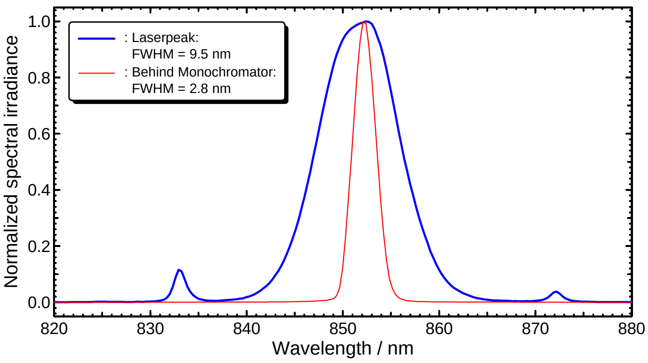

Fig. 7: Spectral irradiance of the fs laser in front of and behind the monochromator.

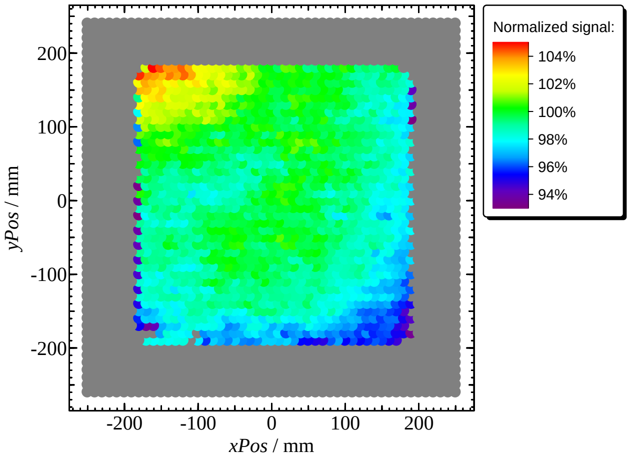

Fig. 8: Uniformity of the monochromatic radiation field. Within a 250 x 250 mm² field the inhomogeneity is better than 2% and within a selected 20 x 20 mm² field only 0.4%.

4. RESULTS

After setting up the facility it was characterized in more detail. Power measurements were performed with the laser system in dependence of the wavelength. The results are shown in Fig. 6. The maximal power of about 3800 mW is obtained at 800 nm. Behind the monochromator still more than 100 mW of optical power is obtained at 800 nm. The old lamp-based system produces a maximum power of about 100 µW under the same bandwidth conditions, thus the increase of the optical power behind the monochromator is a wavelength depend factor between 100 and 10.000. As the signal of the solar cell does not need to be 1000 times higher in comparison to the old setup, the additional power is used to improve the uniformity of the monochromatic field (see Fig. 8), to increase the distance of the solar cell from the effective origin of the radiation and to decrease the spectral bandwidth of the radiation.

The spectrum of the laser radiation at one wavelength is shown in Fig. 7. The need of a monochromator is quite evident, because the spectrum of the pulsed laser has

a) a too high spectral bandwidth,
b) outer-band peaks, and
c) a small part of the SHG signal in the THG signal.

Thus a monochromator is needed to obtain a well-defined wavelength.

First Laser-DSR measurements show within the uncertainty the same results as obtained with the old facility.

5. CONCLUSION

By the use of a tunable laser, the irradiance increased by a factor of 100 to 10.000 compared to the monochromator-based facility. With the shown realization of this flexible new concept of a laser-based solar cell calibration setup, PTB meets the needs of the PV industry concerning a significant reduction of measurement uncertainties and the extension of the measurement capabilities to new types of reference solar cells. The results of some characterizations and of the first calibrations are shown. The end of the complete validation and the start of the regular calibrations are expected for the end of 2012. In addition the facility will enable precise characterizations of solar cells, due to the possibility of measuring the spectral responsivity of 156 x 156 mm² large solar cells between -70 °C and +180 °C and at any incident angular of the radiation by the inclusion of a climate chamber or a solar cell goniometer at the end of the optical path.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] S. Winter, T. Wittchen, J. Metzdorf: "Primary Reference Cell Calibration at the PTB Based on an Improved DSR Facility"; in "Proc. 16th European Photovoltaic Solar Energy Conf.", ed. by H. Scherr, B. Mc/Velis, E. Palz, H. A. Ossenbrink, E. Dunlop, P. Helm (Glasgow 2000) James & James (Science Publ., London), 4 p., ISBN 1 902916 19 0

[2] T. Fey, I. Kröger, S. Winter: "Nonlinearity effects of detectors due to pulsed radiation"; in "Proc. 27th European Photovoltaic Solar Energy Conf.", (Frankfurt 2012), submitted