FRONT GLASSING INFLUENCE ON THE PRIMARY CALIBRATION OF WPVS REFERENCE SOLAR CELLS

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ABSTRACT: To primarily calibrate WPVS reference solar cells with lowest uncertainties it is necessary to determine the influence of each measurement parameter in detail. One of these parameters is the absolute spectral irradiance on the measurement plane. In this work we show that a magnification effect during photo current measurements with divergent light sources on WPVS solar cells lead to an offset of the measurement plane for cells with a covering front glass. Next to its physical background two methods are presented to determine this virtual mounting depth. The found experimental results show an offset of 1.4 mm, in correspondence to the theoretical predicted value.
Keywords: Calibration, Reference Cell, Qualification and Testing.

1 INTRODUCTION

For photo current calibrations of world photovoltaic reference solar cells (WPVS cells) differential spectral responsivity (DSR) measurements offer the advantage of low measurement uncertainties below 0.5% [1]. In this uncertainty regime effects become apparent which under normal measurement conditions are not obvious but nevertheless can lead to significant measurement errors. During DSR measurements wavelength dependent photo currents are measured via lock-in technique. These currents are induced by a modulated monochromatic light source while the sample is illuminated by constant DC bias light to determine non-linearity effects [2]. Due to the r^{-2} dependence of the irradiance (r corresponds to distance to a perfect light point source) it is necessary to exactly determine the position of the device under test (DUT) within the WPVS housing. During calibrations of WPVS cells with standard HOQ fused silica front windows against primary calibrated photo diodes at different distances to the light source it is observed that the estimated position from data evaluation deviate by over 1 mm from the data sheet value. At typical measurement distances of about 500 mm this deviation leads to an unintended increase in photo current of about 0.4%, an effect in the scale of the whole extended measurement uncertainty budget of the experiment. WPVS cells without front glass do not show this effect. During the last years this effect was phenomenally corrected in PTB’s primary calibrations. After first geometrical considerations to explain the effect (sect. 2) an experimental study (sect. 3) is performed to determine the exact influence of the front glass when measurements with divergent light sources were performed. In sect. 4 an alternate measurement method is presented which is used to determine the virtual mounting depth (thickness) of WPVS solar cells, followed by sect. 5, the conclusion.

2 GEOMETRICAL CONSIDERATIONS

In figure 1 the light path scheme from a divergent light source in a WPVS solar cell is shown. The front glass leads to a diffracted light path for the outermost beams so that more light reaches the solar cell surface as it would be expected with parallel light. Effectively this virtual mounting position of the solar cell inside the front glass can be described by determining the intersection of the prolongation of the outermost rays (without diffraction) which reach the solar cell and the perpendicular prolongation of the border of the solar cell. This mounting position, i.e. offset, depends on the diffractive index of the glass as well as on the glasses thickness.

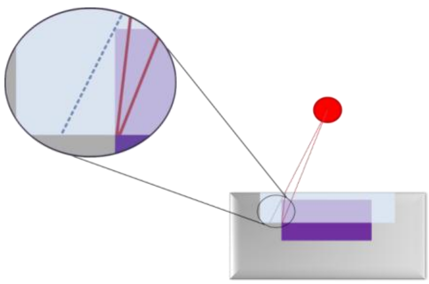

Figure 1: Light path from a close divergent light source in front of a WPVS cell. Red: light source, Grey: housing, light blue: fused silica front glass, violet: solar cell. Red lines: real light path, dotted blue line virtual light path, light violet: virtual position of solar cell.

For small angles the following approximation can be found from figure 2.

$$j = d \cdot \frac{s}{2(d + n \cdot l)}$$

with d thickness of fused silica, s edge length of solar cell, n diffractive index of fused silica and l distance from light source to glass surface.

Geometrically also the following is determined:

$$z_{\mathrm{off}} = \frac{s}{2} \cdot \left(\frac{\frac{s}{2} - j}{l}\right)^{-1} + l + d$$

With z_{off} corresponding to the previously described virtual offset.

With values taken from real calibrations (s=20 mm, l=500 mm d= 4mm and n=1.47) j becomes 0.054 mm, leading to an offset of z_{off}=1.28 mm, a value which lies in the same range as expected from the calibration measurements.

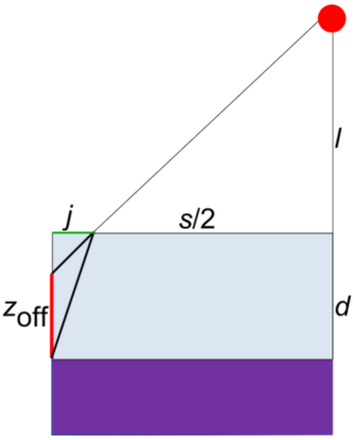

Figure 2: Geometrical drawing to determine the relation between virtual offset z_{off}, solar cell edge length *s*, glass thickness *d* and light source distance *l*. Red: light source, light blue: front glass, violet: solar cell.

3 EXPERIMENTAL APPROACH

To find an experimental value for the virtual mounting depth z_{off}, distance dependent photo current measurements were performed. Here the virtual offset between two similar WPVS cells, one with (DUT) and one without front glass (Reference) was determined. Samples were mounted on PTB's new Laser-DSR setup [3] and equally adjusted to the laser light source. At varying distances between samples and light source the AC photo current was measured via lock in technique (I_{DUT}, I_{Ref}) and corrected by a monitor signal from a photo diode coupled to the lighting system via beam splitter. The monochromatic light source was set to 400 nm wavelength during the whole experiment. At all distances a constant DC photo current was generated by bias lamps to reduce the influence of non-linarities of the photo current under different irradiance levels. From the fundamental radiometric law the following distance dependence of the photo current is expected:

$$I_{DUT} = \frac{k_1}{z_{DUT}^2};\ I_{Ref} = \frac{k_2}{z_{Ref}^2}$$

With $z_{Ref,DUT}$ the distance between light source and respective solar cell and $k_{1,2}$ a sample dependent proportionality factor.

Figure 3 shows distance dependent AC-photo currents for both devices with the expected z^{-2} decay.

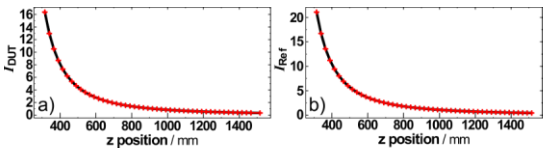

Figure 3: Distance decaying photo currents of samples. a) device under test with front glass, b) reference cell without front glass.

To evaluate the virtual offset due to the front glass a variable position offset z_{off} is added to z_{DUT}.

$$I_{DUT} = \frac{k_1}{(z_{DUT} + z_{Ref})^2}$$

When the virtual position of the DUT corresponds to the real position of $z_{Ref,}$ or

$$z_{DUT} + z_{Ref} = z_{Ref}$$

it follows:

$$\frac{I_{Ref}}{I_{DUT}} = \frac{k_2}{k_1} = \text{const}$$

In this case the quotient I_{Ref}/I_{DUT} becomes constant for all z positions. In figure 4 the z dependence of I_{Ref}/I_{DUT} with an offset of +-8 mm is shown to indicate how this quotient varies between two offset extremes.

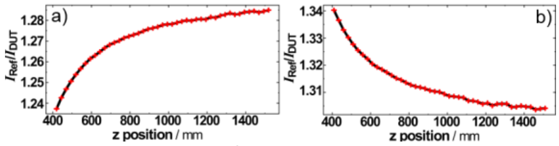

Figure 4: Quotient of I_{Ref} and I_{DUT} with a constant z offset of +8mm (a) and -8mm (b) plotted over the z position to demonstrate its asymptotic decay.

In fig 5 a) I_{Ref}/I_{DUT} with a z_{off} of 1.6 mm is shown. As discussed above for the case of a correctly chosen offset the quotient I_{Ref}/I_{DUT} becomes independent of the distance to the light source. As criteria for an analytical evaluation in figure 5 b) the average derivative of the quotient I_{Ref}/I_{DUT} over a varied z_{off} is shown. The intersection with the x-axis provides z_{off}=1.4 mm. This shows that in experiments with close light sources a device housing depth of 14.2 mm instead of 12.8 mm (geometrical position, stated in data sheet) has to be taken into account.

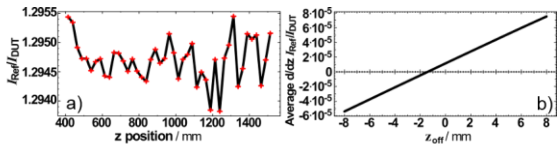

Figure 5: a) Quotient of I_{REF} and I_{DUT} with a constant offset of 1.6 mm plotted over z position, b) average derivative of I_{REF}/I_{DUT} to determine virtual offset mathematically z_{off}=1.4 mm.

To demonstrate the necessity of the AC methodology demonstrated above figure 6 shows the result from a distance dependent DC photo current measurement of the same samples to a standard halogen 1000 W light source. Due to the large infrared spectral part non-linearities become a dominant measurement influence so that no z_{off} with constant I_{Ref}/I_{DUT} could be found. The average derivative determines an unlikely value of 4 mm for the offset positions.

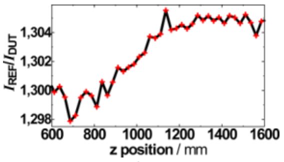

Figure 6: : a) Quotient of DC measured I_{REF} and I_{DUT} photo currents to a 1000 W normal light source with a constant offset of 4 mm (offset that produces the most constant quotient). Reason for this is the non-linearity of the solar cell.

4 ALTERNATVE METHODOLOGY

A commercially available confocal distance and thickness measurement device can be used to determine the virtual housing depth as well (Micro-Epsilon, ConfocalDT 2451).

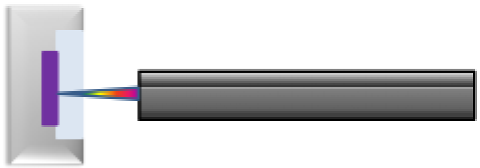

Figure 7: Scheme of the measurement principle of the confocal probe head on a WPVS cell. The wavelength of the light which is focused to the surface and reflected depends on the distance to the probe head. Its position is calculated from the spectral measurement of the surface reflectance.

In fig 7 the working principle is described. Light from a white LED is projected through a probe head onto a WPVS sample. The focus of each wavelength varies hereby with the distance to the probe head. Reflected light from the sample is passing the same probe head and is then measured by a connected array spectroradiometer. Due to the position dependence of the detected peak wavelength the absolute position of reflecting surfaces can be calculated. From multiple reflections from transparent samples the thicknesses of these objects in dependence of their refractive index n_{sample} is determined. If the correct value for n_{sample} is known, the exact geometrical position of the DUT could be determined. Since we are interested in the DUT's virtual position we assume that n_{sample} =1. With this assumption a similar result as in section 3 is obtained. This is shown in fig 8 where the results with spatial resolution of a confocal measurement on a WPVS cell with front window are shown.

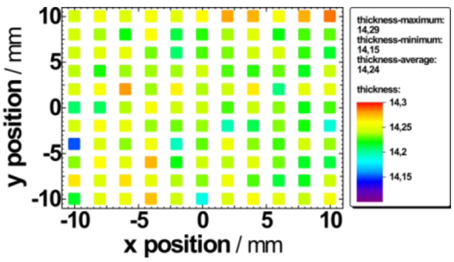

Figure 8: Spatial measurement of the effective mounting depth of a WPVS cell with the described confocal device.

The average device housing depth shows in this configuration again 14.2 mm.

5 CONCLUSION

In this work we showed that in measurements with close divergent light sources and WPVS solar cells a magnification effect due to the cells front glass shows a significant increase of the photocurrent (at 500 mm distance to the light source the irradiance 1 mm closer to the light source is 0.4 % higher leading to a measurement error in this order of magnitude). Further it was shown that distance dependent photo current measurements as well as measurements with a confocal probe head are suitable tools to determine the correct values for the virtual solar cell position inside its housing. These findings have to be taken into account for all precise solar cell calibrations with divergent light sources against a calibrated cell without a front window or against calibrated photo diodes to ensure the DUT and the reference are measured in the same plane thus the result is valid for parallel light.

6 REFERENCES

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