BIFACIAL SOLAR CELLS IN STC MEASUREMENT

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ABSTRACT: New cell concepts need to be evaluated for their potential in competition with standard solar cell technologies. At Fraunhofer ISE CalLab PV Cells measurement methods are developed which shall allow including newer cell technologies in this competition. This work investigates the influence of bifaciality on high precision measurements under standard test conditions on bare solar cells. A certain degree of bifaciality is an intrinsic property of most back contact solar cell concepts due to the gaps in the back metallisation. We measured the reflectivity for a range of chuck surfaces and the optical transmission of bifacial cells from actual cell technologies. With the measured rear spectral response then the extent of the additional current contribution is calculated for the different chuck surfaces both, spectrally resolved and integral. This is the basis for an optimisation of cell mounting systems suitable to ensure comparable measurement results. The results clarify the contribution from bifaciality to the measurement uncertainty and help to define standard conditions.
Keywords: Calibrations, Bifacial, Back Contact

1 INTRODUCTION

Photovoltaic production reached 7.2 GWp/a capacity in 2009 and there are expectations for an increase up to 29 GWp/a in 2014 [1]. Thus the accuracy of efficiency measurements has increasing economic impact. Traceable measurements are the basis for the prices of photovoltaic devices, which are valued according to power measured under Standard Testing Conditions (STC) defined in IEC standards [2, 3]. A difference between two cell technologies of 0.1 % converts to 58 Mio €/a for the yearly world production assuming 2 €/Wp. The central question followed in this contribution is how to ensure a level of accuracy and thus lab-inter-comparability for new cell technologies which is similar to the one for standard technologies. For the latter standard testing conditions are defined to ensure comparable results. For some properties of new cell technologies these conditions need to be expanded. This contribution addresses solar cells with a not fully metallised back side, which are usually bifacial. Bifacial solar cells may be developed for bifacial use, but more importantly, a new cell concept may just have bifacial properties as a by-product. Back contact solar cells as a rule have a certain degree of bifaciality. These cells transmit radiation in the long wavelength region (900-1200 nm) which can be reflected back into the cell from the measurement chuck surface (s. Fig. 1).

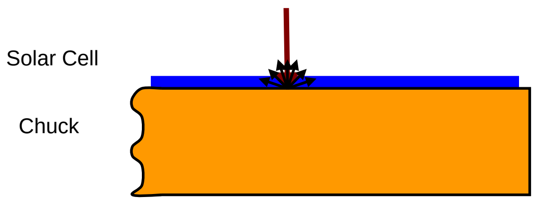

Figure 1: Scheme of bifacial solar cell on measurement mounting chuck. Transmitted radiation will be reflected back into the cell.

This leads to an increase of the measured cell current, which depends on the reflection of the individual chuck in use in a measurement lab and thus introduces unpredictable differences between calibration results.

We analyse the impact of bifacial properties on solar cell calibration first with a simplified model. In this approach we calculate the total spectral response including the back contribution and the additional integral current as:

$$SR_{meas}(\lambda) = SR_{front}(\lambda) + SR_{back,contrib}(\lambda) \quad (1)$$
$$= SR_{front}(\lambda) + T_{Cell}(\lambda) R_{Chuck}(\lambda) SR_{back}(\lambda)$$

and

$$I_{back,contrib} = \int E(\lambda) T_{Cell}(\lambda) R_{Chuck}(\lambda) SR_{back}(\lambda) \partial\lambda \quad (2)$$

with $SR_{meas}(\lambda)$ as the spectral response measured with a mounting chuck with reflectivity $R_{chuck}(\lambda)$, cell transmission $T_{cell}(\lambda)$ and spectral response of front and back side $SR_{front}(\lambda)$ and $SR_{back}(\lambda)$.

The relative back current contributions are referred to the $SR_{front}(\lambda)$ respective $I_{SC,front}$ value:

$$SR^{rel}_{back,contrib} = SR_{back,contrib} \big/ SR_{front} \quad (3)$$

$$I^{rel}_{sc,back,contrib} = I_{sc,back,contrib} \big/ I_{sc,front} \quad (4)$$

This approximation assumes, that the cells respond linearly to the additional generation from the rear, i.e. especially that there are no injection dependent effects.

2 ESTIMATION OF BIFACIALITY EFFECT

To estimate the order of magnitude for bifacial influence on the measurements we used a set of measured data to calculate the additional spectrally resolved as well as integrated current contribution from the back side with eqn. 1 and eqn. 2. Spectral response (s. Fig. 2) and transmission (s. Fig. 3) data of different cell technologies and reflection data of different chuck surface materials (s. Fig. 4) are used. The spectral response data include already a contribution of individual chuck surface reflection, but this will have negligible influence (2. order) on these calculations. The spectral response measurement takes the whole cell area into account including the metallised regions with no response.

The cell technologies selected represent a broad range of bifacial behaviour. Cell B is a fully bifacial cell, i.e. it has nearly the same short circuit current (I_{SC}) from both sides. Cell A, C and D are different technologies of back contact solar cells with interdigitated grid design. Cell C is a EWT structure. The different magnitude of the spectral response on the back side of the cells depends strongly on the degree of metallisation. Due to the rear emitter of the back contact cells the contribution of the reverse IR response to the respective total current may be higher compared to front irradiation.

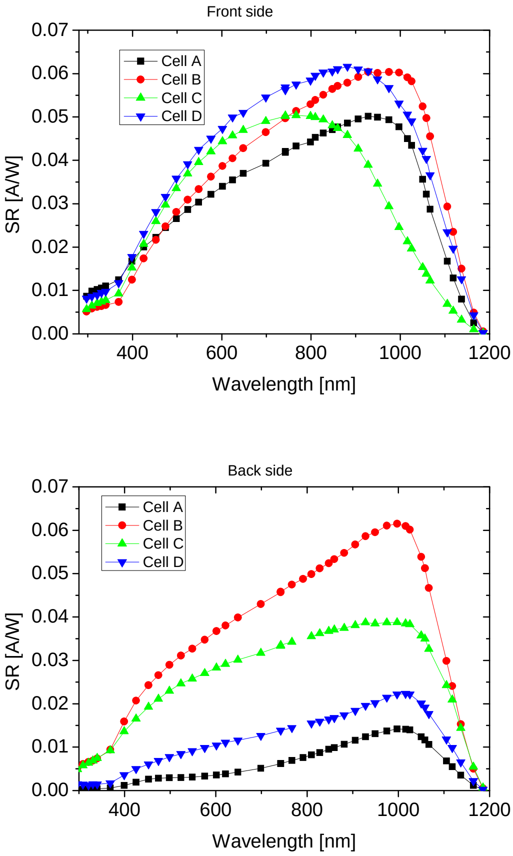

Figure 2: Spectral responses of various actual cell concepts with bifacial properties. Cell B is a fully bifacial cell, cells A, C, D are back contact cells where the bifacial property is a by-product of the cell technology.

The transmission of the different solar cell types depends on the degree of metallisation as well. It has to be regarded in the calculation that the metal fraction is only included once, in the spectral response or the transmission. The fraction of regions with metallisation to the gaps in-between is 1 for the fully bifacial cell (Cell B), 1.52 for the lab cell structures (Cell C and D) under development and 2.35 for the highly developed cell structure (Cell A).

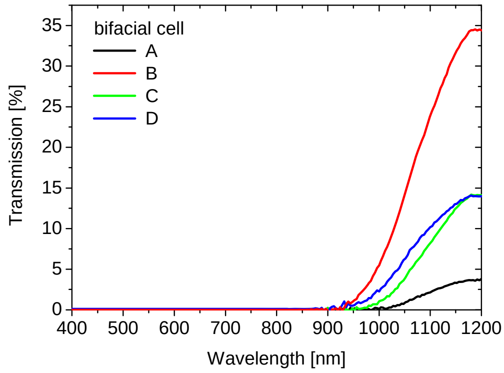

Figure 3: Transmission of four different bifacial solar cells compared to a standard solar cell covered completely with metallisation on the back side.

For lab measurements under steady state sun-simulator radiation a cell mounting with temperature stabilisation and high thermal conduction to the cell is needed. Thus in most labs metal plates with a vacuum-based contacting are used. If additionally the electrical contact is made with this plate materials with low resistance - like copper and brass - for homogenising the potential distribution are used. Gold plating improves the contact to the cell and avoids aging of the chuck surface. If only a thermal contact is needed anodizing and thin plastic foils can be used to establish specific surface properties. We selected a series of chuck surfaces for the present investigation and measured the reflection data (Fig. 4) including diffuse and direct component of reflectivity.

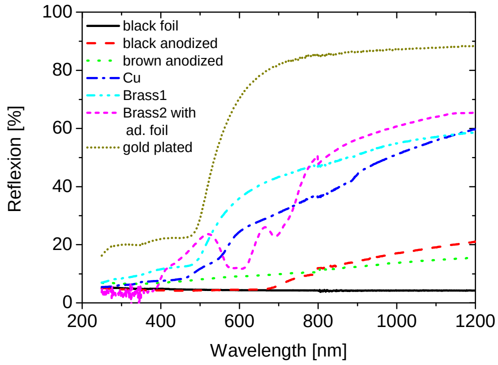

Figure 4: Reflectivity of different solar cell mounting chuck surfaces.

From these data (Fig. 2, Fig. 3 and Fig. 4) we can estimate via eqn. 1 and eqn. 2 the influence of the bifacial properties on the measurement. We obtain for the different cell types similar curves (Fig. 5) with different magnitude (compare the scales). The reason for the strong variation in these data is not only the different ratio of metallised regions to the gaps on the cell. For the spectrally resolved data the ratio of $SR_{front}(\lambda)/SR_{back}(\lambda)$ has also a strong influence.

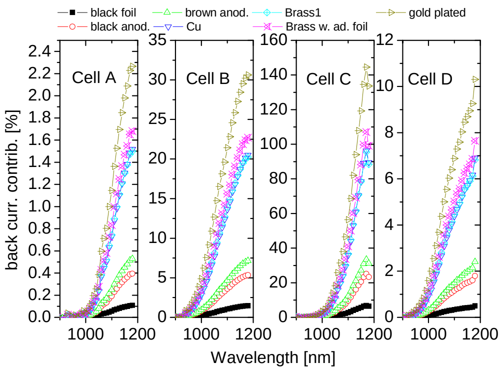

Figure 5: Current contribution calculated for the cells from Fig. 2 with different mounting chuck surfaces.

In order to calculate the influence of the bifaciality on the integral I_{SC} of the cells we used a class A (according to [4]) xenon sun-simulator spectral distribution in eqn. 2.

back current contribution				
	Cell A	Cell B	Cell C	Cell D
black plastic foil	0.00%	0.05%	0.01%	0.03%
black anod.	0.01%	0.22%	0.06%	0.11%
brown anod.	0.00%	0.18%	0.05%	0.09%
Cu	0.02%	0.66%	0.17%	0.33%
Brass1	0.02%	0.69%	0.19%	0.34%
Brass w. ad. foil	0.02%	0.77%	0.20%	0.38%
gold plated	0.03%	1.07%	0.30%	0.52%

Table 1: Current contribution calculated for a class A Xe-sun-simulator spectral distribution for the different chuck surfaces.

For a meaningful assessment of the merits of different cell technologies and precise calibration of solar cells contributions above 0.1 % are taken to be relevant. For the gold plated surface we find the highest values, but already for the copper and brass plates significant current contributions occur.

3 MEASUREMENTS

At Fraunhofer ISE CalLab PV Cells a mounting chuck (s. Fig. 6) was build to investigate and improve bifacial solar cell measurements. This chuck features changeable surface plates with different reflectivity. Additionally the contact to the busbars of the back side is made in an appropriate way (see [5]). The present version of the chuck is designed for research type 5” solar cells with 62.5 mm distance between the busbars (referring to the center of the busbars). The chuck concept is applicable for bare back contact solar cell measurement and described in more detail in [6].

Figure 6: Solar cell mounting chuck for bifacial 5” solar cells with 62.5 mm busbar distance. The changeable surface plates allow the variation and assessment of the surface reflectivity.

The reflectivity of the four different plates varies from nearly wavelength independent (black plastic foil, 4-6%), rather weak wavelength dependent (brown plate, 5-20 % to the strong wavelength dependence of the black anodized (5-45 % and the grey anodized plates (5-50 %).

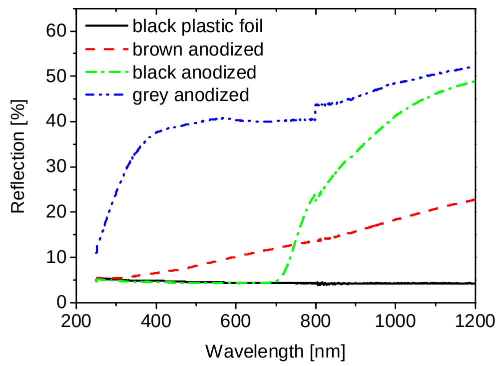

Figure 7: Reflectivity of changeable surfaces of solar cell mounting chuck for bifacial 5” solar cells.

Due to the transmission of silicon wafers (compare Fig. 3) in the 900-1200 nm region only the reflections in this region are relevant. From these data it is obvious that the black anodized plate (second plate from right in Fig. 6) is nearly as highly reflective in the relevant region as the grey plate (compare first plate from right in Fig. 6).

As in the previous section we calculated the back current contribution. Additionally we measured a bifacial cell with all four plates in order to compare the calculations with experimental data. For the determination of the spectral current contribution we used the measurement with the lowest reflectivity (see Fig. 7, black foil) as reference. We find a good agreement between calculated and measured spectrally resolved current contribution for the brown plate (Fig. 8).

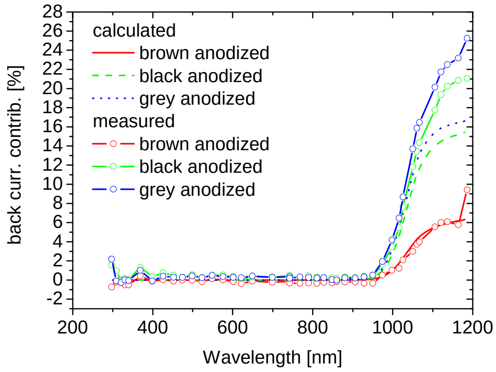

Figure 1: Calculated and measured current contributions with different measurement chuck surfaces.

For the black and grey anodized plates we obtain approximately 25 % higher values for the experimental data. This is likely due to a difference in the light incidence to the cell: The spectral response measurement at the back side is done with direct (low angle, < 4°) radiation. In contrast, the light reflected back from the chuck surface is at least partly diffuse. The solar cell has thus due to the light trapping design and the small critical angle of 17° for silicon an improved spectral response in the long wavelength region compared to the direct incidence.

We can now use the calculated data for the black foil with low reflection to determine its residual influence on the measurement and take this as an estimation for the contribution to the measurement uncertainty for the case that bifacial cell measurements are done on a chuck with this surface. The resulting back current contribution is plotted in Fig. 9. Even if we add the 25 % deviation which we have seen for the anodized plates, we stay below 2 % for the spectral response contribution and 0.05 % for the I_{SC} contribution for this bifacial cell measurement.

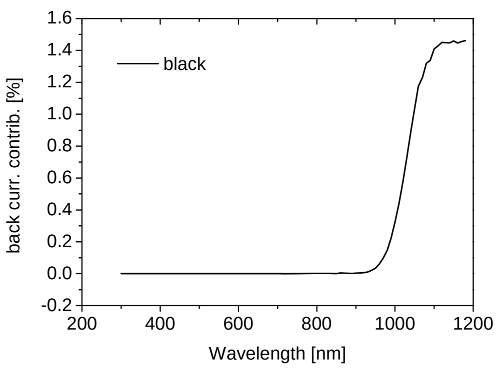

Figure 2: The spectrally resolved current contribution with black plastic foil is reduced to less than 2% (contribution to I_{SC}(STC) < 0.05 %).

The magnitude of this additional current contribution to the measurement depends strongly on the ratio $SR_{front}(\lambda)/SR_{back}(\lambda)$ in the relevant wavelength region. For example with the cell C in Fig. 2 we see in Fig. 5 up to 9 % for the spectrally resolved current increase, but in **Table** only 0.01 % for the integral value.

4 DISCUSSION

Ideally, the measurement of the individual sides of a bifacial cell should be performed independently of the respective other side. From the variation range of the reflectivity of various backgrounds it becomes obvious that adapting chuck surfaces in their reflectance properties will always lead to a certain overestimation of the measured current compared to the real single-side current. Although this additional error can be made relatively small, such a systematic overestimation is not a satisfying solution for a standard condition for high precision measurements. In addition, a single sided measurement may rate a bifacial solar cell with lower performance compared to the situation in a bifacially irradiated module due to a performance increase with increasing excess carrier density.

In the previous calculations we used the black foil with the lowest reflectivity as reference and have seen that we are able to realise measurements with acceptable bifaciality influence. If we consider, however, that PV modules usually are manufactured with a white back sheet the definition of a high reflection albedo might be also an interesting option for a standardized bifacial bare cell measurement. In Fig. 10 we compare the reflectivities of two different module back foils: As a reference, the measurements on both sides of a black foil are added.

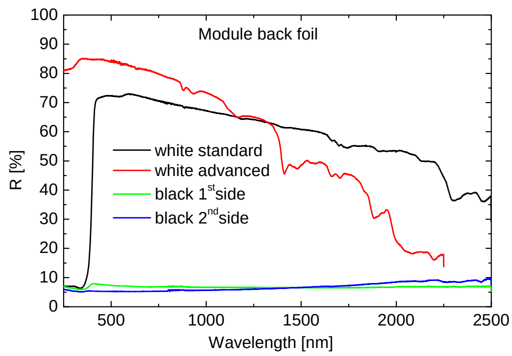

Figure 3: Reflectivity of different PV-module back foil. The reflectivity variation of these foils appears to be close enough that definition of a standard albedo appears feasible.

Superposition of independently measured current response does not necessarily lead to a result, which reflects the cell performance, if non-linear behaviour of the current response exists. E.g. the current response from the back side may well be affected by a decrease of the surface recombination velocity due to the increase in the minority carrier density. On the other hand, from the results in Fig. 8 we know, that the angle dependence of the current response has a strong influence on the measurement results. This implies that for any standardisation of a highly reflecting background not only the albedo, but additionally its angular dependence should be precisely defined.

4 CONCLUSION

A bare cell measurement under STC defines the three conditions 25°C, AM1.5G and 1000W/m², how to handle bifaciality is not considered. As a consequence, at present the calibration of a cell with bifacial character should be accompanied with a statement on the chuck surface reflectivity in order to define the measurement conditions. We conclude from our investigation that for the moment the condition with the lowest potential for additional measurement uncertainties is to realise low reflectivity of the mounting chuck surface. For the definition of a standard it has the charm to be easily realised and that it assures a high inter-lab comparability. The definition of a highly reflective background is an alternative and should be further discussed.

5 ACKKNOWLEDGEMENT

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6 REFERENCES

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