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Electrical Contact Solution for Measuring Back Contact Solar Cells

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Abstract. Due to the cell design, it is challenging to measure back contact cells. In this study, we have designed and tested a contact chuck based on printed circuit board (PCB) technology. Both full cells and cut Interdigitated Back Contact (IBC) cells were tested and compared to a conventional spring-loaded probes based measurement chuck. Results show that IV parameters, especially fill factor (FF), can be measured with high accuracy and repeatability. In this case, the FF results are closer to the FF of modules. The chuck can also be used for other measurements, for example, electroluminescence and spectral response. The PCB layout can be adjusted according to the cell design, providing a more flexible, faster, and cost-effective approach than the traditional measurement chuck. The technology is suitable for measuring back contact cells in lab environments and in industry.

Keywords: Contacting, Back Contact, IV Measurement

1. Introduction

Back contact cells such as Interdigitated Back Contact (IBC) cells have attracted the attention of both researchers and end users due to their high efficiency potential and aesthetic appearance. However, with all the contact points at the rear (shown in Figure 1), one of the challenges is how to conduct electrical measurements such as current-voltage (IV) characteristics [1] or electroluminescence (EL). Few reports have been published regarding the method of contacting the back contact cells. For measuring back contact cells, probe-contact chucks typically require special designs [2, 3] and customized manufacturing, which can be time-consuming and costly. Meyer Burger has developed a measurement solution based on PCB technology, called “PCBTouch”, and won the Solar Industry Award in 2015 [4]. However, there are few technical details, especially on the measurement results reported.

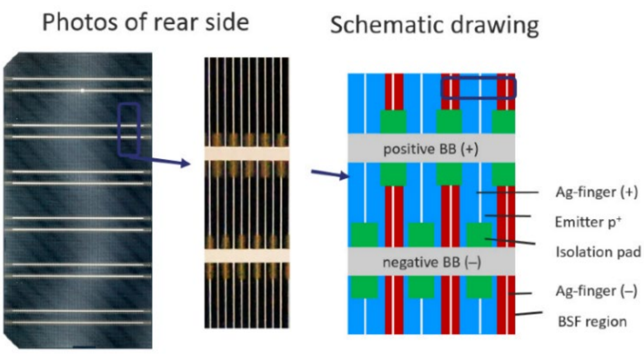


Figure 1. Rear side design (photo and schematic drawing) of a ZEBRA IBC cell, reprinted from [5].

Furthermore, with the fast development of interconnection technologies, the design of IBC cells has evolved rapidly to achieve higher efficiency and lower cost (especially for the reduction of silver usage). As can be seen in Figure 2. The busbar of ZEBRA IBC cells developed at ISC Konstanz has been changed from 4 pairs of busbars to 6 pairs, 9 pairs, and even busbar-less cells configurations (not shown).

Figure 2. Different designs of ZEBRA IBC solar cells, from left to right: cell with 4 pairs of busbars, 6 pairs of busbars, and 9 pairs of busbars.

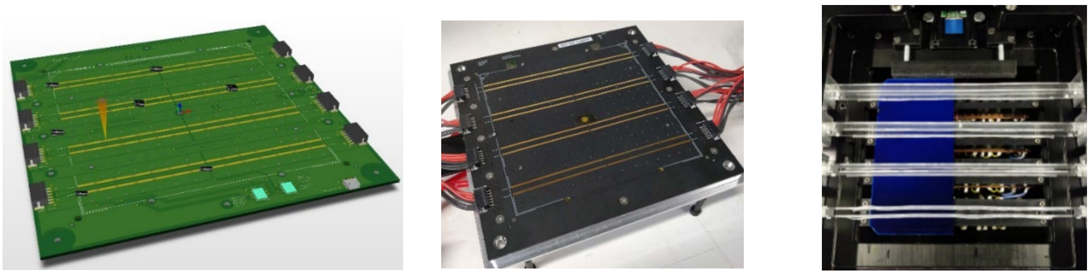
In order to keep up with the ever changing IBC cell design, an easy and flexible contact for measuring the electrical performance of the cells is required.

This study proposes a novel electrical contact design for back contact cells using standard PCB technology. Compared to traditional chucks, this product is cheaper and easier to fabricate. On both full and cut IBC cells, the design contacting chuck was studied to determine its measurement accuracy in a lab environment where the handling of the cell is done manually.

2. Experimental

2.1 Contact chuck design

The chuck was designed based on the busbar layout of the solar cell shown in Figure 3 (a). For measuring cells with 4 pairs of busbars, there are four pairs of contact pads with a width of 1mm. They are structured in such a way as to include several sense pads of $1x1mm^2$. Various holes are designed on the chuck to hold the cell using vacuum during the measurement. The chuck was designed to contact full cells as well as cut cells of different sizes. A drawing of the chuck is shown in Figure 3 (a), and the photo of the finished device is shown in Figure 3 (b). A standard chuck based on spring-loaded probes and Plexiglas bars pressing the cell down from above can be seen in Figure 3 (c).



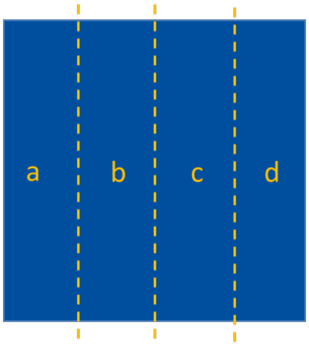
(a) (b) (c)

Figure 3. (a) Design of the PCB chuck in this study; (b) photo of actual PCB chuck, vacuum is connected from the bottom of the chuck to hold the cells; (c) Probe contact chuck with Plexiglas bars (referred to as “Plexiglas chuck”) used as a reference, the top bars are made from Plexiglas. For both chucks, the alignment was done by edge stoppers.

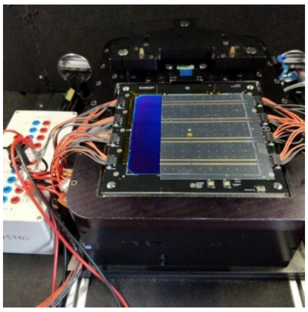
2.2 IV evaluation on full cells and cut cells

IV measurement was done using both PCB and Plexiglas chucks using the Halm system setup. An M2-size IBC cell was measured five times with repositions. The measurement cycle, including the loading/unloading of the cell, was repeated five times to account for the uncertainties due to contacting.

The IV measurement of cut cells is important for new types of modules, such as shingle modules. To evaluate the IV measurement of cut cells, a full cell was laser cut into four pieces (quarter-cut cells), and then measured on both chucks (as shown in Figure 3). Measurement repeatability was also tested by re-measuring a cut cell.



(a)



(b)

Figure 4. (a) A full cell was cut into four pieces (quarter-cut cells), and then measured on both chucks. (b) In order to prevent vacuum leakage, the remainder of the PCB chuck was covered with transparent foil when measuring a quarter cell.

3. Results and discussion

3.1 IV results of full cells

The IV results measured on full cells using both chucks are shown in Figure 5. As compared to Plexiglas chuck results, V_{OC} and J_{SC} were similar on the PCB. Around 0.6%$_{abs}$ lower FF was measured on PCB chuck. Furthermore, PCB chucks exhibit a better degree of repeatability. The deviation of FF measured on Plexiglas is larger than on PCB chuck.

The repeatability can be explained that on the PCB chuck, cells can be accurately positioned accordingly, the FF deviation observed is smaller as compared with the FF measured from the Plexiglas chuck. The repeatability on the Plexiglas chuck suffers from inaccurate positioning the cell accurately on the spring-loaded probes despite the edge stoppers. To measure IV, the cell was aligned by edge stoppers to the position, then contacted by spring-loaded probes. The additional force from the probes can change the positioning of cells, influence the contact between busbars and probes, and thus affect the FF measurement. It is possible to improve the FF measurement of Plexiglas chucks by better alignment from the stopper, and better contacting between the probes and the cells. In contrast, on the PCB chuck, cells can be accurately positioned accordingly with edge stoppers. After position, the cells were fixed on the PCB chuck with a stable vacuum suction.

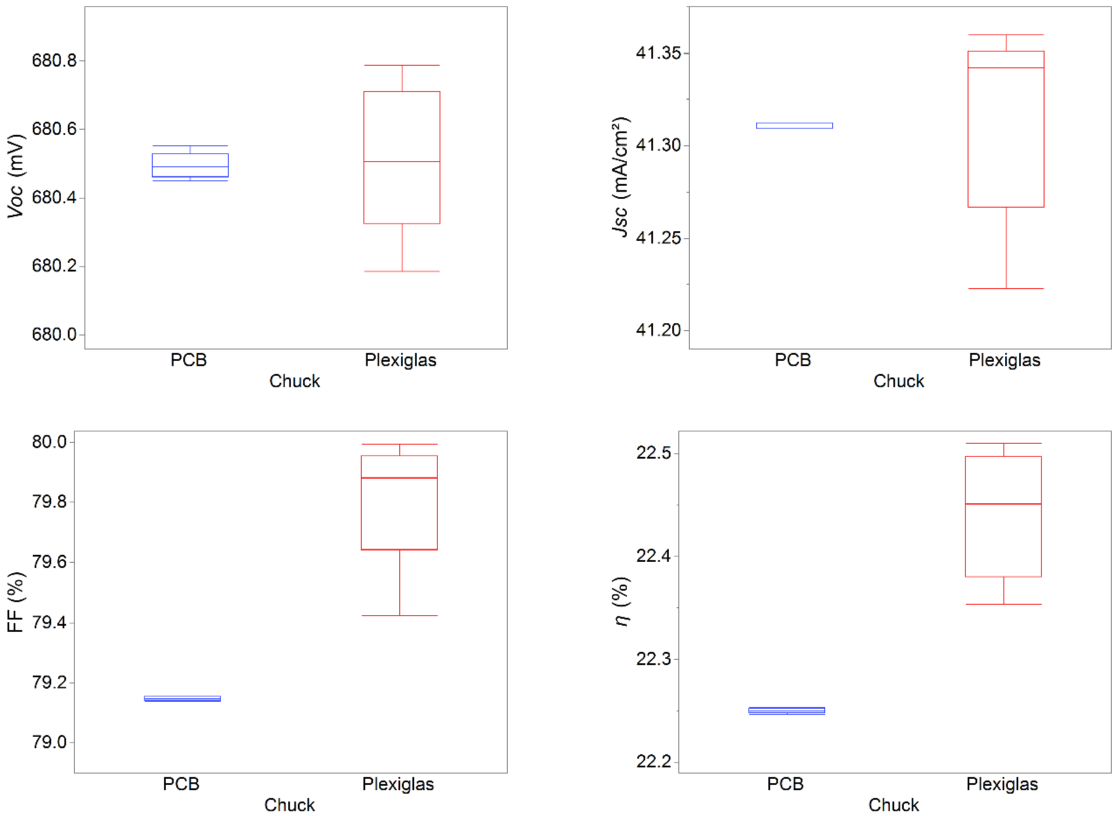


Figure 5. IV results measured on the PCB and Plexiglas chucks. The same cells with M2 size were measured 5 times on each chuck. Before measurement, I_{sc} was calibrated by a reference cell.

The fact that the PCB measurements delivers a smaller value for the FF comes unexpectedly as the one could assume that. To further investigate the FF difference from the measurements, a FF analysis was performed based on calculations [6] and Griddler simulations [7] to determine the FF losses at different stages of the solar cell. In Griddler simulations, PCB measurements can be approximated as current extraction from solder ribbons.

As shown in Figure 6, for the solar cell, a FF_{J01} of 84.33% can be calculated when considering only saturation current densities J_{01} in a two-diode model of solar cells. In the presence of J_{02} recombination and shunt resistance (R_{sh}), the pseudo fill factor (pFF) is reduced by 1.87%$_{abs}$ when compared with FF_{J01}. When measuring with Plexiglas chuck, a 2.64%$_{abs}$ FF is lost because of finger resistance and transport loss; when measuring with PCB chuck, in addition to the finger resistance and transport loss, a 0.68%$_{abs}$ is lost due to busbar resistance and resistance of the PCB contact bars. The FF difference between PCB and Plexiglas measurements is because of the resistance from the solar cell busbars and the resistance of PCB contact bars. FF is further reduced by interconnector ribbon resistance when made into modules. A 2%$_{abs}$ difference between FF measured with Plexiglas and modules is estimated. The PCB chuck extracts the current from cells through the contact bars similar to ribbons contacting the solar cells in solar modules. Accordingly, the FF measured using PCB chuck is expected to be close to module FF based on ribbon contact. To accurately determine the solar cell's FF, the software based on [6] and [7] could be used to compensate for additional PCB series resistance for PCB measurement. However, for the purpose of sorting cells, the relative differences matter and the sorting results for both measurent chucks will be the same. However, the PCB chuck provides a closer estimate of the FF of a module.

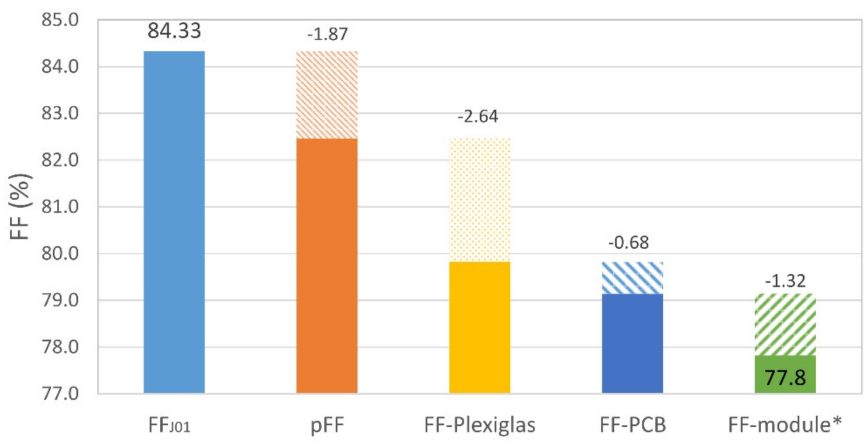


Figure 6. FF changes, from FF_{J01}, pFF, FF-Plexiglas, FF-PCB, to FF-module. *Module FF is estimated by a loss of $2\%_{abs}$ compared with FF-Plexiglas.

3.2 IV results of cut cells

The IV results measured on cut cells are presented in Figure 7. In addition to measuring individual slices, combinations of several slices were also measured simultaneously to examine the effect of different measurement chucks on FF accuracy. Due to the design, cut cells can be measured accurately using a PCB chuck. In the results measured by PCB chuck on 1/4 cells, the FFs are lower but with good repeatability. When 2 cut cells (2/4) or 4 cut cells (4/4) were measured simultaneously, the results of PCB chuck show lower FF due to the location design of sense pins; while the results measured from PCB chuck are comparable. With more pieces of cells measured, the resistance effect from PCB chuck is less, and a slightly higher FF was measured on the 4/4 group.

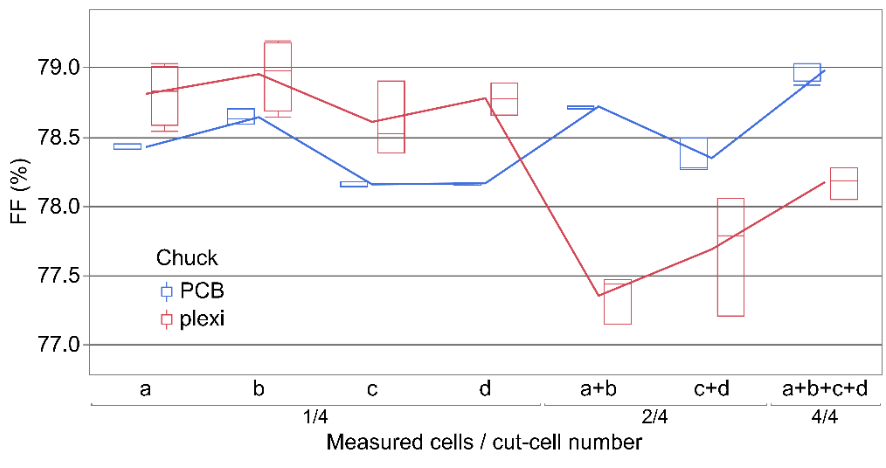


Figure 7. FF difference between full cells and cut cells. Full cells cut into four pieces, labelled as a, b, c, and d. Cells measured separately or together (with different parallel combinations) using different chucks (PCB chuck or Plexiglas chuck).

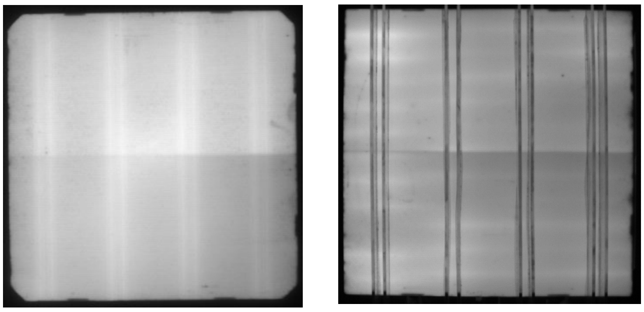
The repeatability measurement results are presented in Table 1 on a 1/4 cut-cell basis using the PCB chuck. The IV repeatability of cut cells is excellent.

Table 1. IV results measured on a 1/4 cell at different time of the same day.

Measured sequence	V_{oc} (mV)	J_{sc} (mA/cm2)	FF (%)	pFF (%)	η (%)
1	690.2	40.891	78.19	82.26	22.07
2	690.0	40.890	78.22	82.31	22.07
3	690.1	40.893	78.12	82.28	22.05
4	690.0	40.892	78.15	82.32	22.05
5	690.2	40.892	78.14	82.32	22.05
6	690.1	40.890	78.18	82.33	22.06
7	690.3	40.891	78.30	82.34	22.10
Average	690.1	40.891	78.18	82.31	22.06
St.Dev.	0.1	0.001	0.06	0.03	0.02

3.3 Electroluminescence images and spectral response measurement

In addition to IV measurement, the PCB chuck can be also used for other measurements which need electrical contracting. Electroluminescence (EL) images were measured using the Halm system. For example, the EL images shown in Figure 8 were measured by using the PCB chuck and the standard Plexiglas chuck. A clear difference can be distinguished between the two images. The image measured from the Plexiglas chuck shows shading from the front contact Plexiglas bars. In production lines, the EL measurement system is integrated within the IV measurement [8] setup, and shadow-less EL images are important for cell performance evaluation and quality control.



(a) (b)

Figure 8. EL images measured using a PCB chuck (a), and a standard Plexiglas chuck (b).

Similarly, the chuck can be integrated into other tools. For example, the PCB chuck can be installed in a spectral response measurement system as shown in Figure 9.

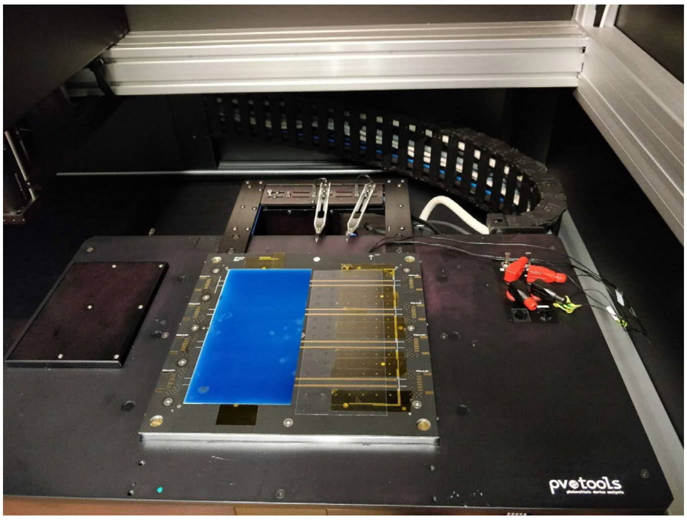


Figure 9. PCB chuck installed in pv-tools (Spectral quantum efficiency & reflectance measurement system from pv-tools GmbH) for measuring spectral response of a half-cut cell.

4. Conclusions and discussion

This study presents a contacting solution for measuring the electrical performance of back contact cells. IV values can be measured with high accuracy and reproducibility due to more accurate placement of the cell and cell pieces on the chuck. In addition, due to the mature process of PCB design and manufacturing, the contact design can be easily changed and new chucks can be fabricated. This contact solution is easier and cheaper, especially for research labs where the metallization layouts are updated frequently.

The FF measured from the PCB chuck is lower than the results measured from the probe contact chuck, which is due to the chuck resistance (a lumped resistance including contacting resistance and resistance from the chuck itself). However, when cells are interconnected to modules, for example, using ribbons. The FF of the module is also lower due to the contact resistance and resistance from ribbons [9]. The PCB measured FF reflects the FF measured in the final device – module. From a module point of view, the FF measured from the PCB chuck is closer to the module FF that can be achieved from the cells.

There are also drawbacks to using the PCB chuck. First, the current design is not suitable for in-line measurement. Second, the measurement requires proper contact between BBs and PCB. If the contact is not proper, for example, due to uneven BBs, then the measurement cannot be done correctly. The PCB for the in-line measurement tool can be tuned for the specific solar cell. Indeed the uneven BBs might be a problem if it’s random, but if the busbars with different polarities have different heights, it can be solved.

Data availability statement

The data that support the findings of this study are available from the authors upon reasonable request.

Author contributions

N. Chen: Investigation, Methodology, Validation, Writing - Original Draft. R. Roescu: Investigation, Methodology, Validation, Writing - Review & Editing. F. Buchholz: Funding acquisition, Project administration, Supervision, Writing - Review & Editing. V.D. Mihailetchi: Project administration, Supervision, Writing - Review & Editing.

Competing interests

The authors declare no competing interests.

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