Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 38 (2013) 334 – 339

Energy Procedia

SiliconPV: March 25-27, 2013, Hamelin, Germany

Multi-busbar solar cells and modules: high efficiencies and low silver consumption

Stefan Braun[a], Giso Hahn[a], Robin Nissler[b], Christoph Pönisch[b], Dirk Habermann[b]*

[a] *University of Konstanz, Department of Physics, 78457 Konstanz, Germany*
[b] *Gebr. Schmid GmbH, Robert-Bosch-Str.32-36, Freudenstadt 72250, Germany*

Abstract

Ideally, future photovoltaic modules show higher power output without increasing costs during cell production or module interconnection. Today significant losses occur during stringing the cells in a module by using standard 3-busbar technology. In this paper an elegant approach for a front side design is discussed by using more busbars than the widely used 3-busbar design for the solar cell front electrode. Simulations demonstrated that the multi-busbar design allows higher cell and module efficiencies compared to a state of the art 3-busbar cell design, and in the same time reduces the amount of silver needed for the front electrode. A conventional full area Al BSF and standard screen printing for the front contact was used for the 6" Cz-Si multi-busbar solar cells and efficiencies of up to 19.5% have been reached. The solar cells were analyzed on cell and module level and a reduction in Ag consumption for the front electrode of >50%$_{abs}$ could be achieved using the multi-busbar cell design. An additional silver reduction was achieved by replacing the rear side Ag/Al pads with tin pads for the soldering process. These changes in solar cell design reduce significantly the metallization costs and in the same time increase the efficiency.

Selection and/or peer-review under responsibility of the scientific committee of the SiliconPV 2013 conference

Keywords: Multi-Busbar Design; Ag/Cost Reduction; Interconnected Solar Cells

1. Introduction

To confirm simulations carried out for the multi-busbar cell design [1] on cell and module level, multi-busbar and state of the art 3-busbar solar cells are processed, characterized and integrated into 1-cell modules to determine the losses occurring after encapsulation under module conditions. A further Ag

* Stefan Braun. Tel.: +49-7531-88-2082; fax: +49-7531-88-3895.
E-mail address: Stefan.Braun@uni-konstanz.de.

Selection and/or peer-review under responsibility of the scientific committee of the SiliconPV 2013 conference
doi:10.1016/j.egypro.2013.07.286

reduction could be achieved using Sn stripes instead of Ag pads. With the TinPad technology a full Al back surface field (BSF) is printed, followed by deposition of Sn stripes onto the Al surface [2]. This leads to a higher V_{oc} of the solar cell because of a reduced recombination of charge carriers on the rear side.

2. Experiment

In the experiment common 3-busbar solar cells are compared with multi-busbar solar cells on cell and module level. All 6 inch semi-square Cz wafers (B-doped, 2 Ωcm) are alkaline textured and obtain a 55 Ω/sq $POCl_3$ emitter diffusion. The wafers are masked by inkjet printing and etched back to 110 Ω/sq to form a selective emitter structure[3]. The mask is removed and an edge isolation is performed by chemical etching. The wafers are cleaned afterwards and a SiN_x:H layer is deposited on the front surface. The wafers are divided into two groups. Group 1 is the 3-busbar reference group with a full area Al BSF on the rear side. The front grid was applied via screen printing and the finger spacing was optimized to 2 mm. The busbar width was 1.3 mm for each busbar.

Group 2 has a multi-busbar front grid and a full area Al BSF on the rear side. The finger grid was also applied by screen printing (as well as the Al rear sides). For the multi-busbar front grid, rectangular finger pads with 500 µm x 700 µm are also screen printed on the front side fingers to enhance the contact ability between the wires and the fingers. After the co-firing process in a belt furnace, all groups are characterized using a HALM flasher to determine the IV parameters.

For module interconnection, three 1.5 mm wide and 200 µm high Cu strings are attached on the front and rear side of the 3-busbar solar cells. The multi-busbar solar cells are interconnected with 15 round Cu wires on the front and rear side of the solar cells. The Cu wires have a diameter of 300 µm. The wires and strings of the front and rear side of both cell types are soldered to a 5 mm wide, 500 µm high Cu ribbon each. On this ribbon the current and voltage for front and rear side is collected for the module measurements.

The interconnection process is carried out by soldering. A screen printed Al rear side cannot be connected by direct soldering. Therefore, Sn stripes are deposited on the rear side of group 1 and 2 using the TinPad technology provided by company Gebr. Schmid GmbH. Group 1 solar cells obtained three Sn stripes with a dimension of 153 mm x 4 mm. For the multi-busbar solar cells five tin stripes are deposited perpendicular to the finger orientation. This is equivalent to a pad structure of five pads for each wire with the dimension of 4 mm x 400 µm. The interconnected solar cells are laminated. The components of the module are EVA- and Tedlar sheet plus a module glass (200 mm x 200 mm x 3 mm) with anti reflection coating.

For IV measurement of the modules a shadow mask with the size of the encapsulated cell was used to avoid the generation of charge carriers by photons reflected on the module glass outside the cell area.

3. Results

3.1. Front side metallization

The consumption of Ag paste could be directly determined after the screen printing process. For the 3-busbar cell front grid 140 mg of Ag paste are needed. The amount of Ag needed for a sufficient metallization of the multi-busbar front grid was 68 mg. This makes a total Ag paste saving of 72 mg which is a reduction of >50%.

The finger width of the 3-busbar solar cell was in the range of 70 µm compared to 50 µm for the multi-busbar cell design. The finger width of a 3-busbar solar cell is limited to design considerations. The finger length is in the range of 25 mm for a 6 inch solar cell with 3-busbars. For a multi-busbar solar cell with 15 wires the effective finger length is only 5 mm. The series resistance contribution of a metallized front finger is directly proportional to the square of the finger length. This means that the series resistance contribution of a multi-busbar finger is 25 times smaller compared to a 3-busbar finger. In direct relation 25 times less Ag paste is theoretically needed for the same series resistance contribution. This can easily be regarded in Fig 1. In general this means that the finger width (or better the finger cross section) for a multi-busbar cell design is dependant from the technology. Finger widths in the range of 10 µm would be possible with series resistance contributions even lower that a 90µm 3-busbar cell finger.

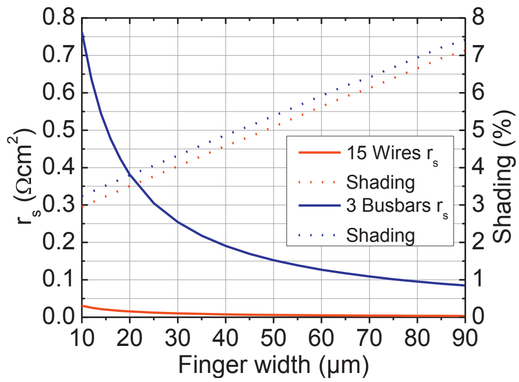

Fig. 1. Finger width of a 3-busbar and a multi-busbar solar cell with screen printed front side metallization over the series resistance contribution (y-axis left). Shading of both cell types (y-axis right)

The shading for both solar cell types decreases with decreasing finger width. This leads to a higher current of the solar cell.

3.2. Solar cells

After solar cell processing both groups are measured with a HALM IV flasher. The results are visible in Table 1.

Table 1. IV-parameters of the 3-busbar and multi-busbar solar cells. In addition, the differences of the average values are listed.

Type	V_{oc} (mV)	j_{sc} (mA/cm²)	FF (%)	eta (%)
3-busbar	640.2	38.1	80.1	19.52
3-busbar	638.6	38.1	79.7	19.39
3-busbar	638.5	38.1	80.0	19.44
Multi-busbar	641.1	37.8	80.0	19.41
Multi-busbar	639.6	37.6	80.2	19.28
Multi-busbar	640.4	37.6	80.3	19.34
delta	+1.37	-0.43	+0.23	-0.11

The open circuit voltages of both groups are in the same range. Due to the same solar cell design this was expected. The average current density of the 3-busbar solar cells is 0.43 mA/cm² higher. This can be explained by a reduced shading because of narrow busbars of 1.2 mm width, and a non optimized front pad geometry of the multi-busbar solar cells. The fill factors are in a high range for the 3-busbar solar cells. This is related to an advanced screen printing process which allows narrow finger width with an excellent height to width ratio. The fill factors of the multi-busbar solar cells are in the expected range. For the IV measurement a special setup adapted for measurement of these cell designs was used. In the end the average efficiency of the 3-busbar solar cell is 0.11%$_{abs}$ higher.

3.3. Modules

For an IV measurement with high accuracy the modules have been independently measured at the ESTI (European Solar Test Installation) in Ispra, Italy. The module results are presented in Table 2.

Table 2. IV parameters of the 3-busbar and multi-busbar modules. In addition, the differences of the average values are listed.

Type	V_{oc} (mV)	j_{sc} (mA/cm²)	FF (%)	eta (%)
3-busbar	638.5	36.9	76.9	18.14
3-busbar	637.0	37.3	76.6	18.20
3-busbar	636.0	37.2	76.7	18.14
Multi-busbar	638.4	37.4	77.8	18.56
Multi-busbar	636.0	37.2	78.0	18.43
Multi-busbar	637.7	37.2	77.9	18.46
delta	+0.2	+0.14	+1.2	+0.33

The open circuit voltages of the modules are like the solar cells in the same range. For the current density a beneficial effect of the round wires can be observed. To clarify this effect the current densities on cell- and module level are presented in Fig 2.

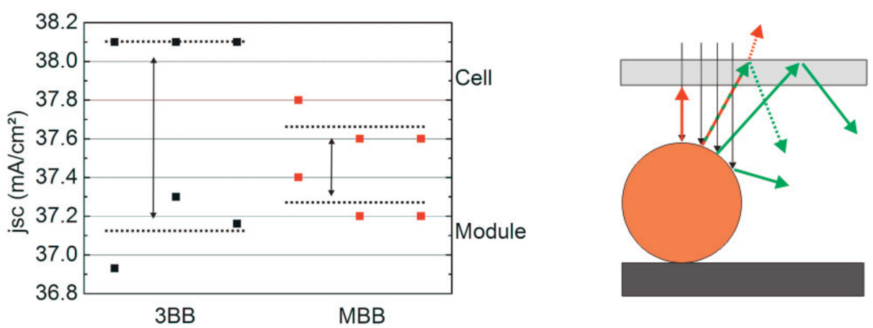

Fig. 2. (left) Differences in current density on cell- and module level for both solar cell designs, (right) incidenting light reflected on a round wire in a multi-busbar module; reflected light from the wires is reflected again on the glass / air interface and can enter the surface of the solar cell.

The current density loss for the modules can be related to light reflection at the air / module glass interface and a partial absorption in the EVA sheet. An additional drop in current density can be observed for the 3-busbar cells integrated in the module. This can be explained by two phenomena. The first reason is related to the broad ribbons of 1.5 mm width which cause additional shading because the screen printed busbar width is only 1.3 mm. The second effect is the shape of the ribbons which are in first approximation rectangular. These effects lead to a current density drop of around 0.9 mA/cm² for the 3-busbar modules. This stands in contrast to the multi-busbar modules. Because of the round shape of the wires 70% of the incident light is guided to the surface of the solar cell as indicated in Fig. 2. (right) [4]. After reflection, part of the light is directly guided to the surface. Another part of the reflected light after encapsulation is totally reflected at the module glass / air interface and can afterwards enter the surface of the solar cell. A third part is partially reflected and transmitted [5]. These effects lead to a reduction in current density loss for the multi-busbar modules. The total loss of current density is only around 0.4 mA/cm².

The multi-busbar solar cell is optimized for module integration. This can be observed taking a look at the fill factors of the modules. The average fill factor of the 3-busbar modules is in the range of 76.7%, whereas the average fill factor of a multi-busbar module is 77.9%. This difference of $1.2\%_{abs}$ explains the differences in efficiency of both module types. The 3-busbar solar cell modules have an average efficiency of 18.16%, but the multi-busbar modules could reach an average efficiency of 18.48%. This makes an efficiency gain of $0.32\%_{abs}$. The highest efficiency of a multi-busbar module was 18.56%.

4. Conclusion

With the multi-busbar cell design it is possible to stick to the existing solar cell process and reach higher module efficiencies. Only the inkjet mask and the screens for the screen printing process have to be adapted. In addition, a different kind of cell stringer is needed.

The multi-busbar design significantly reduces the amount of Ag needed for the front side metallization. In the experiment 72 mg of Ag paste was saved which was >50% compared to a screen printed 3-busbar solar cell. In contrast to the 3-busbar solar cell the width of the metal grid is not design dependant. Using new metallization technologies a further reduction of finger width is easily possible because the series resistance contribution of a finger is only 4% of a finger from a 3-busbar solar cell using the same layout.

It was demonstrated that the multi-busbar design shows its advantage on module level. An efficiency gain of $0.32\%_{abs}$ compared to a 3-busbar module could be reached. The average efficiency of 3 multi-busbar one cell modules was 18.48%. The highest efficiency for a multi-busbar module was 18.56%. These results were independently measured at the ESTI in Ispra, Italy.

Acknowledgements

The authors would like to thank the Company Gebr. Schmid GmbH for partly funding this project.

Another part was funded by the collaborative project ’20 percent efficiency on less than 100 µm thick industrially feasible c-Si solar cells’ (20plµs) by the European Commission under FP7 with the contract number 256695.

The team of Harald Müllejans at ESTI is gratefully acknowledged for the module measurements.

References

[1] Braun S, Micard G, Hahn G. Solar cell improvement by using a multi busbar design as front electrode. *Energy Procedia* 2012;**27**:227-33.

[2] von Campe H, Huber S, Meyer S, Reif S, Vietor J. Direct tin-coating of aluminum rear contact by ultrasonic soldering. *Proceedings 27th EUPVSEC,* Frankfurt 2012, p. 1150-3

[3] Haverkamp H,Dastgheib-Shirazi A Raabe B, Book F, Hahn G. *Minimizing the electrical losses on the front side: development of a selective emitter process from a single diffusion*. 33rd IEEE Photovoltaics Specialist Conference 2008:1-4

[3] Blakers AW. Shading losses of solar-cell metal grids. *J Appl Phys* 1992;**7**:5237-41.

[4] Braun S, Herguth A, Micard G, Hahn G. Multi-busbar approaches for solar cell and module optimization. *Proceedings Workshop on crystalline Silicon Solar Cells & Modules: Materials and Processes,* Vail 2012, p. 18-26