Preprint 2nd WCPSE, Vienna 1998

11% semitransparent bifacially active POWER crystalline silicon solar cells

R.Kühn, A. Boueke, M. Wibral, M. Spiegel, P. Fath, G. Willeke, E. Bucher,
University of Konstanz, Faculty of Physics, P.O. Box X916, 78457 Konstanz, Germany
Phone : ++49-7531-88-2260, Fax : ++49-7531-88-3895, e-mail : Ralph.Kuehn@uni-konstanz.de

ABSTRACT: First semitransparent POWER crystalline silicon solar cells (area: 24cm²) with an efficiency exceeding 11% have been fabricated on Cz-silicon. Attention has been paid to apply a fully industry compatible production process. It uses mechanical texturization of the front and rear side of the silicon wafer and screen printing metallization. In the POWER solar cell concept [1] perpendicular grooves on the front and rear side create holes with a variable diameter at their crossing points. This results in an optical transparency of the solar cell. In this study holes of 200µm diameter lead to an transparency of 18% on average for the total cell area. Another purpose of these holes is the electrical interconnection of the emitter on the front and the rear side of the cell. The whole rear side cell surface except the regions underneath the metal grid is diffused with an n-type emitter. As a consequence this solar cell type can collect light bifacially. The front side efficiency of the best bifacial POWER solar cell is 11.6% including a high optical transmittance of 18%. On the rear side this cell achieves 7.2% efficiency.
First results using multicrystalline silicon as well as 10x10cm² substrates are presented.
Keywords: bifacial - 1: solar cell efficiencies - 2: texturisation - 3

1 INTRODUCTION

In the POWER (Polycrystalline Wafer Engineering Result) silicon solar cell concept [1] grooves were implemented into a silicon wafer on the front and rear side perpendicularly using a mechanical dicing saw. At the crossing points of these grooves holes are created which yield a variable semitransparency of the wafer depending on the number and the size of the holes. The semitransparent property of solar cells opens new markets for photovoltaics especially in solar architecture. Existing semitransparent PV modules consist of thin film solar cells (with $\eta < 3\%$) which are cut in small pieces (about 1x2cm²) leaving space in between these cells. The consequence from this system is an undesired inhomogeneous light distribution behind the module. In contrast to this, the presented semitransparent crystalline silicon solar cell gets its semitransparency from about 500 holes/cm² with a diameter of 200µm which offers a very homogenous light distribution. The optical transparency can be varied from 0 - 30% depending on the distance between the holes and their size.
The second purpose of the holes is the electrical interconnection of the front side with the rear side of the cell. As about 70% of the rear side is covered with an active emitter the presented solar cells can collect light bifacially. Optimal arrangement of bifacial solar cells in front of a white background can yield a 59% higher light collection efficiency in comparison to monofacial cells [2].

2 PROCESSING SEQUENCE

After alkaline saw damage etching a dicing saw structures the front surface using 150µm thick dicing blades. In a combined step the rear side of the cell is textured with grooves running perpendicular to the front grooves and at the same time the p-base region on which the rear contacts will be printed gets defined. The arising saw damage is etched in hot NaOH. During the following $POCl_3$-diffusion the n-type emitter is formed. Not only the whole front surface but also around 70 % of the rear surface is covered with an active emitter. The rest of the cell surface is protected by a passivating silicon nitride layer. After P-glas removal a PECVD silicon nitride antireflection coating is deposited on the front as well as on the rear side of the cell. The front and rear metal contact grid is screenprinted and fired through the silicon nitride layer. An accurate alignment of the grid (100µm wide fingers) on the plateaus (<600µm width) is absolutely necessary to prevent shunts. A final edge isolation improves the cell performance because it removes eventual shunts over the cell edge but with a careful handling during the preceding processing steps it is not absolutely necessary.
A scheme of the obtained POWER cell is outlined in Fig.1 whereas Fig.2 summarises the process sequence.

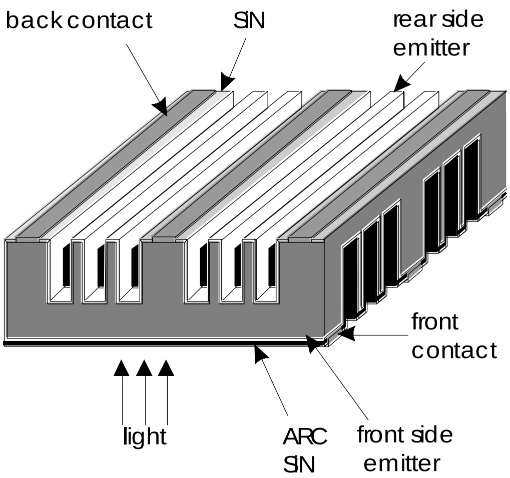

Fig. 1: Scheme of a bifacial POWER solar cell

as-cut Si-wafer

⇓

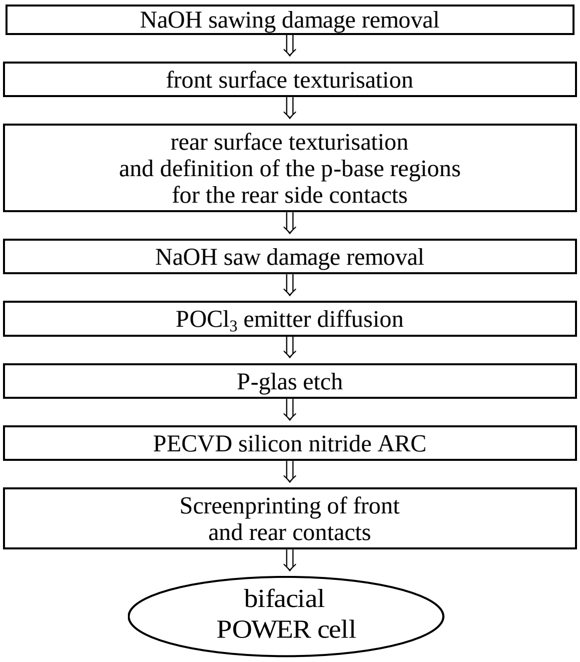

Fig. 2: Diagram of the processing sequence for bifacial POWER silicon solar cells.

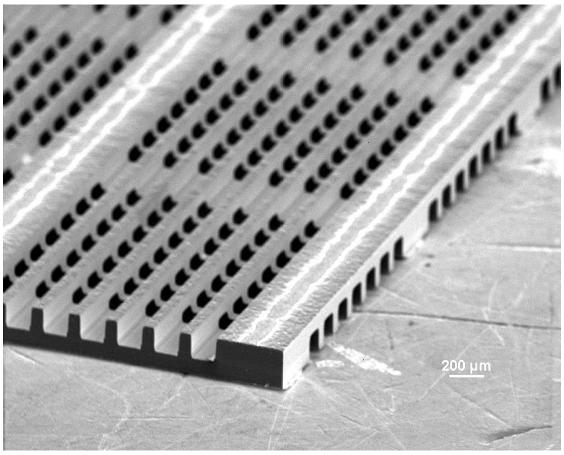

Fig. 3: SEM-picture of a semitransparent POWER silicon solar cell.

The POWER solar cell concept reveals its main advantages on multicrystalline silicon substrates. Due to the short average emitter-bulk distance within this novel device it is especially suitable for materials with a short or medium diffusion length. In order to eliminate variations of the material characteristics during the general cell design optimisation the presented processing scheme has been applied to Cz-silicon.

We learned from the investigation of monofacial POWER solar cells [3] that a good surface passivation is very important for POWER solar cells. Due to the surface texturing the cell surface grows by a factor 3 to 4 and influences the performance of the cell strongly. Especially the regions around the holes where the pn-junction borders on the cell surface are very sensitive to passivation. In order to achieve a high Voc it is absolutely necessary to etch the saw damage completely before covering the cell with a passivating silicon nitride. The effect of pn-junctions bordering on the surface of a silicon solar cell has been studied in detail experimentally and by the help of computer simulations in [4].

3 CELL CHARACTERIZATION

3.1 IV-Measurements

The processing sequence for bifacial a POWER cell is more complex than the one for monofacial POWER cells [3] but it leads to increased cell efficiencies. Table 1 shows the highest results on POWER solar cells achieved so far.

With 586mV the V_{oc} of the bifacial POWER solar cell is only 15mV less than that of equally processed non-textured reference cells despite the enhanced surface area. This fact indicates that the problems of the extended surface area and the junction edge effects are not too serious assuming that the entire cell surface is well passivated and all saw damages are removed. Further more the V_{OC} of POWER cells can profite from the high short circuit current and the thinning of the cell during groove formation. With the process currently used to produce monofacial POWER cells the rear surface remains unpassivated. This reduces the Voc remarkably. The J_{SC} of bifacial POWER cells is very high despite 18% of optical transparency. J_{SC} profits from the short average bulk-emitter distance due to the additional emitter on the rear surface of the cell. The relatively low fill factor is mainly due to a non-optimised contact grid design. To high finger distances lead to a high series resistance (1.35 Ωcm²) within the emitter especially for strongly textured cells where current paths on the surface are 2-3 times longer than on non-textured ones.

Cell-type	Voc [mV]	Jsc [mA/cm²]	FF [%]	η [%]
bifacial POWER. Cz-Si. 5x5cm². front illumination	586	30.0	66.1	**11.6**
rear illumation	560	19.9	64.7	7.2
bifacial POWER. Cz-Si. 10x10cm²	570	26.3	62.0	9.6
bifacial POWER. multi-Si. 5x5cm²	556	27.6	62.6	9.6
monofacial POWER. Cz-Si. 5x5cm²	540	25.4	69.0	9.4

Tab. 1: Characteristics of the best bifacial and monofacial POWER solar cells. All cells have an optical transparency of 18%.

A second point is the increased second diode current I_{02} of POWER solar cells compared to non-textured solar cells due to the enlarged cell surface area and junction edge effects. Due to this increased J_{02} the fill factor is limited to values <75% neglecting series resistance [5].

A more technical and fundamental question is the way how to measure the IV-characteristic of these new solar

cell designs. Due to the holes within the cell standard vacuum chucks can not be used. On the other side the brass chuck reflects parts of the incident light transmitted through the holes. As the cell is bifacially active this light can generate additional charge carriers and improve J_{SC}.
Measurements with a black chuck deliver a 10-15% reduced J_{SC}. The more „political“ question about measuring standards for semitransparent bifacial solar cells is not yet solved.

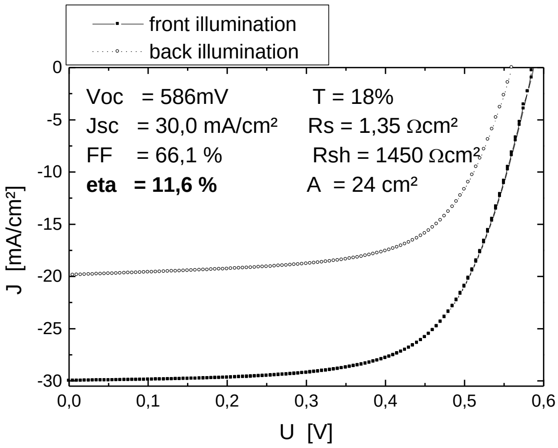

Fig. 4: IV-characteristic of a semitransparent bifacial POWER solar cell illuminated from the front or from the rear side.

3.2 Optical Transparency
In contrast to some other approaches for semitransparent solar cells using thin films, the POWER solar cell shows a homogeneous transparency over the whole visible spectral range (see fig. 4). Another advantage is the homogeneous light transmission as a result of more than 500 holes/cm² . No hard shadows can be seen within the transmitted light except the opaque regions for the busbars.

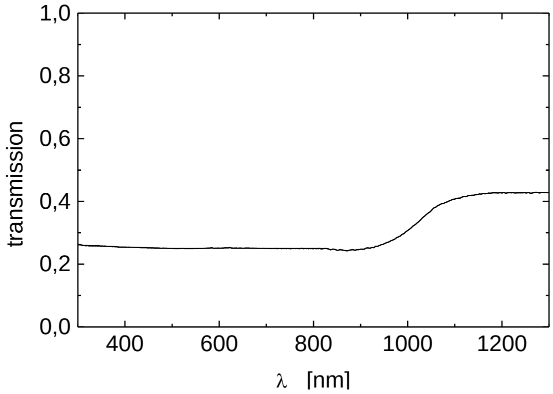

Fig. 5: Optical transmission of a POWER solar cell. The busbar region is excluded. The average transmission over the whole cell area is 18%.

4 CONCLUSIONS

The first semitransparent bifacial POWER solar cell with an maximum efficiency of 11.6% is presented. It shows a very high Jsc of 30mA/cm² due to short bulk-emitter distances. The high Voc of 586mV in spite of the enlarged cell area proves the very good passivation over the entire cell surface. The fill factor is actually limited by a high series resistance due to a non-optimised contact grid. The cell reveals a very good homogeneity in spectral transparency as well as in the light distribution behind the cell.

ACKNOWLEDGEMENTS

We want to thank M. Keil and S. Kühne for the technical support and S. Keller for the help with the IV-measurements. The financial support by the *bmbf* (Germany) and the company „*sunways*“ is gratefully acknowledged.

REFERENCES

[1] G. Willeke, P. Fath: „The POWER Silicon Solar Cell Concept“, Proc. 12th European PVSEC, Amsterdam 1994
[2] A. Luque et al.: „Diffusing reflectors for bifacial photovoltaic panels“, Solar cell 13 (1984-1985), pp. 277-292
[3] A. Boueke, R. Kühn, M. Wibral, P. Fath, G. Willeke, E. Bucher : „ Progress in semitransparent crystalline silicon solar cells“, to be presented on this conference
[4] R. Kühn, A. Boueke, C. Zechner, P. Fath, G. Willeke, E. Bucher: „Investigation of the effect of p/n-junctions bordering on the surface of silicon solar cells“, to be presented on this conference
[5] A. de Vos: „ The fill factor of a solar cell from the mathematical point of view“, Solar cells, 8 (1983), pp. 283-296