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20%-EFFICIENT REAR SIDE PASSIVATED SOLAR CELLS IN PILOT SERIES DESIGNED FOR CONVENTIONAL MODULE ASSEMBLING

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ABSTRACT: In the Reiner Lemoine Research Line at Q-Cells a pilot series fabrication of double-side contacted mono-crystalline solar cells using a dielectric passivated rear side with local metal contacts was implemented. A few hundred of such large area (156 mm x 156 mm) high efficiency solar cells were fabricated on boron doped Cz silicon material per week. Median efficiencies of up to 20% before light-induced degradation are reached. The best large area solar cell has an efficiency of 20.2% after deactivation the light induced degradation due to the boron-oxygen complex. The efficiency is independently confirmed by Fraunhofer ISE and demonstrates the high potential of this cell structure even under production like conditions. The R&D cell development of the passivated rear side was supported by a cooperation work with Fraunhofer ISE. In this paper we present R&D results of the cooperation work with Fraunhofer ISE and Q-Cells continuous technical improvements of the mono-crystalline solar cell process in the pilot series fabrication, which also included testing of quality and reliability of these R&D cells integrated into modules.

Keywords: High-efficiency, passivation, Q.ANTUM technology

1 INTRODUCTION

The double-side contacted and rear side passivated solar cell concept is of particular interest due to its efficiency potential on cell level [1] and compatibility to standard module assembly. For the local rear side metallization the laser-fired contact (LFC) process is a very promising technology for implementing such a cell structure into industrial mass production [2]. Using the LFC technology in combination with a passivated rear side efficiencies up to 21.7% on small area were achieved with amorphous silicon rear side passivation. Small-area multi-crystalline cells with LFC contacted rear side reaching 20.3% efficiency were reported in the past, too [3,4].

On large area (156 mm x 156 mm) boron doped Cz material stable efficiencies of up to 18.6% in pilot series are reported in the literature [5]. These double-side contacted solar cells feature a thermal oxide passivated rear surface and local laser alloyed rear contacts.

Finally, at Q-Cells a R&D pilot series of large area multi-crystalline cells with efficiencies of > 18% [6] and mono-crystalline cells with efficiencies of 19.5% [7] using a passivated rear side and local contacts are implemented. The R&D results of these high-efficiency *p*-type Si solar cells based on the new Q-Cells Q.ANTUM technology demonstrate the high potential of this cell concept. In this paper the R&D technology transfer work of a passivated rear side cell in cooperation with Fraunhofer ISE is presented starting with cell efficiencies of 18.4% at the beginning of 2010. It is also shown the process improvments at the Reiner Lemoine Research Center that lead to the latest R&D results of the 20%-efficient cell pilot series on mono-crystalline wafers based on the Q.ANTUM cell technology in 2011. Mini–modules consisting of four R&D cells are presented which pass the standard IEC climate chamber tests indicating the mechanical and electrical stability of these rear side passivated cells.

2 CELL DESIGN AND BEST MONO-CRYSTALLINE CELL

The design of the large area cells based on the Q.ANTUM cell technology is depicted schematically in Figure 1. The high-efficiency R&D cells benefit from a lowly doped emitter on the front side and a dielectric layer on the rear side using local laser-fired contacts for the rear side metallization.

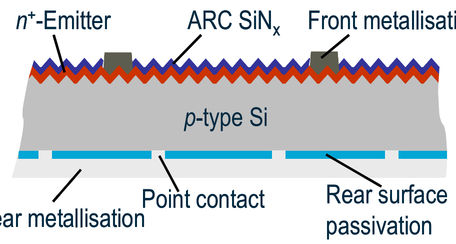

Figure 1: Schematic cross section of the Q.ANTUM cell.

In the Reiner Lemoine Research Line several hundred cells based on the Q.ANTUM cell technology are processed per week. For cell and module development the batch sizes are ~ 50 wafers. Up to now best cell reaches an efficiency of 20.2% after permanently deactivating the light induced degradation due to boron-oxygen-complex [8]. This cell is fabricated on a 156 mm x 156 mm full square Cz wafer reaching an output power of 4.93W_p. Measurement results of this top cell is independently confirmed by Fraunhofer ISE and shown in Table 1.

Table 1: Measurement results of the top cell based on the Q.ANTUM cell technology and measured at the Fraunhofer ISE CalLab.

Status	A	V_{OC}	J_{SC}	FF	η
	[cm²]	[mV]	[mA/cm²]		[%]
After permanent deactivation of boron-oxygen complex	243	652	38.9	79.9	20.2

3 COOPERATION WORK WITH FRAUNHOFER ISE

In cooperation with Fraunhofer ISE starting at the end of 2009, the processes rear dielectric layer deposition, rear screen-print metallization, thermal firing and the laser-fired contacts (LFC) process were set up at the Q-Cells Reiner Lemoine Research Center. An experiment with hybrid Q-Cells–ISE cell processing lead to up-to-18.2%-efficient (18.4% before LID) solderable large-area cells as shown in Figure 2, 3 and Table 2. As the wafers still exhibit a rather highly doped emitter and standard screen-printed metallization, further potential for improvement was left open for Q-Cells on the cell front and rear side leading to higher efficiencies as presented in the previous and following chapters.

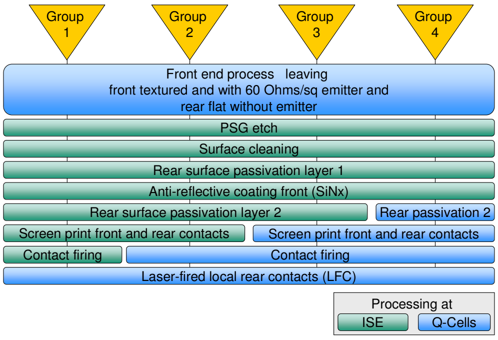

Figure 2: Process flow of 4 investigated groups. Laboratories in which the processes were performed are indicated.

For a quick and successful implementation of the mentioned processes, groups of wafers were partly processed at ISE and at Q-Cells. This allowed an efficient comparison and optimisation of the transferred processes. The quantum efficiency (QE) curves as depicted in Figure 3 show the high quality of the both, the front side and the rear side passivation in high QE values in the short- and long-wavelength regimes. Additionally, the long-wavelength reflection (internal rear-side reflection) is significantly increased compared to the industrial standard Al-back surface field structure.

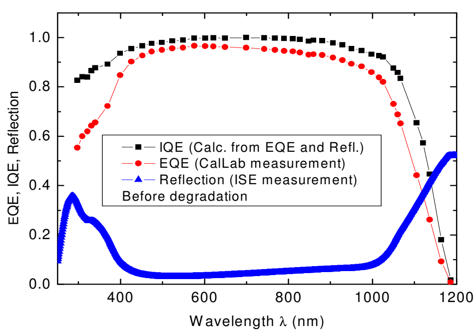

Figure 3: Results of the best cell of the joint experiment (group 3). External quantum efficiency (EQE) measured at Fraunhofer ISE CalLab, reflection characteristics measured at Fraunhofer ISE PV-TEC lab. Internal quantum efficiency (IQE) calculated from EQE and reflection.

Table 2: IV characteristics of the best cell (group 3) as measured at the Fraunhofer ISE CalLab.

Status	A	V_{OC}	J_{SC}	FF	η
	[cm²]	[mV]	[mA/cm²]	[%]	[%]
before degradation	236.9	629.2	37.8	77.4	18.4
after degradation	236.9	625.2	37.7	77.2	18.2

Comparable V_{oc} results of the 4 different groups give proof to a successful passivation layer transfer to the Q-Cells Research Centre. The lower fill factors of group 1 show that the firing process at Q-Cells was better adapted to the Q-Cells emitter compared to the firing process applied at ISE.

Table 3: IV characteristics of the best cells of each group as measured in the Q-Cells Reiner Lemoine Research Centre. Group numbers correspond to Figure 2.

Group	V_{OC}	J_{SC}	FF	η
	[mV]	[mA/cm²]	[%]	[%]
1 before degradation	631.5	38.2	72.9	17.6
1 after degradation	627.5	37.9	72.1	17.1
2 before degradation	632.6	38.1	76.4	18.4
2 after degradation	627.6	37.8	75.5	17.9
3 before degradation	631.5	38.3	76.7	18.5
3 after degradation	627.4	38.0	75.7	18.1
4 before degradation	631.9	37.8	76.9	18.4
4 after degradation	627.0	37.5	76.2	17.9

4 R&D PILOT SERIES OF MONO-CRYSTALLINE REAR-SIDE PASSIVATED SOLAR CELLS

Since the process transfer, we further optimized the complete solar cell process, the front side and the rear side processes in the Reiner Lemoine-Research Center. Several hundred mono-crystalline cells which are double-side contacted and rear-side passivated are processed per week in the R&D environment of the Reiner Lemoine Research Line. For cell and module development the batch sizes are ~ 50 boron-doped Cz wafers. The mono-crystalline cell efficiency based on the Q.ANTUM cell technology was strongly improved step by step in 2011 as shown in Figure 4. The box plot indicates the median values of the efficiency of the batches together with minimum, maximum, and upper and lower quartiles (before light-induced degradation). Up to now best cell run consisting of around 130 cells reaches a median efficiency of 20% before light-induced degradation as shown in Figure 5. High short-circuit current densities of around 39 mA/cm^2 are reached due to the optimized fine-line print metallization on the front side, the lowly doped front-side emitter and the dielectric layer on the metallized rear side enabling an improved infra-red light trapping. The combination of the improved emitter, the passivated rear side and the local contacts enables average open-circuit voltages of 646mV. Afterwards light-induced degradation of the batch the voltages and currents of the cells slightly decrease and a stable median batch efficiency of 19.6% is achieved. Beginning with cell efficiencies of around 18.4% before light-induced degradation in the R&D Research Line the optimization of the front-, rear-side technology and the process flow leads to the 20.2% efficient R&D Q.ANTUM cell and gives a boost of current, voltage and fill factor of 1.1 mA/cm^2, 11 mV and of 3.2% absolute. A comparison of the 18.4% and the 20% cell batch results is given in Table 4.

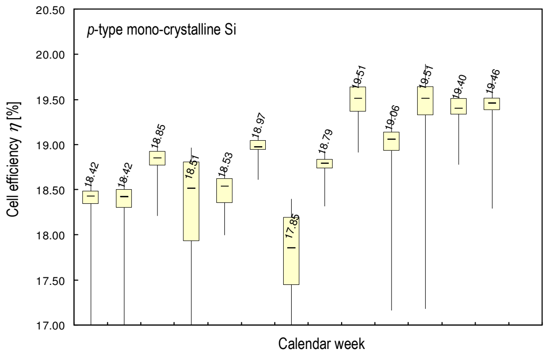

Figure 4: Recent results of the pilot series of mono-crystalline cells based on the Q.ANTUM cell technology at Q-Cells for different calendar weeks.

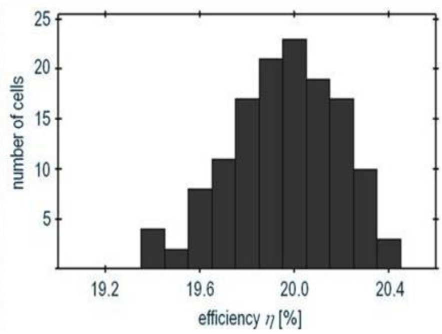

Figure 5: Best R&D cell run consisting of around 130 cells with a median cell efficiency of 20%, an open-circuit voltage of 646 mV, a short-circuit current density of 38.9 mA/cm^2 and a fill factor of 79.8% before light-induced degradation. Measurements were done at Q-Cells.

Table 4: Comparison of a 18.4%-efficient cell batch fabricated at the beginning of 2011 and of the 20%-efficient top batch fabricated in the middle of 2011. Measurements were done at the Q-Cells Research Centre.

	V_{OC}	J_{SC}	FF	η
	[mV]	[mA/cm²]	[%]	[%]
Median batch values before LID	635	37.8	76.6	18.4%
Median batch values before LID	646	38.9	79.8	20.0%

4 QUALITY AND RELIABILITY TESTING OF CELLS AND MODULES

For testing the quality of the R&D Q.ANTUM cells processed at Reiner Lemoine Research Line soldering and adhesion tests of the front- and rear-side busbars were continuously tracked. Peel forces above 2 Newton are reached allowing a conventional assembling of the solar cells into standard modules (see Figure 6).

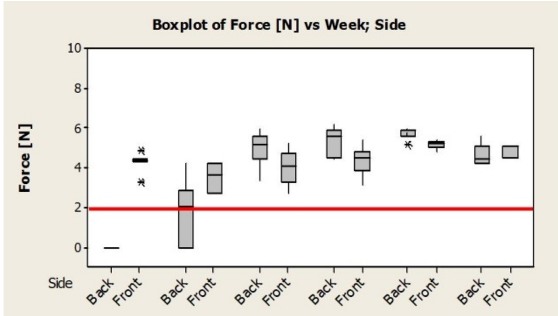

Figure 6: Soldering and adhesion tests of the front- and rear-side busbars. Due to optimisation of the metallization concept peel forces above 2 Newton are reached over several weeks.

In order to evaluate the reliability of the Q-Cells high-efficiency R&D Q.ANTUM cells mini-modules with four cells have been fabricated and climate chamber tests according to IEC 61215 have been performed. The modules are conventionally packaged assemblies of solar glass, polymer foil, interconnected solar cells, polymer foil and transparent back-sheet. The power loss of these mini-modules shown in Figure 8 and Figure 9 is less than 5% after 1000 hours of damp heat testing and also after 50 temperature cycles in combination with 10 humidity freeze cycles. The successful climate chamber tests indicate the quality and long-term stability of our large-area R&D Q.ANTUM cells interconnected and encapsulated with conventional module technology.

Since the presented first R&D results, Q-Cells has provided a lot of work in quality and module testing of the Q.ANTUM technology [9].

Figure 7: Photograph of exemplary mini-module before testing.

Figure 8: Photograph of exemplary mini-module after 1000 hours of damp heat testing. The power loss is less than 5%.

6 CONCLUSIONS

In the pilot series fabrication of double-side contacted and rear-side passivated mono-crystalline cells based on the new so-called Q.ANTUM technology at the Research Line of Q-Cells, the best 130 wafer run reaches a median cell efficiency of 20% before light-induced degradation. The top cell has a stable cell efficiency of 20.2% after permanent deactivation of the boron-oxygen complex which is independently confirmed by Fraunhofer ISE. All cells are fabricated on large area (156 mm x 156 mm), Cz grown and boron-doped silicon wafer material.

Prior to that the processes rear dielectric layer deposition, rear screen-print metallization, thermal firing and the laser-fired contacts (LFC) process were set up at the Q-Cells in a cooperation with Fraunhofer ISE. An experiment with hybrid Q-Cells–ISE cell processing lead to up-to-18.2%-efficient cells on standard boron-doped Cz wafer material. As the wafers still exhibit a rather highly doped emitter and standard screen-printed metallization, further potential for improvement was left open for Q-Cells.

In order to evaluate the reliability of the Q-Cells high-efficiency R&D Q.ANTUM cells mini-modules with four cells have been fabricated and standard climate chamber tests have been performed. The successful climate chamber tests indicate the quality and the long-term stability of the large-area cells. Since the presented first R&D results, Q-Cells has provided a lot of work in quality and module testing of the Q.ANTUM technology.

7 ACKNOWLEDGEMENT

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