Ultra-Large 20 x 20 cm^2 Multi-Crystalline Solar Cells With Spray-On Emitter

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Abstract: PV industry has to reduce costs per W_p if solar energy wants to become competitive to conventional energies. Thinner and larger wafers are two possible ways to decrease solar cell production costs without major changes of cell production technology. While reducing wafer thickness implies the risk of higher breakage rates and increased cell bending, processing of larger wafers is a definite trend of photovoltaic industry. To be compatible to inline production lines cell processing experiments on ultra-large scale multi-crystalline wafers (ULS) were carried out using spray-on technique as alternative emitter diffusion. Technological challenges and the potential of ULS production are pointed out. ULS cells with different front grid designs were processed resulting in a solar cell efficiency of 15.1 %.

Key Words: Sizing, Diffusion, mc-Si Solar Cells

1 Introduction

In the sixties industrial production of silicon solar cells in Germany started on 100 x 100 mm^2 silicon wafers. Latest production facilities are able to process 8 inches multi-crystalline silicon wafer material fully automated. The enlargement of wafer size within the last 10 years by 100% implies an inherent advantage of wafer size for solar cell production. This implicates of course lower production costs per W_p due to higher production capacity, less handling steps per W_p (wafer, cell and module production) and higher packing density in the module. The focus of our studies is on the solar cell production.

2 Potential and Limits of ULS Cells

2.1 Technological Challenges

Taking a closer look to the differences of processing ULS wafers compared to standard wafers, the main problems are a more complicated handling, homogeneity and stability issues. The technological challenges of processing ULS wafers are:

- Mechanical yield during wafer manufacturing.
- Mechanical yield in cell production line.
- Homogeneity over total wafer surface (diffusion, SiN-deposition, screen printing).
- Accuracy of automation.

To estimate the mechanical yield, wafers of different sizes (100 up to 200 mm) were tested with a stability testing tool. The system was used in a twist testing configuration, which gives a relatively good correlation with stress during processing. The measurements show almost no stability change for the range of wafer sizes (measured was max. force or breakage force). On the other hand absolute bending of the wafers is increased and can cause handling problems. However, our first experiments on ULS wafers have shown a different aspect. In spite of the stability experiments wafer breakage was dramatically increased during wafer manufacturing and cell processing (appr. by a factor of 2). Handling and automation has to be adjusted in order to fulfil the ULS requirements. The effect seems to be quite similar to that of thin wafer handling (150 – 200 µm thickness).

2.2 Cost Reduction Potential

Cost calculations in comparison with 125 and 156 mm sized cells were made showing a great cost reduction potential for ULS wafers in batch-type production lines [1]. No efficiency limitations are related to wafer enlargement in principle. But in comparison with chip industry product size of solar cells is total wafer size and leads to additional problems during back-end production (automation & yield). Therefore new production equipment has to be developed, e.g. tabbing or stringing machines to handle three busbars per cell. Assuming that all production and cell values are the same for ULS wafers compared to 125 mm wafers a cost reduction of up to 20 % can be achieved. Even for efficiencies of below 13 % and yields below 90 % (standard for 125 mm cells is about 97 %) a cost reduction is feasible.

Taking additional effects during module production into account, the potential value of wafer size enlargement compared to wafer thickness reduction becomes obvious. Further enlargement of wafer size seems to be limited mainly by handling problems and wafer production.

3 Experiments and Results

Processing of 150 mm edge length has been established as a standard processing size at the University of Konstanz. The experiments on 200 mm wafers were carried out using the spray-on technique as alternative emitter diffusion in order to be compatible to inline processing.

3.1 Solar Cell Process

We integrated the spray-on emitter diffusion into our standard solar cell process (saw damage etch, tube furnace $POCl_3$ diffusion, phosphorus glass etch, edge isolation, PECVD SiN_x ARC, screen printing metallization and co-firing) by replacing only the $POCl_3$ emitter diffusion as shown in Figure 1. All process steps had to be adapted to ULS wafer material.

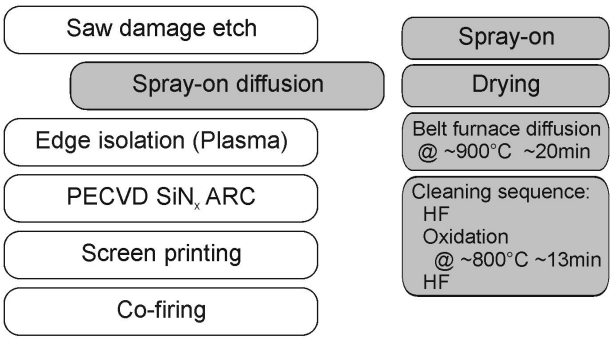

Figure 1 Flow chart of the solar cell process using the spray-on technique.

For the precursor deposition we used a commercial available phosphorus spin-on dopant. The precursor was sprayed onto the wafer surface on both sides. Double sided diffused wafers have a better performance and higher open circuit voltage since phosphorus enables P-gettering of silicon during the diffusion process [2]. After a drying step the diffusion was performed in a belt furnace at temperatures between 890°C and 920°C leading to sheet resistances of 30 to 50 Ω/sq.

One major difficulty of the spray-on technique was the removal of residuals on the surface after diffusion. With the used spin-on dopant the surface of the wafer was not hydrophobic after a first HF dip. An oxidation at about 800°C in the belt furnace and a further HF-dip led to a clean and hydrophobic surface. As alternative cleaning step an acidic oxidation within a HF-Piranha etch-HF sequence is possible [2]. Even better and more suitable for industrial use would be a modified belt furnace design with additional oxygen supply. Diffusion, drive in and oxidation of the phosphorus glass could be achieved in one single step.

3.2 Solar Cell Results

Shown in table I are the results for ULS cells with 30 and 40 Ω/sq emitters. For the most wafers of this run we chose a front grid design with two bus bars.

	sheet res. [Ω/sq]	**bus bars**	**FF** [%]	**J_{sc}** [mA/cm^2]	**V_{oc}** [mV]	**η** [%]
mean	~ 30	2	74.7	32.2	616	**14.8**
best cell	29.9	2	75.1	32.2	617	**14.9**
mean	~ 40	2	72.3	33.5	617	**14.9**
best cell	40.7	2	72.7	33.6	616	**15.0**

Table I Parameters of ULS solar cells with 30 and 40 Ω/sq emitters and two bus bars.

Cells with 30 Ω/sq emitter show a higher fill factor due to better contact formation in the stronger diffused emitter. The lower J_{sc} is a cause of larger penetration depth of a 30 Ω/sq emitter and therefore enhanced losses in this region. A few cells were processed with a four bus bar front grid design. The results are presented in table II.

	sheet res. [Ω/sq]	**Bus bars**	**FF** [%]	**J_{sc}** [mA/cm^2]	**V_{oc}** [mV]	**η** [%]
best cell	30.4	4	76.6	31.4	613	**14.7**
best cell	42.0	4	75.0	32.7	617	**15.1**

Table II Parameters of ULS solar cells with 30 and 40 Ω/sq emitters and four bus bars.

The four bus bar cells show a higher fill factor compared to the cells with two bus bars. This can be explained by lower series resistance losses in the front grid. On the other side the shadowing is increased, leading to a lower J_{sc}.

One ULS cell with four bus bars was sawed into four separate cells in order to compare the cell parameters of big and small cells respectively. The result of the cell with a 30.4 Ω/sq emitter is shown in table III.

	area [cm^2]	**bus bars**	**FF** [%]	**J_{sc}** [mA/cm^2]	**V_{oc}** [mV]	**η** [%]
ULS cell	**400**	**4**	**76.6**	**31.4**	**613**	**14.7**
small cell 1	100	2	77.6	31.6	618	**15.2**
small cell 2	100	2	77.8	31.4	623	**15.2**
small cell 3	100	2	76.3	31.6	616	**14.9**
small cell 4	100	2	77.5	32.0	615	**15.3**

Table III Parameters of one ULS solar cell before and after sawing in four 10x10 cm^2 cells.

The small sawed cells show a much better performance than their ULS mother cell. This is mainly caused by lower series resistance losses as the ULS cell has to deal with a current of 12.6 A compared to 3.2 A for the small cells. Except for cell 3, the 100 cm^2 cells are quite homogeneous. This proves, that processing over the whole wafer area was acceptable homogeneous.

Calculations based on existing results show, that front grid design optimum is a three bus bar design [3, 1]. Within the next experiment we plan processing of ULS cells with two, three and four bus bars in order to find the optimum front grid.

4 Conclusions

Wafer size enlargement seems to be an effective cost reduction strategy of solar cell production. Several cell manufacturers already announced production of multi-crystalline solar cells based on ULS wafer material. But firstly technological challenges like mechanical yield during wafer and cell manufacturing respectively and homogeneity over total wafer surface have to be mastered. Calculations for industrial production show, that a minimum of 12.3 % efficiency or on the other hand a minimum yield of 88 % is needed to get a cost reduction compared to 125 mm cells [1].

Our solar cell process with alternative emitter diffusion provides cells with acceptable performance and homogeneity and is suitable both for batch and inline production. The resulting ULS cells have efficiencies around 15 % and there is still potential for optimization, e.g. texturization and optimized front grid.

5 Acknowledgements

This work was partly supported within the CRYSTAL CLEAR program by the European Commission and the FAKT project by the federal state of Baden-Württemberg.

We would like to thank PV Silicon AG and Deutsche Solar AG for delivery of ULS multi-crystalline wafers.

6 References

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