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# THE OPTIMAL CHOICE OF THE DOPING LEVELS IN AN INLINE SELECTIVE EMITTER DESIGN FOR SCREEN PRINTED MULTICRYSTALLINE SILICON SOLAR CELLS

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ABSTRACT: A selective emitter from a single diffusion process has been applied to screen printed multicrystalline silicon solar cells. The influence of different dopant concentrations in the highly doped regions intended for metallisation and alignment tolerances has been investigated. It was found that the gain reached by increasing the dopant concentration and thereby lowering the specific contact resistance of the emitter electrode can be outweighed by the loss in the short circuit current density ($J_{SC}$) caused by an increased recombination at the front surface and in the emitter. Therefore the process parameters have to be chosen carefully. The open circuit voltage ($V_{OC}$) was found to be nearly independent of the initial doping level.

Keywords: Selective Emitter, Doping, Manufacturing and Processing

## 1 INTRODUCTION

Screen printing and high temperature sintering of thick film metal pastes has become the dominant technology for contacting of the n-doped emitter in crystalline silicon solar cells. One of the main drawbacks of this metallisation technique is its need for a high dopant concentration near the surface in order to achieve a low specific contact resistance of the emitter electrode. The development of new pastes and advanced sintering furnaces has allowed for a decrease of the dead layer thickness with dopant concentration of $10^{20}$ - $10^{21}$ cm$^{-3}$ resulting in the sheet resistance ($R_{sh}$) of the emitter increasing to 55 - 60 Ω/□. It has been reported that in a laboratory environment even emitters with a sheet resistance of 100 Ω/□ have allowed for a low-ohmic contacting by screen printing and sintering [1]. Still, in industry the dominant sheet resistance is lower and the doping level of the emitter much higher as it allows for a wider processing window which is essential for sufficient process stability. This leads to the negative effects of high doping, i.e. a pronounced Auger-recombination in the highly doped regions as well as an increased surface recombination at the Si/SiN$_x$-interface.

A selective emitter design - featuring a high dopant concentration underneath the emitter electrode while reducing the recombination rate in the remaining areas - is able to overcome the limitations that a screen printed contact forces upon the cell structure with regard to the performance of the front surface.

We have applied a selective emitter process similar to that described by Zerga et al. [2] while varying the dopant concentration of the initially diffused emitter resulting in an emitter sheet resistance between 34 - 55 Ω/□.

As screen printing is used for both the masking and metallisation process warping of each screen and alignment tolerances have to be taken into account when designing both the mask and the electrode layout. This leads to a larger areal fraction of the wafer with high doping for the metallisation than necessary in principal. These highly doped regions display a high recombination activity and therefore should be minimized in order to reap the full benefit of a selective emitter design.

## 2 EXPERIMENTS CONDUCTED

50 cells were fabricated on 125 mm multicrystalline wafers with a thickness of 240 µm and a resistivity of 2 Ωcm. After an acidic texturisation, the wafers underwent an inline phosphorus diffusion at Solland Solar Cells GmbH in which the diffusion temperature was varied in order to achieve different doping levels in the wafer. Afterwards, the selective emitter process was applied. A resist mask featuring 400µm wide fingers was screen printed on the wafer before etching back the unmasked areas to a varying sheet resistance between 70 and 110 Ω/□ respectively [3]. The wafers were then coated with an antireflection PECVD-SiN$_x$:H layer. In a last step the front side grid and the full area base electrode were screen printed and sintered in a belt furnace.

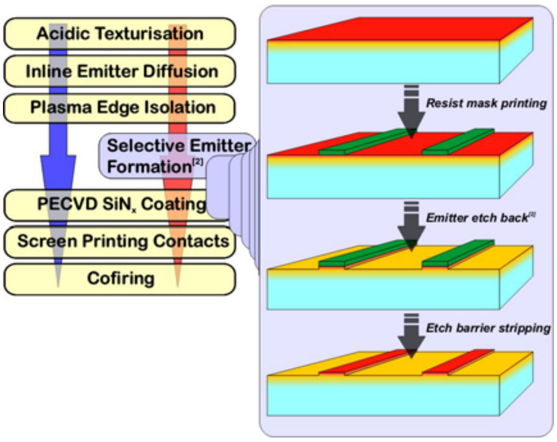

**Figure 1:** Process charts of the selective emitter solar cells (red arrow) and the reference cells with homogeneous emitter (blue arrow). The selective emitter (SE) formation is highlighted and illustrated.

In parallel, a reference batch of wafers was processed in the same way except for the steps leading to the selective emitter formation. Their applied emitter featured a sheet resistance of 55 Ω/□.

## 3 RESULTS

First of all, it can be stated that implementing a selective emitter yields a gain in open circuit voltage as well as in short circuit current for every parameter set on the whole range. However, we have found that increasing the doping level of the emitter further and further does not necessarily improve the cell efficiency via better fill factors. Instead, the losses in the short circuit current density of the cell can outweigh the slight gains that have been reached. This is due to a lower blue response of the cell in the areas needed for alignment tolerances. The results of the IV-measurements are shown below in Table I.

**Table I:** Results of the IV-measurement of the different cell groups, averaged over 4 - 12 cells. The groups are named after their initial sheet resistance after diffusion (first number) and their final sheet resistance after emitter etch back (last number).

| Cell Group | $V_{OC}$ [mV] | $J_{SC}$ [mA/cm²] | FF [%] | η [$\%_{Abs}$] | Gain [$\%_{Abs}$] |
|---|---|---|---|---|---|
| Ref. | 604 | 32.9 | 75.9 | 15.1 | - |
| 45-80 | 609 | 33.8 | 75.4 | 15.5 | + 0.4 |
| 45-100 | 608 | 33.7 | 73.8 | 15.1 | 0 |
| 38-70 | 610 | 33.6 | 76.0 | 15.6 | + 0.5 |
| 38-90 | 610 | 33.7 | 75.7 | 15.6 | + 0.5 |
| 34-80 | 610 | 33.5 | 76.1 | 15.5 | + 0.4 |
| 34-110 | 609 | 33.3 | 73.3 | 14.9 | - 0.2 |

On one hand, there exists a sweet spot for the initial doping level. At values of 34 Ω/□ or below, the small masking tolerance that has not been metallised becomes more and more detrimental as it is a major source for recombination and needs to be minimised [4].

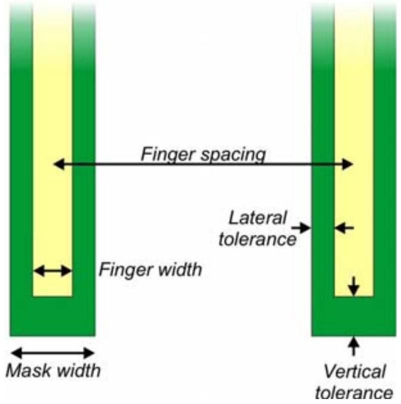

**Figure 2:** Overview over masking parameters. Unmetallised area that was masked for printing tolerance reasons is shown in green.

So it seems wise to limit the initial doping level to values in the 40 Ω/□ range to exploit the beneficial effects on the fill factor and still keep overall emitter recombination low.

On the other hand it can be seen that the gain from etching the emitter back to a sheet resistance higher than 90 Ω/□ has no positive effects with regard to the achieved open circuit voltage. The short circuit current density could not be increased either. Instead, the losses resulting from a drop of the fill factor lead to a reduction of the cell efficiency. The reduction in fill factor is attributed to an increased series resistance in the emitter, as the grid finger spacing was the same for all cells produced.

Measurements of the spectral response show that all groups that received an etch back of the emitter have a significantly increased internal quantum efficiency (IQE) in the short wavelength region (Figure 3).

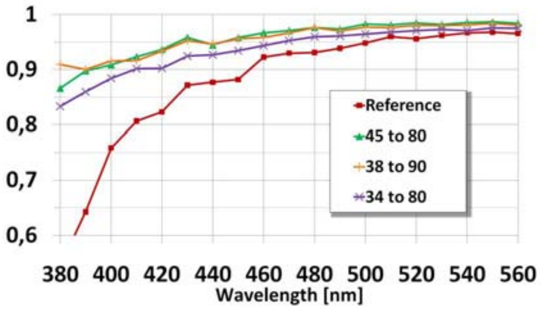

**Figure 3:** Comparison of the determined internal quantum efficiency (IQE) for the best reference cell (red) and three average sample cells featuring an etched back emitter. For the strongest emitter (purple), the masking tolerance already affects cell performance.

Furthermore, it can also be seen that etching back multicrystalline cells yields the best results up to sheet resistances around 80 Ω/□ because further decreasing of the emitter doping does not seem to improve the overall IQE very much. This can be attributed to other factors like material quality that become limiting factors as the emitter improves.

The difference in the IQE in the short wavelength spectrum of the reference cells and the cells with a selective emitter is pronounced. On the contrary, in the long wavelength region the samples show no significant gain that could be due to better gettering properties of the diffusion process with increased temperature. A comparison of the IQE in the long wavelength region is shown in Figure 4.

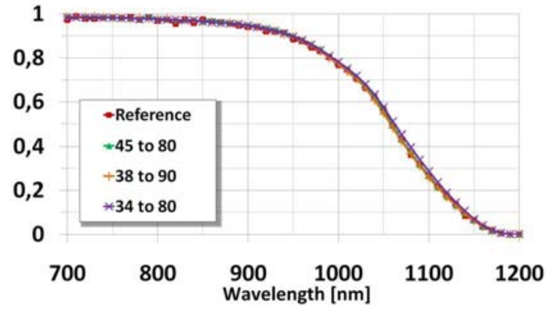

**Figure 4:** Comparison of the IQE of cells with an emitter diffused at different temperature. No significant difference which could be caused by improved phosphorus gettering at higher diffusion temperatures was observed.

## 4 CONCLUSIONS AND OUTLOOK

We have found that a selective emitter concept applied on inline-diffused multicrystalline silicon wafers can significantly improve the cell performance. The gain that can be expected is approximately 0.5%$_{abs}$. If a local etch back of a homogeneous emitter is used, the optimal sheet resistance of the etched back emitter is dependent on the sheet resistance of the initial doping. We have found an emitter sheet resistance of 80 – 90 Ω/□ to show the best performance. These results are in excellent accordance with Shirazi et al. [3] who have shown that no significant performance gain can be expected from the front surface if the sheet resistance of the emitter is increased beyond 100 Ω/□.

It has also been shown that initial doping levels should be stronger than usual in homogeneous emitter designs, but not so strong that unmetallised parts of the non-etched back regions impede cell performance too much.

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The content of this publication is the responsibility of the authors.

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