DETAILED ANALYSIS OF HIGH SHEET RESISTANCE EMITTERS FOR SELECTIVELY DOPED SILICON SOLAR CELLS

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ABSTRACT: A selective emitter structure is a promising approach to improve the cell efficiency of industrial type silicon solar cells by minimizing the losses at the front surface and in the emitter. Selective emitters can be produced by numerous processing sequences, resulting in different doping profiles. This work focuses on evaluating the potential of the high sheet resistance emitters that are created by the selective emitter processes developed at the University of Konstanz (UKN). In these processes, the high sheet resistance emitter is created by a heavy diffusion and an etchback of the heavily doped surface layer [1, 2], or by a weak diffusion with a subsequent drive-in step [4, 5]. QSSPC samples were fabricated to evaluate the emitter quality by measuring the emitter saturation current j_{0E}. On some emitter profiles, SIMS measurements were performed. For the etchback emitter a strong improvement in j_{0E} can be achieved by etching back a heavily doped emitter, resulting in a highest cell efficiency of 18.9%. For the drive-in emitter we have shown that the masking SiN_X layer should be removed and redeposited after drive-in in order to obtain a good hydrogen passivation and a low emitter saturation current.
Keywords: Selective Emitter, Etching, Porous Silicon

1 INTRODUCTION

On today's industrial type solar cells, the front side is homogeneously doped to a level of typically 50 Ω/□, which is a compromise between emitter performance and sufficiently low contact resistance. In order to optimize the emitter, this compromise can be overcome by a selective emitter, which is heavily doped underneath the contact grid, and weakly doped in the illuminated area. This leads to a reduced contact resistance as well as lower Auger- and SRH recombination, resulting in an improved blue response and a higher open circuit voltage.

The selective doping can be accomplished by different processing sequences, resulting in different emitter profiles. In this work, we investigated the properties of the high ohmic emitter region for two selective emitter production sequences that are used at UKN (figure 1). For the one-diffusion process, the emitter is etched back to a higher sheet resistance, while for the two-diffusion process, the high ohmic emitter encounters a drive-in step by the following heavy diffusion.

The emitters were characterized by secondary ion mass spectroscopy (SIMS) doping profiles and quasi steady state photoconductance (QSSPC) measurements on symmetrical FZ-Si samples, furthermore 5" monocrystalline Cz-Si solar cells were processed for each production sequence.

2 CELL CONCEPTS

The processing sequences used to obtain the selective emitter structure are based on the standard screen printing process which is widely used in industrial production.

2.1 One-diffusion selective emitter

This process sequence uses a heavy diffusion which is masked in the area that will be contacted. The mask can be printed with a screen printer [1, 2] or an inkjet printer [3]. The emitter is then etched back in an acidic solution to the desired sheet resistance. During the etching process, a thin layer of porous silicon is formed,

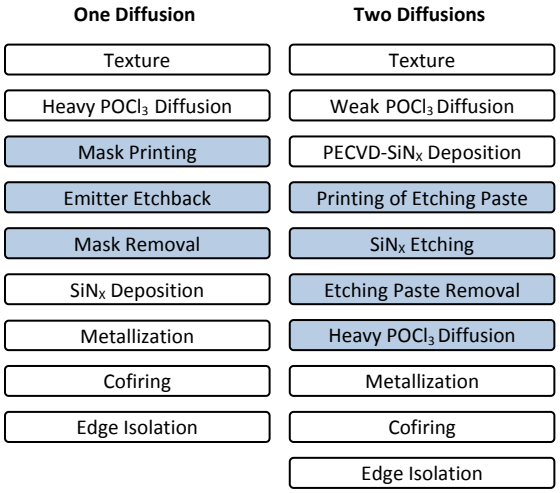

Figure 1: Processing sequence for the formation of a one (left) and two (right) diffusion step selective emitter. The additional steps to the standard screen printing process are marked in blue.

which acts like an antireflective coating (ARC), so the emitter sheet resistance and the etching homogeneity can be controlled by the wafer color. The porous silicon and the masking layer are subsequently removed in an alkaline solution. The following process steps remain unchanged from the standard process, which continues with the plasma enhanced chemical vapor deposition (PECVD) of SiN_X, screen printing of the metallization, cofiring and edge isolation.

2.2 Two-diffusion selective emitter

The two-diffusion process uses a PECVD-SiN_X layer as a mask which is deposited after the first diffusion. This layer has to be opened in the contact area by an etching paste that is screen printed and then heated to approx. 400 °C. The paste residues have to be removed in an ultrasonic bath with water, some KOH can be added [4]-[7]. After the heavy diffusion, the front side metallization can be printed into the opened area using the masking SiN_X layer as an ARC. The SiN_X can also be removed

and redeposited before printing the metallization in order to ensure a good passivation quality.

3 EMITTER CHARACTERIZATION

The high ohmic emitters created by the described process sequences differ in their doping profile and emitter saturation current. For the etchback emitter, the highly doped dead layer is removed, resulting in a lower surface phosphorous concentration ($[P_s]$). The two-diffusion process also reduces the surface concentration by a drive-in of the high ohmic emitter during the heavy diffusion. It can be assumed that the passivation quality of the masking SiN_X is influenced by the heavy diffusion.

3.1 QSSPC measurements

The QSSPC measurements were performed on symmetrical FZ-Si samples passivated by a standard PECVD-SiN_X layer. For each group, six samples were processed, the results are shown in figure 2.

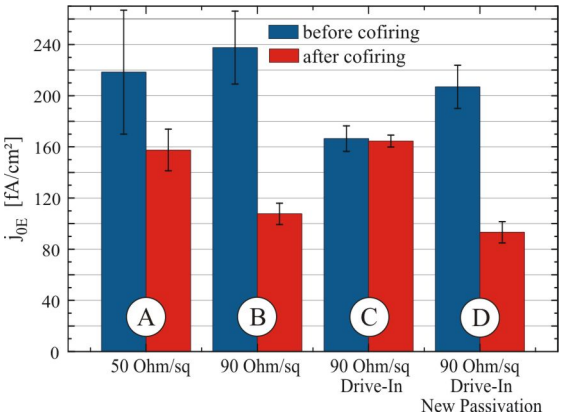

Figure 2: Emitter saturation currents of a 50 Ω/□ reference emitter (A), a 90 Ω/□ emitter (B), a 90 Ω/□ drive-in emitter passivated with the masking SiN_X (C) and a 90 Ω/□ drive-in emitter with a new SiN_X passivation (D).

As a reference, a 50 Ω/□ emitter was chosen (group A). All other samples were diffused to 90 Ω/□ (B) by reducing the peak diffusion temperature, and passivated with a 75 nm SiN_X layer. Group C and D were then exposed to a 50 Ohm/sq diffusion, as can be used as a heavy diffusion for the two-diffusion process, while the SiN_X layer acts as a diffusion barrier. Finally, on group D the SiN_X was removed in diluted HF, and the same layer was deposited again. All samples were measured before and after firing in an IR belt furnace.

Comparing group A and B, an improvement of 50 fA/cm² after firing can be observed, which is attributed to the lower doping level. Group C shows a strong increase in j_{0E} and no improvement can be achieved by the firing step. This gain, which is clearly visible at the other groups, is due to the hydrogen passivation from the silicon nitride. It seems as if all the hydrogen diffuses out of the SiN_X during the drive-in diffusion. This suggests that no voltage gain should be possible by a two-diffusion SE process in which the masking PECVD-SiN_X is also used as an ARC. In group D the positive effect of the drive-in is visible, compared to group B, j_{0E} is improved by 14 fA/cm².

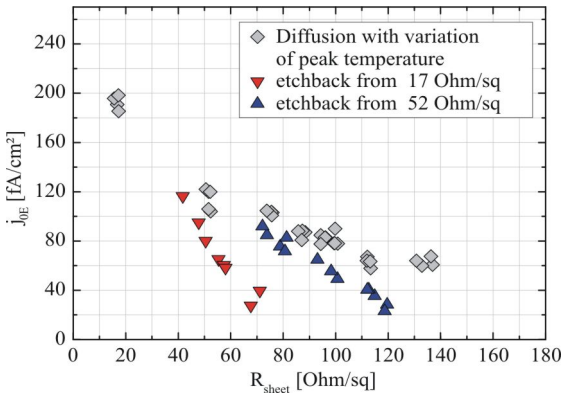

Figure 3: Comparison of j_{0E} from directly diffused QSSPC samples and emitters etched back from 17 and 52 Ω/□.

In order to compare the direct diffusion to an etchback emitter of the same sheet resistance, 7 groups of samples with a sheet resistance between 17 and 137 Ω/□ were directly diffused, only by changing the peak diffusion temperature. Etchback emitter samples were etched to sheet resistances up to 119 Ω/□ using two of these groups (17 and 52 Ω/□). The sheet resistance measurement was performed contactless by a Semilab WT-2000 before the SiN_X deposition. The measured j_{0E} values after firing are shown in figure 3.

The directly diffused samples show a decay of j_{0E} with R_{sheet} that saturates above 110 Ω/□ to a constant level of approx. 60 fA/cm². For the emitters etched back from 52 Ω/□ a reduction in j_{0E} compared to the directly diffused emitter can be observed, when etching back from 17 Ω/□ an extremely low j_{0E} of 28 fA/cm² at 68 Ω/□ was achieved. On cell level, this for a selective emitter comparably low sheet resistance increases the lateral emitter conductivity, allowing larger finger spacing and thereby a higher short circuit current.

3.2 SIMS doping profiles

The doping profiles measured by SIMS show the chemically active phosphorus concentration. The profiles were taken from the same samples as were used for the QSSPC measurements.

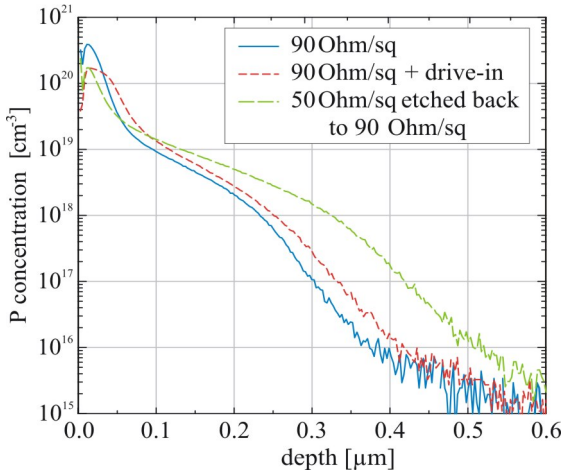

Figure 4: SIMS profiles of emitter B and C/D from Fig. 2 and an etchback emitter etched from 50 to 90 Ω/□.

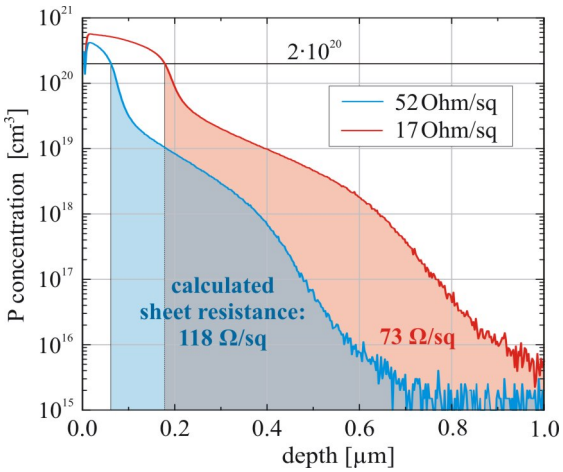

Figure 5: SIMS profiles of a 17 and 52 Ω/□ emitter. The colored areas mark the emitters etched back to the same surface concentration of $2 \cdot 10^{20}$ cm^{-3}.

Figure 4 shows the doping profiles of emitter B and C/D from figure 2, and an etchback emitter that is etched from 50 to 90 Ω/□. In the doping profile, the drive-in effect of the 50 Ω/□ diffusion is clearly visible, the profile is deeper and [P_s] is decreased from $3.9 \cdot 10^{20}$ cm^{-3} to $1.7 \cdot 10^{20}$ cm^{-3}. The etchback emitter features the same [P_s], but the concentration decreases faster at the surface and the emitter is even deeper than the drive-in emitter.

From the emitter profiles of the 17 and 52 Ω/□ emitter (figure 5), which were used as the heavy diffusion for the etchback emitters in figure 3, the sheet resistance starting from a given depth into the emitter can be calculated with a software written by G. Schubert using a mobility model from Masetti et al. [8]. If the depth from which the sheet resistance is calculated is set to the sheet resistance value measured on the QSSPC samples, this gives a good estimation of their [P_s]. In figure 6, the j_{0E} of each etchback emitter is plotted versus the calculated [P_s]. In this plot it seems to make no difference from which sheet resistance the emitter was etched back, which implies that j_{0E} is mainly determined by [P_s].

The colored areas in figure 5 show emitters etched to the same [P_s] of $2 \cdot 10^{20}$ cm^{-3}. Although these emitters should have the same j_{0E}, the calculated sheet resistance

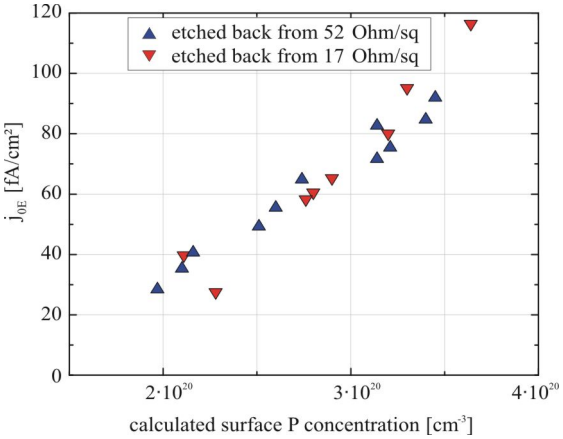

Figure 6: Measured j_{0E} of each etchback emitter from figure 3 versus the calculated [P_s] according to the mobility model of [8].

for the emitter etched back from 17 Ω/□ is only 73 Ω/□, compared to 118 Ω/□ if the emitter is etched back from 52 Ω/□. For the one-diffusion process that means, that by choosing a low starting sheet resistance, not only the contact resistance is improved, but also the finger spacing can be enlarged leading to a higher j_{SC}. A very low starting sheet resistance should still be avoided, because an etchback of 180 nm as would be necessary to etch from 17 to 73 Ω/□ influences the surface texture, leading to an increased reflection. The optimal choice of the heavy diffusion therefore also depends on the random pyramid size. If the low ohmic area is chosen larger than the metallization in order to have a tolerance for misalignment, the low IQE of this area also has to be considered.

4 SELECTIVE EMITTER SOLAR CELLS

For each process sequence 5" Cz-Si solar cells were processed. The alkaline texture was applied by Solarwatt Cells GmbH. For all printing steps, a screen printer was used. The mask for the one-diffusion process, the etching paste for the two-diffusion process and the front side metallization were printed with the same screen. A full area Al BSF without soldering pads was used for rear side metallization and the edge isolation was carried out by an automatic dicing saw.

The etching of the masking SiN_X for the two-diffusion SE cells was carried out on a hotplate with a SiC surface at 375 °C. For the 'new passivated' cells, the masking SiN_X was removed in diluted HF and a new PECVD-SiN_X layer was deposited.

Table I: IV measurement results of 5" Cz-Si solar cells. The average values are taken from 7-10 cells.

Cell		FF [%]	V_{OC} [mV]	j_{SC} [mA/cm^2]	η [%]
Reference	avg.	78.1	629	36.9	18.2
45 Ω/□	best	78.5	630	36.9	18.3
1-diff. SE	avg.	78.1	639	37.5	18.7
30/65 Ω/□	best	78.4	640	37.6	18.9
2-diff. SE	avg.	76.9	631	37.5	18.2
30/65 Ω/□	best	77.3	632	37.6	18.4
2-diff. SE	avg.	71.0	635	38.1	17.2
New passiv.	best	74.4	635	38.2	18.0

With the one-diffusion SE process an efficiency gain of 0.5%$_{abs}$ was achieved. The increased emitter series resistance is compensated by a lower contact resistance, so no loss in fillfactor occurs.

The two-diffusion SE process increases j_{SC} by 0.6 mA/cm², V_{OC} is only improved by 2 mV, which agrees with the QSSPC results and can be explained by the lower passivation quality of the masking SiN_X layer. The reduction in fillfactor is caused by a locally increased contact resistance, which can be seen on an electroluminescence (EL) image.

With a new passivation layer, V_{OC} is increased by 4 mV, these cells also feature the highest j_{SC} which can only partly be explained by the lower reflection of the new passivation layer. The strong reduction in fillfactor is again due to a bad contact resistance. An explanation for the contact problems at the two-diffusion SE cells could be an incomplete opening of the SiN_X layer by the

etching paste. This would lead to a locally higher sheet resistance in the contacted area.

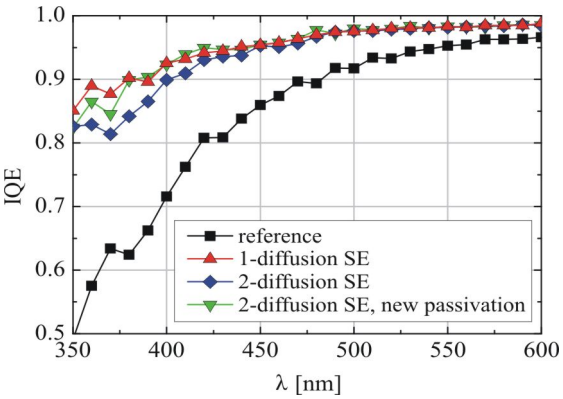

Figure 7: Internal quantum efficiency (IQE) for all cell types. The selective emitter cells show an improved blue response, which leads to the higher j_{SC}.

5 SUMMARY

In this work, the properties of high ohmic emitters resulting from a one- and a two-diffusion selective emitter process were investigated. The emitter saturation current j_{0E} was measured on symmetrical FZ-Si samples. It was shown, that for an etchback emitter as created in the one-diffusion process, j_{0E} could be reduced to 28 fA/cm² for a 68 Ω/□ emitter by etching back from a very low sheet resistance of 17 Ω/□.

For the two-diffusion process, the measurements show an increase in j_{0E} for an emitter, on which the passivating PECVD-SiN_X layer was exposed to a 50 Ω/□ diffusion used as a drive-in step. The positive effect of the drive-in can only be observed after a new passivation and in the SIMS profile.

On cell level, the two-diffusion SE cells feature a lower V_{OC} compared to the one-diffusion process, which is in agreement with the j_{0E} results. The one-diffusion process resulted in an efficiency gain of $0.5\%_{abs}$ and a highest efficiency of 18.9% on 5" Cz-Si solar cells.

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