ETCH BACK SELECTIVE EMITTER PROCESS WITH SINGLE POCL$_3$ DIFFUSION

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ABSTRACT: Selective emitter by etch back is an easy method to obtain a better blue response and lower contact resistivity and therefore to improve the performance of a solar cell. To achieve a selective emitter with only one diffusion step provides a cost reduction. In this work it is shown that it is possible to achieve a selective emitter by etch back with commercial etching paste applied by screen printing. Both activation of the etching paste and cleaning afterwards can be done with inline production equipment. Accurate alignment of the screen printed front side grid is essential. The selective emitter cells show a big improvement in open circuit voltage and efficiency. It is shown that the improvements are due to a better IQE and lower front side recombination.

Keywords: selective emitter, c-Si, etch back

1 INTRODUCTION

In wafer based p-type silicon solar cells the n-type emitter has to be highly doped to enable low contact resistivity between emitter and front side metallization. However, highly doped solar cell emitters show losses due to low short wavelength spectral response, increased Auger recombination and high surface recombination. The losses can be reduced with the selective emitter approach [1].

There are different approaches in literature to achieve such a selective emitter. Röder et al. are developing a process where the doping concentration and emitter depth underneath the contact fingers is increased by laser doping from the phosphorus silicate glass [2]. Another approach by Lauermann et al. uses an etching resist which is deposited by inkjet [3]. With this mask it is possible to etch back the emitter between the fingers. Afterwards the resist has to be stripped and a further cleaning step is necessary. A process with two diffusion steps using a structured antireflection coating as mask is already in production [4].

All these processes have advantages as well as disadvantages. Laser processes for instance are very slow and the need of two diffusion steps is expensive. The new etch back emitter process with Merck's etching paste, isishape® SmartEtch™ AQS is a simple method using standard screen printing technology for selective emitter formation with only one diffusion step.

2 EXPERIMENTALS

Alkaline texturized 6" Cz-Si wafers were used in our experiments. The process steps of our selective emitter concept are outlined in figure 1. After a strong POCl$_3$ diffusion (45 Ω/sq) the emitter is selectively etched back by screen printing of an etching paste which has recently been developed by Merck. The etching paste is printed directly on the phosphorous silicate glass (PSG) surface. We developed a screen layout with closed areas (bars) for the fingers and open areas between the fingers. We used a semi automatic Baccini screen printer and for this system it is necessary that the widths of the closed bars are broad enough to ensure a save alignment during front contact metallization. In this experiment we used a screen with 300 µm closed bars.

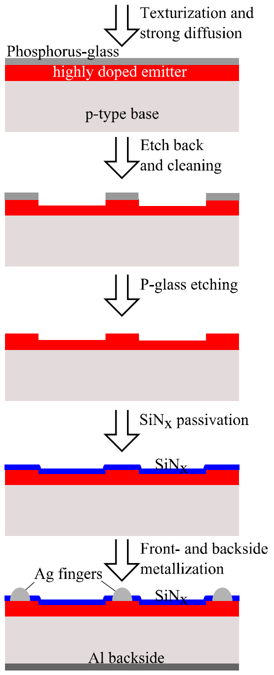


Figure 1: Process steps of our selective emitter concept (not true to scale).

The etching paste gets reactive at 280°C. Therefore after printing the paste is activated in an industrial infrared belt furnace. During activation the phosphorous glass and parts of the emitter are etched away in the coated areas. The achieved sheet resistance in the etched areas is dependent on the belt speed which means the duration time in the furnace. Hence the etching depth could be easily adjusted.

The remaining etching paste is removed with an inline cleaning system, equipped with ultra sonic bath filled with 0.07% KOH diluted in DI water at 50°C, cascade rinsing with DI water and drying afterwards. After the cleaning step the remaining phosphorous glass on the highly doped regions is etched off and PECVD-SiNx is deposited as passivation and antireflection layer. With the same screen printer and a negative screen compared to the etching paste screen, the front side silver is printed onto the highly doped plateaus which were not treated during the etch back process. It is essential that the alignment is as good as possible to minimize necessary tolerance in the etching step. As paste we used state of the art commercial silver paste to ensure best possible results for the reference cells. However these recent pastes are developed for contacting high sheet resistant homogeneous emitters and are thus not necessarily optimal for contacting our highly doped regions. Full area aluminium screen printing is used for rear side contact and back surface field formation. After the co-firing process and laser edge isolation the cells are characterised by IV, spectral response (SR), Suns-Voc and electroluminescence measurements (EL). Reference wafers are processed with a homogeneous emitter for comparison. These wafers passed through the same process sequences without the etch back and the cleaning step. Representative wafers were measured by electrochemical capacitance voltage (ECV) measurement before and after the etching step.

3 RESULTS AND DISCUSSION

In the first step of the development we tested which etching time (duration time in the belt furnace) is the most adequate. Therefore we etched samples with different belt speeds and measured the sheet resistance with a four point probe measurement system. Afterwards we finished the solar cells and measured their IV characteristics. The best cell results were obtained at a sheet resistance between 85 and 110 Ω/sq. This could be achieved with a belt speed between 6 and 7 m/min for a standard furnace with 2.4 m heating zone.

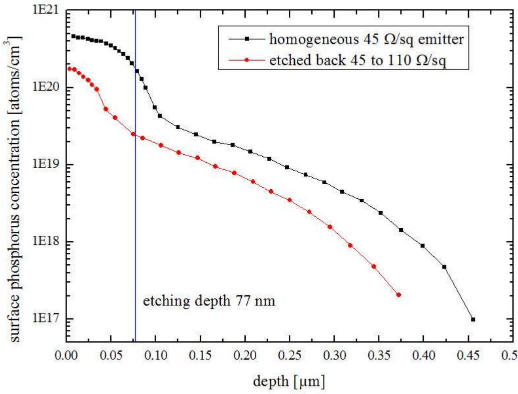


Figure 2: ECV profiles of a homogeneous 45 Ω/sq emitter and an etched back emitter.

With this information we produced selective emitter (SE) cells with a high doping and compared them to reference cells with a homogeneous emitter and 68 Ω/sq sheet resistance. To control the diffusion profile we measured the ECV profiles of a cell with 45 Ω/sq sheet resistance. The profile plotted in figure 2 shows the electrical active phosphorus surface concentration versus the emitter depth. Etching of around 77 nm results in an emitter sheet resistance of 110 Ω/sq. The resulting concentration profile is also plotted in figure 2. Due to the etching the surface phosphorus concentration is reduced, which also means that the surface recombination velocity is lower [5, 6].

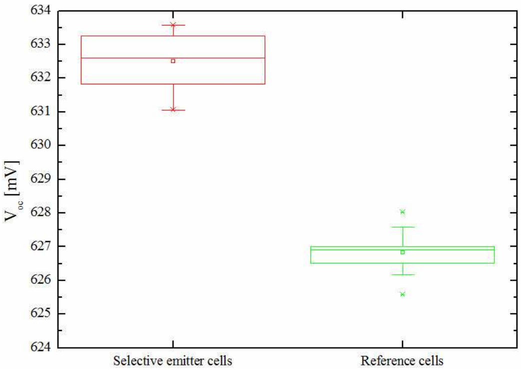


Figure 3: V_{oc} of the selective emitter cells (45/110 Ω/sq) and the reference cells with 68 Ω/sq sheet resistance (material 2).

V_{oc} and FF results are plotted in figure 3 and 5 respectively and the IV data of the cells processed for each group is summarized in table 1. The open circuit voltage of the selective emitter cells is about 5 to 6 mV higher than the open circuit voltage of the reference cells (see figure 3). This effect could be explained due to less Auger recombination and therefore longer charge carrier lifetime in the emitter region and reduced electrical inactive doping surface concentration in the etched area.

Table 1: IV data of SE cells and reference cells with homogeneous emitter (5 cells per group) and IV data of second experiment with another material (10 cells per group).

	ρ_s [Ω/sq]	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
material 1					
SE	45/90	632.1	36.9	78.9	18.4
Ref.	45	623.7	35.8	79.5	17.8
material 2					
SE	45/110	632.6	36.5	78.2	18.1
Ref.	68	626.9	36.2	78.5	17.7

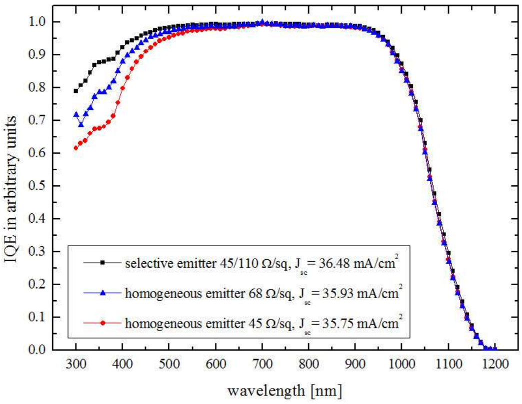


Figure 4: IQE of one SE cell and two cells with homogeneous emitter, 45 and 68 Ω/sq respectively.

Also the short cuircuit current is obviously better (see table 1). This is explainable due to the better blue response of the high ohmic emitter between the metal grid of the selective emitter cells. This effect is confirmed by the spectral response (SR) measurements, which were done with one SE cell and two cells with different homogeneous emitters. The resulting IQE curves are plotted in figure 4. The difference between all three cells in the wavelength range from 300 to 550 nm is in evidence. As expected the homogeneous 68 Ω/sq emitter cell is better than the 45 Ω/sq homogeneous emitter cell. In the short wavelength range the SE cell has the highest IQE and above 550 nm the curves of all three cells are similar. This effect is reflected in the higher short circuit current of the SE cells. The emitter between the contact grid is high ohmic and has thus a lower recombination velocity [7].

The mean efficiency of the SE cells is increased by about 0.6% and accordingly 0.4% absolute (table 1). The increased Voc and J_{sc} values are responsible for this improvement.

The fill factor of the SE cells in figure 4 is lower than the fill factor of the cells with homogeneous emitter. However the pseudo fill factor of SE cells is almost similar. Since this measurement is independent from the series resistance the little difference of the pseudo fill factor can be explained through material differences. Further series resistance losses in the high resistivity emitter between the fingers are responsible for the lower FF of the SE cells.

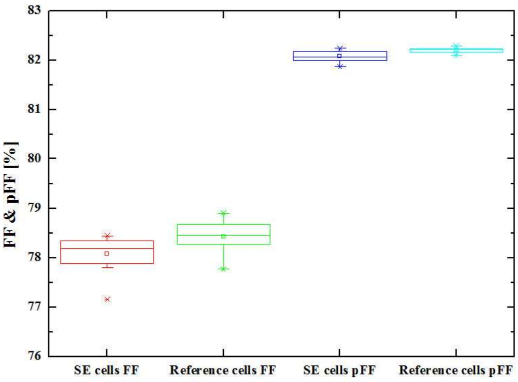
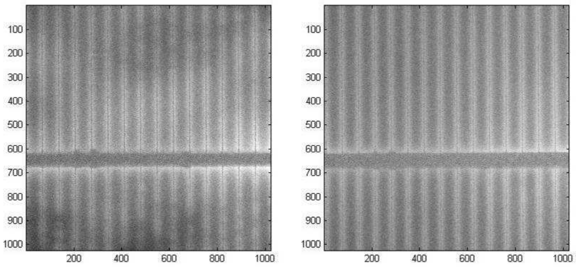


Figure 5: Fill factor and pseudo fill factor of the two groups (material 2).



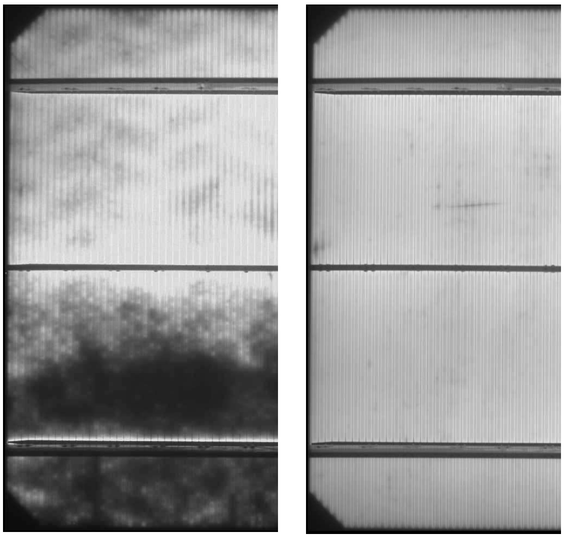
6 a) 6 b)

Figure 6: a) EL image of a cell with homogeneous emitter (68 Ω/sq), **b)** EL image of a SE cell (45/110 Ω/sq).

To proof this assumption we made zoomed EL images of two different cells at 5 and 10 A. The image at a low current shows a result with lower series resistance effect than the image at a high current. In each figure 6 a) and b) the 10 A image is divided by the 5 A image. The resulting electroluminescence signals are on the same level and reduced by stray light. Figure 6 a) shows such an image of a homogeneous emitter cell with 68 Ω/sq and figure 6 b) an image of a SE cell (45/110 Ω/sq). It is obvious that the contact of the SE cell is more homogeneous but still a more detailed statement about the sheet resistance between the metal fingers is not possible.

The finger distance of both screens is still not the optimum and adjustment of the screen layout both regarding the finger distance and the selective emitter width is necessary. As mentioned before the width of the unetched area under the finger is 300 µm. The metal fingers have a width of about 100 µm, so there is an area of 200 µm width around the fingers, which is highly doped. This large distance was necessary to ensure a good and reliable alignment between the etching paste printing and metal printing. But the low ohmic area around the fingers has a high Auger recombination and lower blue response. Hence this area should be reduced as much as possible.

Electroluminescence measurements (EL), which we use for process control of the metallization and firing, are a good indicator for misalignment. Such a misaligned cell is shown in figure 7 a). The etched grid and the metallization grid are tilted: One part of the cell is well aligned and therefore the contact is good, while in the other part the metallization is on the etched area instead. The high sheet resistance of this region leads to an insufficient contact. For this reason this region is dark in the EL picture.



7 a) 7 b)

Figure 7: a) Image of a misaligned cell done by electroluminescence measurement, **b)** EL image of a well aligned SE cell. The series resistance is very homogeneous over the whole cell.

In figure 7 b) the EL measurement of such a cell with good alignment is shown. The difference to the cell in figure 7 a) is obvious. The whole cell area shows a homogeneous series resistance, which proves that the contact resistivity is low and the alignment fine.

4 CONCLUSIONS

The selective emitter concept with Merck's etching paste improves the cell efficiency and first of all the open circuit voltage of the solar cells. It is shown that the improvements are caused by a better IQE and lower front surface recombination. It is an easy concept using only standard screen printing technology for the formation of the selective emitter and inline production equipment for the cleaning of the etching paste. During this work we improved the alignment by changing the screen layout and upgrading the alignment process of the screen printer. In the corresponding electroluminescence images this improvement is clearly seen in the lower series resistance.

Still further development is necessary. With another front side Ag paste, smaller etching plateaus, diffusion and co-firing adjustments increased gain in efficiency and V_{oc} is possible.

The etch back process has the potential to save the PSG etching step by using chemical edge isolation after diffusion instead of the laser edge isolation after the whole process sequence. The remaining PSG under the contact should have no significant effect on the solar cell performance.

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