SELECTIVE EMITTER FOR INDUSTRIAL SOLAR CELL PRODUCTION: A WET CHEMICAL APPROACH USING A SINGLE SIDE DIFFUSION PROCESS

A. Dastgheib-Shirazi[1], H. Haverkamp[1], B. Raabe[1], F. Book[1], G. Hahn[1,2]
[1] University of Konstanz, Department of Physics, P.O. Box X916, 78457 Konstanz, Germany
[2] also with Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstr. 2, 79110 Freiburg, Germany
Author for correspondence: amir.dastgheib-shirazi@uni-konstanz.de, Tel.: +49 7531 882088, Fax: +49 7531 883895

ABSTRACT: This work describes the implementation of a novel process for a single diffusion selective emitter fabrication on mono- and multicrystalline silicon solar cells. To create a selective emitter structure a wet chemical route for an emitter etch back process has been applied. The areas of the wafer that are intended for front side metallization are shielded from etching by an acid resistant etch barrier. The emitter etch back and the removing of the etch barrier are implemented by a wet chemical process. By means of successfully transferring the described selective emitter structure on a standard screen printed cell process an increase of efficiency of more than 0.3 $\%_{abs.}$ has been achieved.
Keywords: Selective Emitter, Single Diffusion Process, Emitter Etching

1 INTRODUCTION

Today the usually applied homogeneous emitter in screen printed solar cell fabrication of mono- and multicrystalline substrates is one of the main limiting factors of the efficiency of industrial silicon solar cells. The homogeneous emitter with a sheet resistance of about 50 Ω/Sq and a junction depth of about 500 nm is a compromise between a sufficient contact quality of screen printed silver metallization and a low recombination rate at the front surface. An emitter with a high surface dopant concentration and a more expanded dead layer allows for a very good contact quality, but the lifetime of generated charge carriers close to the front surface is strongly decreased because of Auger-recombination and enhanced SRH-recombination caused by a non sufficient surface passivation. To obtain a high quantum yield near the surface a lowly doped emitter with a decreased surface concentration and a reduced thickness of the dead layer has to be applied. The strength of both types of recombination can be evaluated by the saturation current in the emitter. The advantages of both emitters are realized in a selective emitter structure with highly doped regions underneath the front side metallization and a lowly doped region between the front grid lines.

A selective emitter structure with one diffusion step has been realized by a novel etching and masking technique at the University of Konstanz. This approach allows for a controlled and homogeneous reduction of the surface concentration and thickness of the dead layer by a wet chemical etching process.

2 ETCH SOLUTION

The kinetics of several etch back solutions have been investigated to achieve a homogeneous etch back emitter. The homogeneity of the etched-back emitter in a selective emitter structure avoids local high series resistance and local increase of the recombination rate.

Mono- and multicrystalline samples with different texturization and a $POCl_3$ emitter were treated with two different etch solutions, an alkaline solution of aqueous KOH and isopropanol, and an acidic solution of HF, HNO_3 and H_2O to achieve an optimal homogeneity. After etching back of the $POCl_3$ emitter the sheet resistance was measured. By means of the intensity of its standard deviation the homogeneity of the etched-back emitters could be assessed.

The results show that for multicrystalline substrates an alkaline solution does not provide a sufficient homogeneity. The investigation with an optimized acidic etching solution provides a high homogeneity even for multicrystalline substrates. This means that an acidic etching solution is better suited for etching back an emitter. Furthermore, the acidic solution, which has been introduced, can be implemented for batch or inline machinery by adjusting the etching rate and bath temperature.

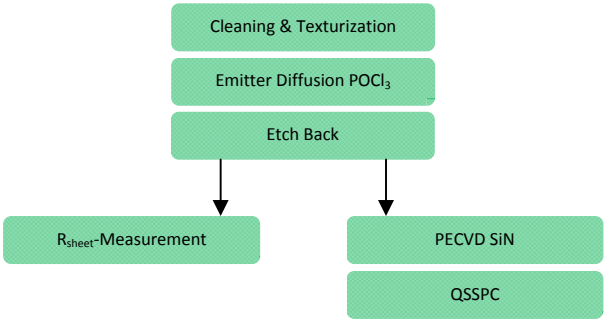

Figure 1: Processing sequence of samples for R_{sheet}- and J_{0e}-measurement.

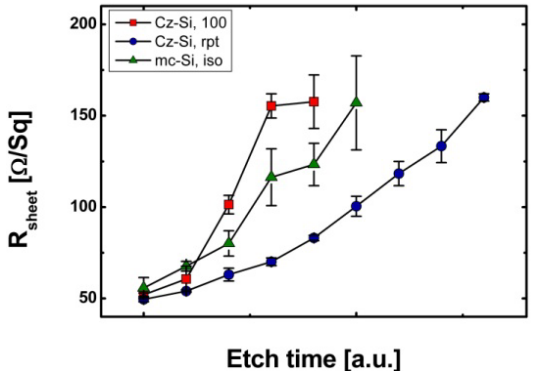

Figure 2: Temporal development of the sheet resistance for etched-back emitters on three different substrates (three different textures: NaOH, random pyramid texturization and acidic texturization for mc-wafers) in an alkaline etch solution at a temperature of 50°C.

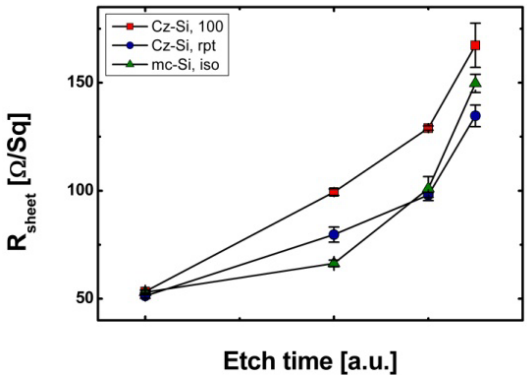

Figure 3: Temporal development of the sheet resistance for etched-back emitters on three different substrates in an acidic etch solution.

To evaluate the quality of an etched-back emitter the emitter saturation current densityJ_{0e} was measured by Quasi State Photo Conductance (QSSPC) in high injection conditions. First the samples underwent a heavily doped $POCl_3$ emitter diffusion (30 Ω/Sq) and were subsequently etched-back to 50, 100 and 150 Ω/Sq. After that step a PECVD SiN_x coating was deposited on both surfaces to passivate the samples and the QSSPC-measurement has been carried out. A comparison of the emitter saturation current density is shown in figure 4.

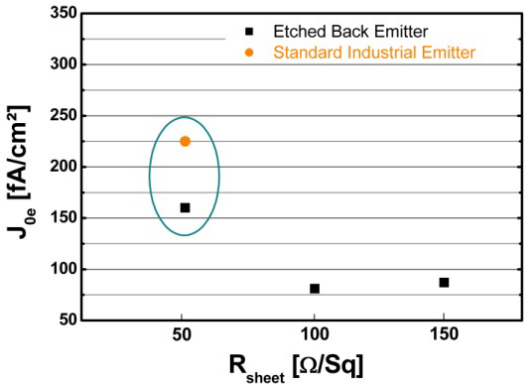

Figure 4: Comparison of QSSPC measurements of etched-back and an industrial standard emitter with PECVD SiN_x coating and the same sheet resistance of 50 Ω/Sq. The etched-back emitter shows a lower saturation current density.

The comparison of an etched-back emitter and an industrial emitter used at the University of Konstanz (both having the same sheet resistance of 50 Ω/Sq.) shows a difference in J_{0e} of about 65 fA/cm², which underlines the high quality of the etched-back emitter.

3 FRONT SURFACE PASSIVATION

In the next investigation the influence of the emitter etching process on the front surface passivation was studied. The process is based on previous investigations, where two different PECVD SiN_x deposition parameters were applied. The samples were p-type float zone wafers, R_B=0.5 Ωcm. After $POCl_3$ diffusion with a sheet resistance of 40 Ω/Sq was carried out, the samples were etched-back to 55 Ω/Sq, 80 Ω/Sq and 100 Ω/Sq and subsequently passivated by a PECVD SiN_x deposition. The effective lifetime (measured by QSSPC) of the non-etched-back emitter shows no differences between the standard and the improved PECVD SiN_x deposition. The variation of the PECVD SiN_x deposition parameters of the etched-back emitter with higher values of sheet resistance show significant differences in the effective lifetime. This means that the decreased phosphorous concentration on the emitter surface allows further optimization of the front surface passivation.

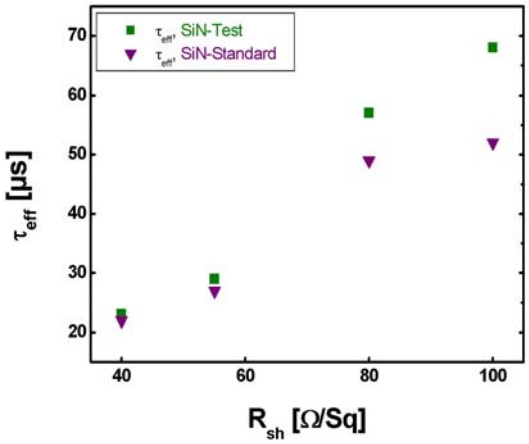

Figure 5: Effective lifetime measurements of etched-back emitter using two different PECVD SiN_x deposition parameters.

4 CELL PROCESSING

The approach creating a selective emitter structure with one diffusion step is suitable for both mono- and multicrystalline substrates.
The material used in this cell processing are 125x125 mm^2, p-type, 1.5 Ωcm, monocrystalline Czochralski silicon wafers from Deutsche Solar.

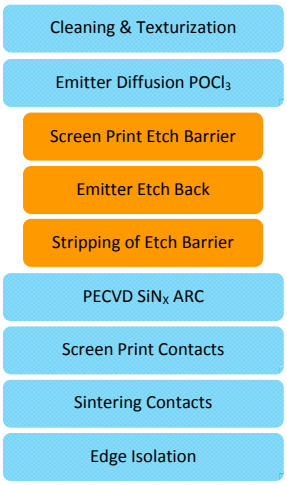

Figure 6: Processing sequence of solar cells with selective emitter (blue and orange) and industrial standard solar cells with homogeneous emitter (blue)

After cleaning and random pyramid texturization a phosphorous diffusion ($POCl_3$) with a sheet resistance of 50 Ω/Sq was carried out. In the next step an acid resistant etch barrier was screen printed onto the wafer and was subsequently cured. Then the surface dopant concentration of the $POCl_3$ emitter was homogenously etched-back in an acidic etch bath of HF, HNO_3, H_2O. After the first etching step the barrier was removed by wet chemical etching. Finally the PECVD SiN_x antireflection coating was deposited on the front side, the rear and emitter metallization were screen printed and co-fired.

5 CELL RESULTS

The two batches of cells with homogeneous and selective emitter structure differ in reflectivity due to process deviations during texturization of the selective emitter cells. Therefore J_{sc} values of these two batches can not be directly compared with each other. Furthermore, the induced difference in surface structure led to an inhomogeneous deposition of the SiN_x antireflection coating.

The comparison of the IV parameters of the solar cells on monocrystalline substrates shows an increase of the efficiency for cells with an etched-back emitter of 0.3 % abs.

The higher efficiency of the etched-back emitter solar cells is first caused by the increase of V_{oc} of more than 3 mV which is caused by a decreased recombination rate in the emitter and on its surface. Spectral response measurements (Figure 7) prove an excellent blue response of the solar cell with an etched-back emitter in the wavelength region ranging from 350 to 500 nm. This explains the increase of the short circuit current density.

Table I: Comparison of the IV-parameters of solar cells on monocrystalline (Cz) substrates with selective emitter structure (etch back emitter) and standard solar cells with homogeneous emitter.

	V_{oc} [mV]	J_{sc} [mA/cm²]	FF [%]	η [%]
Selective emitter best cell	634	36.0	79.4	18.1
Selective emitter average	631	35.9	78.5	17.9
Homogeneous emitter average	627	35.7	78.6	17.6

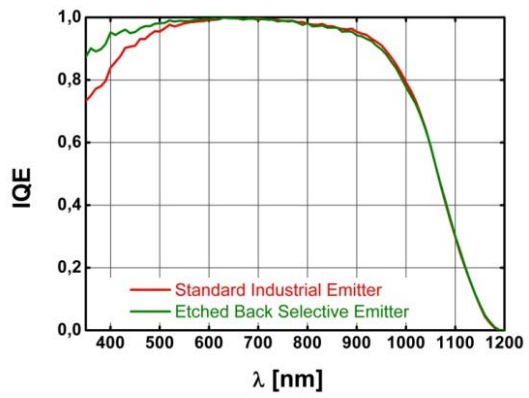

Figure 7: Comparison of internal quantum efficiency (IQE) of the solar cell with etched-back emitter and solar cell with homogeneous emitter.

6. CONCLUSION AND OUTLOOK

We have shown that a $POCl_3$ emitter can be etched-back in acidic solution with excellent homogeneity. The application of an acid resistant etch back barrier allows us to realize a selective emitter structure which has been successfully transferred into a standard screen printed solar cell process. The fabricated solar cells with selective emitter structure have achieved higher V_{oc} and J_{sc} than reference solar cells with a standard emitter. Finally, an efficiency of more than 18% could be demonstrated on 125x125 mm^2 screen printed Cz solar cells.

One of our goals is to optimize the etch back process and apply it to several other substrates like multicrystalline and ribbon silicon materials.

Combining of the etch back process with other solar cell concepts like e.g. the LFC process with dielectric passivation on the rear side will allow a further increase of the solar cell efficiency using screen printed cell processes.

7 ACKNOWLEDGEMENTS

The authors would like to thank S. Ohl, B. Rettenmaier and P. Diaz-Perez for their support during cell processing.

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

8 LITERATURE

[1] P. Choulat, F. Duerinckx, E. van Kerschaver, F. Dross, G. Beaucarne, *Minimizing the Dead layer of Industrial Phosphorous Emitters Formed by $POCl_3$ Diffusion*, Proc. 15th EU PVSEC-15, Shanghai, 2005

[2] J. Horzel, J. Szlufcik, J. Nijs, *High Efficiency Industrial Screen Printed Selective Emitter Solar Cells*, Proc. of the 16th EU PVSEC, Glasgow, 2000

[3] B. Raabe, H. Haverkamp, F. Book, A. Dastgheib-Shirazi, R. Moll, G. Hahn,*Monocrystalline Silicon – Future cell concepts*, Proc. 22nd EU PVSEC, 2007 Milan

[4] A. Zerga, A. Slaoui, J.C. Muller, B. Bazer-Bachi, D. Ballutaud, N. Lê Quang and G. Goaer, *Selective emitter formation for large scale industrially mc-Si solar cells by hydrogen plasma and we etching,* Proc. 21st EC PVSEC, Dresden 2006