THIN MC SI LOW COST SOLAR CELLS WITH 15% EFFICIENCY

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ABSTRACT

The firing-through SiN screen-printing process was adapted for thin mc Si wafers with a thickness of 180 µm. The optimization of this industrially compatible solar cell process resulted in a cell efficiency of 15.2 % for a cell area of 10x10 cm^2 and an emitter with a sheet resistance of 35 Ω/sq. For cost saving and to avoid the bending of thin wafers with an entirely metallized rear side, the coverage of the rear side metallization was reduced. Three different local back contact processes were carried out: including a non-compensated rear side emitter, a back-to-back diffusion, and alternativly a diffusion barrier. All processes include rear side silicon nitride deposition followed by screen-printing a square pattern of lines with Al-paste to perform the back contacts. The reduction of the rear side SiN-layer thickness from 80 nm to 25 nm leads to a short-circuit current density enhancement of 0.7 mA/cm^2 and efficiencies up to 14.1 %.

STANDARD PROCESS

As material 10x10 cm^2 BAYSIX wafers with a thickness of 180 µm and a diffusion length of 220 µm after defect etching were used. Cell processing started as shown in Fig. 1 with the removal of the saw damage in a solution of hot NaOH followed by a cleaning step in HCl. The $POCl_3$ diffusion resulted in an emitter with a sheet resistance of 35 Ω/sq. The phosphorous glass was etched in 5% HF. The antireflection coating was deposited with a direct PECVD (Plasma Enhanced Chemical Vapor Deposition) SiN plasma reactor. The next step was the screen-printing of the front grid with a shadowing of 8%. The rear side was entirely metallized with Al resulting in an Al-BSF after co-firing the contacts in a belt furnace. Processing was completed by mechanical p/n junction isolation with an automatic dicing saw and tabbing of the busbars.

Within the standard process the PECVD SiN was optimized regarding to a high hydrogen content for a good degree of bulk passivation and low absorption in the dielectric film. Another crucial point is the optimization of the firing-through in the belt furnace for thin cells. Due to the faster heating-up of thin wafers compared to thick ones they must be fired with higher belt velocities. As shown in Fig.2 and Tab.1, fill factors of 76-78 % leading to cell efficiencies of 15 % were obtained. The higher firing temperature has a wide range of belt velocities which can be applied.

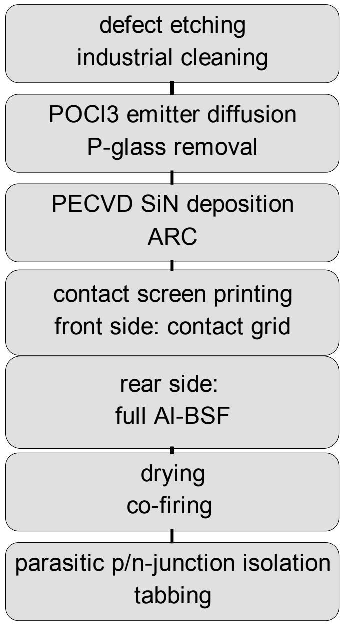

Fig. 1. Standard process sequence for solar cells.

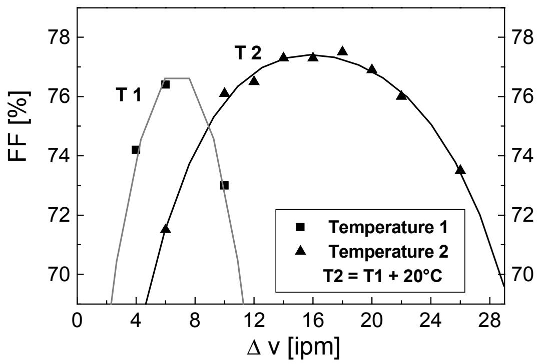

Fig. 2. The fill factor as a function of the belt velocity for different firing temperatures using a 35 Ω/sq. emitter.

Tab. 1. Illuminated I-V-parameters of thin solar cells using the standard process shown in Fig.1.

Cell Parameter	J_{sc} [mA / cm^2]	V_{oc} [mV]	FF [%]	η [%]
Mean	31.8	614	76.9	15.0
Best cell	32.0	617	76.9	15.2

LOCAL BACK CONTACT

The full Al-BSF used in the standard screen-printing process leads to an effective BSF, Al gettering and is simple to perform, but it has two important disadvantages: the high cost of the Al-paste and the bending of the thin wafers after firing in a belt furnace. The bending results from the difference in the thermal expansion coefficients of silicon and metallization paste. Modified automatic handling systems which take advantage of the elastic behaviour of thin wafers might be able to handle the bending, but they are not developed yet. A boron-BSF is difficult to be applied to multicrystalline silicon due to the high process temperatures needed. The poor BSF and cost intensive formation makes an evaporated Al-layer inadequate to suit as a back contact for thin wafers. A way to avoid the bending while saving costs is to reduce the rear side metal coverage by screen-printing a local back contact. The PC-1D simulation [1] in Fig. 3 shows that for thin wafers the cell efficiency significantly depends on the rear surface recombination velocity. In comparison of wafers with a thickness of 180 and 300 µm the efficiency was calculated for two different material qualities. A good rear surface passivation makes a difference up to 1.5 % abs. in cell efficiency. The point of intersection where the efficiency of the thin cells exceeds that of the thick ones moves to lower surface recombination velocities as the diffusion length increases.

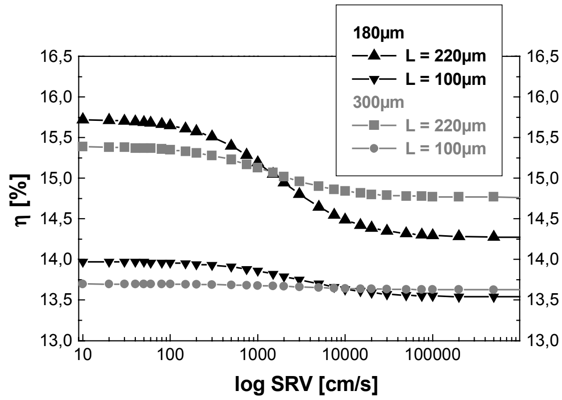

Fig. 3. PC-1D simulation of the solar cell efficiency as a function of the rear surface recombination velocity for a wafer thickness of 180 µm and 300 µm and two different diffusion lengths.

LOCAL BACK CONTACT PROCESSES

The process with the non-compensated rear side emitter includes a further SiN deposition on the rear side followed by screen-printing a square pattern of lines instead of performing a full Al-BSF. Because problems with the overcompensation of the rear side emitter were expected, a second process sequence was carried out. The wafers were placed back-to-back during the emitter diffusion. However this does not avoid the formtion of a

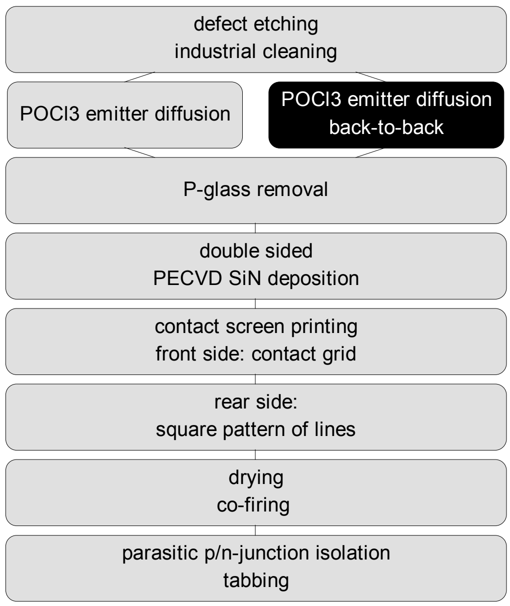

Fig. 4a. Process sequences of local back contact processes with a non-compensated rear side emitter and a back-to-back diffusion.

rear side emitter with a sheet resistivity of about 70 Ω/sq. The third process was performed by depositing a SiN-layer as diffusion barrier before the emitter formation to exclude the rear side emitter diffusion.

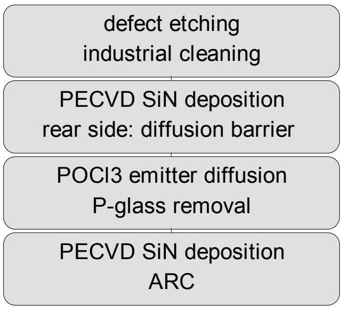

Fig. 4b. Modified processing steps of the local back contact process with a diffusion barrier. The following steps are the same as shown in Fig. 4a.

For the non-compensated rear emitter process the SiN-layer at the rear side was deposited with thicknesses of 80, 45 and 25 nm. The reduction of the thickness of the silicon nitride passivation layer leads to an improved local Al-BSF performance and therefore to a short-circuit current density enhancement of +0.4 mA/cm^2 for the 45 nm and +0.7 mA/cm^2 the 25 nm thick SiN-layer as compared to the 80 nm SiN-layer. Furthermore, the fill factor increases because of a lower contact resistance. Measurements on test structures of Al-paste fired through SiN showed an unacceptable high contact resistance for the 80 nm thick layer, but it decreases to about 8 mΩcm^2 for the 25 nm thick SiN-layer.

In the following results are presented which are based on solar cells with a 25 µm thick passivating SiN-layer. The Al back contact was screen-printed with a coverage of 20 % and 30 %. Tab.3a and 3b show the same tendencies in the illuminated I-V-parameters for both back contact coverages. Using a coverage of 30 % instead of 20 % resulted for all local back contact processes in slightly better cell parameters.

Tab. 3a. Averaged cell parameters for the local back contact processes with a rear side metallization coverage of 20%.

20 % coverage	J_{sc} [mA / cm^2]	V_{oc} [mV]	FF [%]	η [%]
Back-to-back diffusion	30.0	594	75.6	13.5
Non-compensated emitter	30.5	595	75.3	13.7

Tab. 3b. Averaged cell parameters for the local back contact processes with a rear side metallization coverage of 30%.

30 % coverage	J_{sc} [mA / cm^2]	V_{oc} [mV]	FF [%]	η [%]
Diffusion barrier	29.9	593	75.3	13.4
Back-to-back diffusion	30.1	598	76.3	13.7
Non-compensated emitter	30.7	597	76.8	14.1

The obtained fill factors are quite as good as those of the standard screen-printing process. The moderate values of the open-circuit voltage indicate that the rear surface passivation must be improved. The process with a SiN-layer as diffusion barrier deposited before the emitter diffusion leads to the lowest V_{OC} because the high temperature processing step after the deposition reduces strongly the passivation quality of the SiN. The surface recombination velocity increases to about 10^4 cm/s. The process with the non-compensated rear side emitter leads to the highest short-circuit current densities. Cell efficiencies up to 14 % were achieved. As can be seen in Fig. 5, the internal quantum efficiencies of the local back contact processes in comparison with the standard screen-printing process show a reduction of the current at long wavelengths. The effective diffusion lengths [2] of Tab.4 were determined from the IQE-data and show a consistent decrease. Simulations have to be done to explain the role of the emitter at the rear side in consistence with these results.

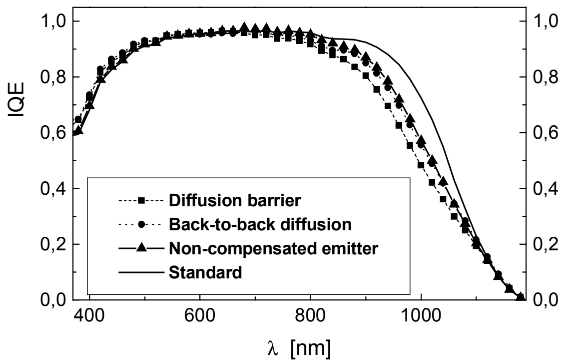

Fig. 5. Comparison of the internal quantum efficiencies of the local back contact and standard screen-printing processes.

Tab. 4. Effective diffusion lengths determined from the IQE-data.

Solar cell process	L_{eff} [μm]
Diffusion barrier	150
Back-to-back diffusion	190
Non-compensated emitter	210
Standard	430

CONCLUSIONS

The firing-through silicon nitride screen-printing process has been applied to thin multicrystalline silicon wafers. Cell efficiencies up to 15 % were achieved. To avoid bending and for cost saving, three process sequences including a rear side SiN deposition and local back contacts had been performed. Efficiencies up to 14% were obtained with a process sequence including a non-compensated rear emitter.

Simulations to explain the effect that the non-compensated rear emitter process results in a better cell performance than that one with the back-to-back diffusion will be a focus of future research.

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