SIMPLIFICATION OF EWT (EMITTER WRAP-THROUGH) SOLAR CELL FABRICATION USING AL-P-CODIFFUSION

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ABSTRACT

Back contact solar cells such as EWT (Emitter Wrap-Through) devices [1] with interdigitated pn-junctions offers various advantages [2] like a simplification in module assembly or a reduction of shadowing losses. Our method to form a rectifying p^+n^+-junction using an Al-P-codiffusion process - without the necessity of electrical isolation of p- and n-type doping regions [3] - was transferred to EWT cells. We were able to fabricate EWT cells with shunt-values up to 10^4 Ωcm^2. The interdigitated pn-junctions of these devices are formed by simply evaporating an Al-finger grid followed by Al-P-tube codiffusion. The effectiveness of the codiffusion for EWT cell fabrication was demonstrated on CZ-Si, mc-Si and EFG (Edge-defined Film-fed Grown)-Si. A main advantage of the developed sequence is a simplification of the EWT cell fabrication process by making single processing steps redundant, particularly the junction isolation, i.e. the separation of the different doping regions at the cell rear.

Standard technologies for junction isolation are:
- the use of a diffusion barrier
- plasma etching [4]
- locally milling off the rear side emitter [4]
- P-B dopant compensation

For industrial applications it would be interesting to form a rectifying p^+n^+-junction without applying one of those additional cost intensive and time consuming processing steps.

INTRODUCTION

The investigation has been carried out under different points of view:

- Transfer of the Al-P-codiffusion process to back contact solar cells and as a consequence thereof to modified potential properties compared to conventional solar cells.
- By optimizing the interdigitated contact grids the performancparameters of the codiffused EWT cells should be comparable with screen printed low cost EWT solar cells [4].
- The processing sequence was applied to polycrystalline Si wafers (cast mc-Si, EFG-Si). The crucial point thererby was the Al alloying performance at the grain boundaries. I.e. the question was wether it is possible to form a rectifying p^+n^+-junction in spite of the lower quality of these Si materials (caused by crystal defects (grain boundaries, dislocations) as well as impurities (carbon, oxygen, ...)).

PROCESSING SEQUENCE

The used materials were Cz-Si (thickness d = 260µm) as reference, Baysix mc-Si (d = 320µm) and EFG-Si (d = 100-240µm). The emitter sheet resistance which was formed during the Al-P-codiffusion process was about 30 Ω/sq. The length of the alloyed Al grids, i.e. of the metal-emitter contact amounted to more than 150 cm (cell area: 25 cm^2). The area of the alloyed Al grid, i.e. of the p^+-BSF region compared to the rear side emitter was in a ratio of nearly 1:1. The number of holes was more than 1000. The shape of the holes was conical with an entrance/exit diameter after the alkaline damage etch of 100µm/60µm slightly dependent on the processed Si material. Up to now the contact grids are deposited by Ti/Pd/Ag evaporation using a set of shadowing masks. Investigations using a screen printing paste, which can be fired at low temperatures (< 577°C, eutectic temperature of Al/Si) are not yet finished. After the codiffusion process the wafers should not be exposed to any further high temperature step so that the alloyed Al can not melt again and short circuit the cell.

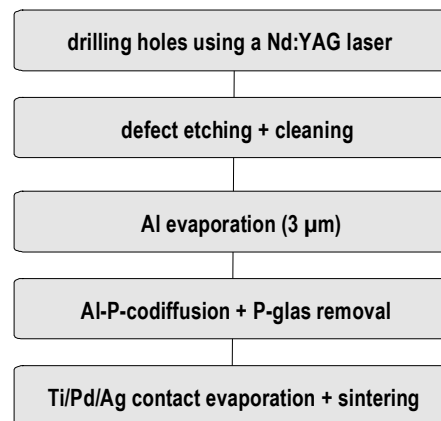In the following an outline of the processing sequence is given:

Fig.1: Sequence of the Al-P-codiffusion process with regard to the EWT solar cell fabrication

RESULTS

For all investigated Si materials (Cz-Si, mc-Si, EFG-Si) repeatedly satisfactory shunt values were reached using the processing sequence presented above. The best shunt values so far of codiffused EWT solar cells, which are partly higher than achievable with any other technique, are shown in the following table:

Material	R_{sh} [Ωcm^2]
Cz-Si	12800
cast mc-Si	3450
EFG-Si	3110

Tab.1: Summary of the best shunt values reached so far for EWT cells itemized for different Si materials. The p^+n^+-contact length was about 150 cm.

The following table 2 shows the cell parameters of a Cz-Si and a cast mc-Si EWT solar cell without ARC and texturisation. The results are approximately comparable with thoses of flat screen printed low cost EWT solar cells without selective emitter. In both cases I_{02} (saturation current density in the 2 diode model) is the limiting factor ($I_{02,Cz}$ = 1.4*10^{-7}, $I_{02,mc}$ = 2.7*10^{-7}). The Cz-Si EWT cell has a series resistance R_s < 1 Ωcm^2, whereas R_s of the mc-Si cell is well above 1 Ωcm^2. The calculated efficiency η of the Cz-Si EWT cell amounts in the case of an evaporated DARC (ZnS/MgF$_2$) approximately to 14.8 %.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	η [%]
	without ARC, untextured			
Cz-Si	23.9	593	71.1	10.1
mc-Si	24.7	575	67.4	9.6

Tab.2: Parameters of flat codiffused EWT solar cells without ARC (R_{sheet} = 30 Ω/sq).

For comparison Tab.3 presents the parameters of codiffused EWT cells made with another set of shadowing masks. The finger spacing was reduced and also the BSF region was decreased compared to the grid design mentioned above. The sheet resistance was about 60 Ω/sq.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	η [%]
Cz-Si	25.4	578	9.6
mc-Si	23.5	557	8.2

Tab.3: Parameters of flat codiffused EWT solar cells without ARC (R_{sheet} = 60 Ω/sq).

The J-U-characteristic of the Cz-Si EWT cell points out the satisfactory shunt values by a horizontal trend in the range of low voltages.
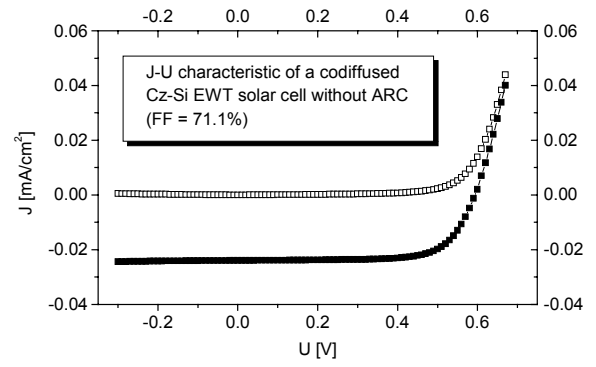

Fig.2: J-U-characteristic of a codiffused Cz-Si EWT solar cell with η = 10.1 %.

The following diagram demonstrates the internal and external quantum efficiency as well as the reflectance of the codiffused Cz-Si, and mc-Si EWT solar cells, described in Tab.2.
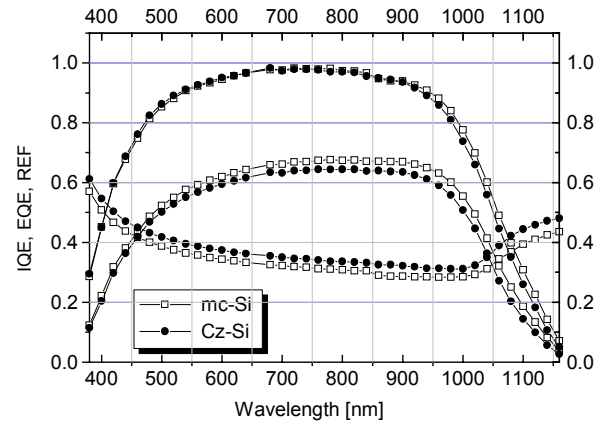

Fig.3: Internal (IQE), External Quantum Efficiency (EQE) and reflectance (REF) of codiffused (Cz-Si, mc-Si) EWT solar cells.

The IQE of the back contact cells is relative low in the short wavelength range. This is probably due to the disadvantageous chosen temperature during the codiffusion of merely 800°C, resulting in an unoptimized emitter profile. At a higher temperatue the phosphorus at the surface will diffuse deeper into the wafer. By lowering the phosphorus concentration at the surface the probability of Auger recombination would be decreased. Furthermore, the emitter used in this work was not passivated, which also reduces the low wavelength IQE.

The IQE in the long wavelength range is rather good. This is on the one hand due to the back side emitter and on the other side due to the large diffusion length ($L_{eff, Cz}$ = 446 µm, $L_{eff, mc}$ = 565 µm, extended spectral response).

The reflectance of the untextured Cz-Si cell is nearly 3.5 % higher compared to the mc-Si cell averaged above the whole wavelength range.

The results of EFG-Si material were not satisfying. Further process optimization for this material has to be undertaken. $I_{02,EFG}$ is in the range of 10^{-6} and R_s is also increased, whereas the shunt values are satisfactory. The alignment of the EFG wafers during the evaporation of the interdigitated contact grids did not cause difficulties, although the wafers weren´t leveled. Best FF of EFG-Si EWT cells were in the order of magnitude of 65 %. Even-tually are hairline cracks responsible for the high $I_{02,EFG}$-values, caused by non optimized laser parameters.

Based on the reached high shunt values it could be verified that grain boundaries of polycrystalline Si do not influence the alloying process. Thus it is possible to form a rectifying p^+n^+-junction using the Al-P-codiffusion process for all investigated materials. The fact - that both monocrystalline and polycrystalline Si wafers show a similar behavior with regard to the shunt formation during the alloying - is an significant result for the transfer of this processing sequence to low cost applications.

SERIES RESISTANCE

The following SEM picture shows the cross-section of a hole in a mc-Si EWT solar cell. In contrast to screen printed EWT cells [5] the interior of the hole is not covered with silver deposited by using the evaporation technique.
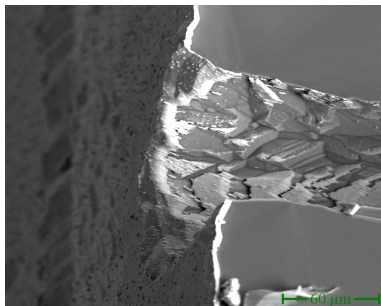

Fig.4: Cross-section of a hole in a mc-Si EWT solar cell

That means the conductivity inside of the holes is merely given by the doping concentration of the emitter.

LBIC MEASUREMENTS

LBIC (Light Beam Induced Current) measurements of both - a Cz-Si as well as of a cast mc-Si EWT cell - clearly show a separation of the p- and n-type doping regions. The definition of the interdigitated contact grids was realized during the simultaneous formation of emitter and BSF in one single high temperature step. Furthermore, the increased collection probability of the rear side emitter is cognizable.
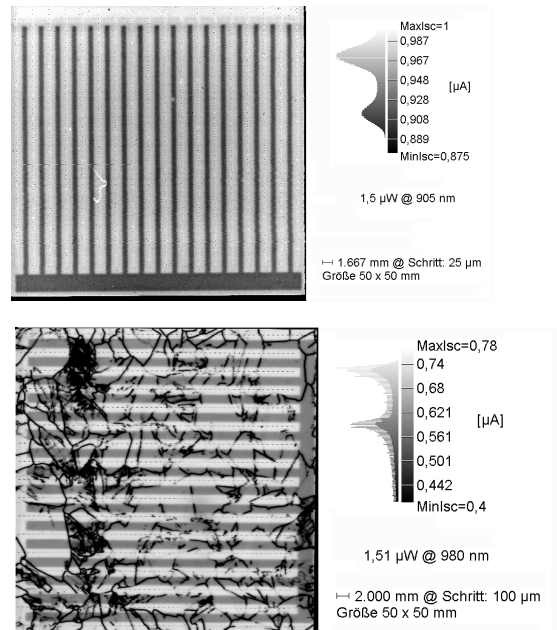

Fig.5: LBIC-mappings of codiffused Cz-Si and mc-Si EWT solar cells. Cz-Si: J_{sc} = 35.5 mA/cm² (with sARC)
mc-Si: J_{sc} = 23.8 mA/cm² (without ARC)

DISCUSSION

Main advantage of the presented Al-P-codiffusion process is the simplification of the fabrication process by making single steps redundant, particularly the separation of the p- and n-type doping regions. Furthermore, the conventional methods of shunt elimination partly entails - according to the chosen technique - to physical disadvantages, such as plasma damage or unpassivated surfaces resulting in increased surfaces recombination. Another advantage of the developed Al-P codiffusion process is the formation of emitter and BSF in one single high temperatue step.

Disadvantage so far is that the deposition of the contacts was done using the evaporation technique. However the metallization done by the screen printing technique is under investigation.

Other possibilities to improve cell performance are:
- Execution of further grid optimizations
- Search of softer laser parameters
- Optimization of the emitter profile

CONCLUSION

Summarizing the results it was possible to transfer the Al-P-codiffusion to back contact solar cells, particularly to EWT cells. The reached cell parameters (η = 10.1 %, without ARC) are comparable with those of conventional low cost EWT cells without texturisation and without selective emitter. The shunt values of all investigated silicon materials (Cz, mc, EFG) were in spite of the large length of the metal-emitter contact (> 150 cm) of the interdigitated grids satisfactory – sometimes even higher than achievable with any other technique.

The formation of a rectifying p^+n^+-junction using the Al-P-codiffusion process is independent of grain boundaries, impurities or other crystal defects.

ACKNOWLEDGEMENT

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