NOVEL TECHNIQUES TO PREVENT EDGE ISOLATION OF SILICON SOLAR CELLS BY AVOIDING LEAKAGE CURRENTS BETWEEN THE EMITTER AND THE ALUMINIUM REAR CONTACT

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ABSTRACT: Whenever the base contacting is effected by overcompensating the rear side electrically active emitter, short-circuits occur between the emitter and the alloyed aluminium rear contact. Without additional costly processing steps for the avoidance of excessive leakage currents this transition is non-rectifying. The development of novel cell designs like POWER (POlycrystalline Wafer Engineering Result) or EWT (Emitter Wrap-Through) solar cells with interdigitated contact grids has made the problem more complicated, because standard edge isolation, where short circuits are limited to the cell edges, cannot be efficiently applied. The aim of our investigation was the formation of rectifying neighbouring p^+n^+-doped regions. Three methods have been investigated whereby two of them yielded a rectifying metal-emitter transition without the necessity of junction isolation. This was achieved by using an Al-P codiffusion process, i.e. the simultaneous formation of the emitter and the BSF (Back Surface Field) in one single high temperature step or by removing the excessive Al after alloying and subsequently depositing a new smaller base contact.

Keywords: Al-P codiffusion - 1: junction isolation - 2: leakage currents – 3

INTRODUCTION

The essential aim of our investigation was to avoid leakage currents between p- and n-type regions of silicon solar cells without junction isolation. Shunt values of more than 10^3 Ωcm^2 were aspired, because shunts strongly influence the IV-characteristic and therefore the fill factor [1].

The problem of avoiding low shunt values has become more complicated since novel cell designs like the POWER [2] or the EWT solar cell [3] have been developed. For these novel cell geometries with interdigitated p- and n-type regions, standard edge isolation, used for solar cell designs with short-circuits limited to the cell edges, cannot be efficiently effected. Additional, costly and time consuming processing steps become necessary such as:

- the use of e.g. silicon nitride as a locally defined diffusion barrier
- local milling off of the rear side emitter in order to define the base contact region [4]
- screen printed rear contacts can serve as self aligned etching barriers [4].

For industrial application it would be interesting to form a rectifying p^+n^+-junction without applying additional processing steps. Furthermore the above methods of eliminating low shunt values, partly lead to physical disadvantages, such as plasma damage, open pn-junctions, etc., resulting in increased surface recombination.

As a result of our investigations we have been able to solve the problem of short-circuits by two different techniques:

- Al-P codiffusion
- Al-Si eutectic removal

They will be described in the following together with the studied approach of overcompensation, which was not successful.

EXPERIMENTAL

During the whole study, Cz silicon wafers (1Ωcm) were used as base material. The typical cell size was 5x5 cm^2. As first control parameters shunt resistance values were extracted from the IV-curves of finished cells assuming a two diode model.

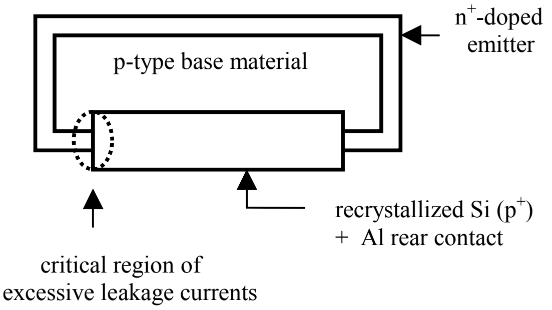


Fig.1: *Schematic illustration of the test structure design used for systematic investigations of the shunt values of silicon solar cells.*

Method 1: Back Surface Field (BSF) formation

In a first attempt the formation of the Al-BSF was investigated more closely to avoid leakage currents across the edge of the silicon solar cells. It had to be verified whether inhomogeneities or spikes within the Al-BSF are responsible for local shunts within the p^+n^+-transition line.

At first we tried to improve the standard processing sequence, i.e. overcompensation of the rear side emitter.

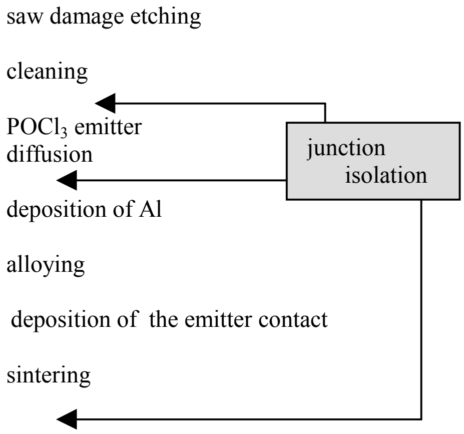
Primarily the $POCl_3$ emitter diffusion was carried out, afterwards the Al was deposited by electron-beam evaporation and alloyed in order to overcompensate the rear side emitter and to form the p^+-layer as well as the rear contact simultaneously. The front contact grid was defined by evaporating Ti/Pd/Ag using a shadowing mask. Our first experiments have been carried out using the evaporation technique for depositing the Al as well as the emitter contact grid in order to avoid misleading conclusions caused by variations within the screen printing process.

It was supposed to obtain an unruffled, homogeneous p^+n^+-interface by slowly cooling down (0.2°C/min.) after the alloying to simulate quasi-equilibrium states described by the phase diagram [5].

The alloying temperature and -duration were varied, in order to observe interdiffusion of Al and Si. Thereby a broadening of the space charge region should be attained.

The independence of the shunt values of the cooling rate and other alloying parameters could be ascertained. The shunt values obtained by this processing sequence without edge isolation however remained at less than 600 Ωcm^2.

Résumé of processing steps - overcompensation



According to the state of the art industrial processing sequence the alternate methods mentioned within the introduction must be applied for junction isolation at different times of the process, for example the use of a diffusion barrier after cleaning the wafer, or plasma etching after the diffusion or at the end of the processing sequence. It was not possible to obtain a rectifying junction by simply optimizing the Al alloying parameters.

Method 2: Al-Si eutectic removal

In another experiment we tried to avoid the leakage currents by etching the excessive Al in hot HCl. Thereby we intended to isolate the metal layer with eutectic composition from the electrical active emitter. During processing the $POCl_3$ emitter was formed, before evaporating Al – analogue to the standard processing sequence. After alloying the excessive Al metallic layer was etched. A new smaller Al base contact was deposited using a shadowing mask. It has to be avoided that the p^+n^+-transition becomes metallized (see Fig. 2).

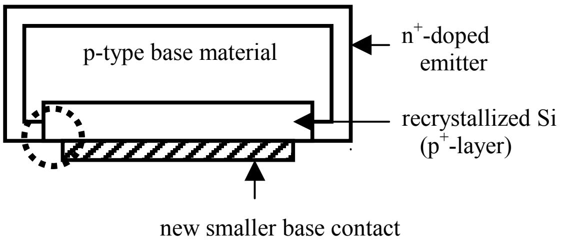


Fig. 2: *Schematic illustration of the critical p^+n^+-region, which had to remain unaffected while re-depositing an Al rear contact.*

Table 1 shows results obtained by etching the aluminium rear contact using a full Al-BSF.

Table 1: *Results obtained by fabricating test structures by means of etching excessive aluminium and afterwards depositing a new smaller Al rear contact.*

number of test-structures	$R_{sh,min}$ - $R_{sh,max}$ [Ωcm^2]	$R_{sh,mean}$ [Ωcm^2]
5	1300 - 11300	5900

Résumé of processing steps - Al-Si eutectic removal

saw damage etching

cleaning

$POCl_3$ emitter diffusion

P-glass removal

deposition of Al

alloying

removal of the metallic rear contact
of eutectic composition

deposition of a new smaller base contact

deposition of the emitter contact

sintering

The shunt values obtained by removing the rear contact of eutectic composition were sufficient, but an additional processing step is necessary to achieve this result.

Method 3: Codiffusion process

In a further approach, edge isolation could be avoided by applying a codiffusion process, i.e. by the simultaneous formation of emitter and BSF in one single high temperature step.

A more homogeneous p^+n^+-interface was expected by using the codiffusion process, because the Al-Si melt is

Table 2: *Results obtained by an Al-P codiffusion process are presented. Both a full and a grid-like Al-BSF were investigated at two different drive-in temperatures.* $R_{sh,mean}$ *was averaged over five 5x5* cm^2 *test structures.* $R_{sh,min}$ *and* $R_{sh,max}$ *describe the best and worst shunt value obtained by equally processed test structures.*

metal-emitter contact length [cm]		**drive-in-temperature 800°C**	**drive-in-temperature 900°C**
20	**$R_{sh,min}$ - $R_{sh,max}$ [Ωcm²]**	**1200 - 10000**	**2300 – 3700**
	$R_{sh,mean}$ [Ωcm²]	**6200**	**3000**
175	**$R_{sh,min}$ - $R_{sh,max}$ [Ωcm²]**	**1400 - 6800**	**-----**
	$R_{sh,mean}$ [Ωcm²]	**3900**	**-----**

formed before the emitter is diffused. Hence the p^+n^+-transition is defined by interdiffusion of the dopands.

Test structures - that means solar cells with not optimized front contact grids - were fabricated both with a full Al-BSF (metal-emitter contact length: 20 cm) and with a grid-like Al-BSF (metal-emitter contact length: 175 cm).

The independence of the shunt values from the metal-emitter length i.e. the length of the alloyed Al contacting the emitter, could be ascertained. This is an important result with respect to the transfer of our approach to more complex cell designs.

After etching and cleaning the wafers, 3 µm Al were deposited by electron-beam evaporation before $POCl_3$ emitter diffusion was carried out. By varying the drive-in temperature, differently doped emitter could be obtained. The drive-in temperature of 800°C yielded a sheet resistance of about 110 Ω/sq, whereas 900°C resulted in an 30 Ω/sq-emitter. This means, that this processing sequence of codiffusion can be incorporated in the fabrication of screen printed solar cells for industrial applications as well as for high efficiency solar cells.

Five test structures were fabricated for each parameter. Table 2 shows shunt values of solar cells fabricated by the Al-P codiffusion process without any junction isolation.

The major advantage of this method is the avoidance of short-circuits, making junction isolation redundant. Additionally, we want to point out that this simple co-processing step replaces two high temperature steps (emitter diffusion + BSF formation), simplifying the entire processing sequence. Moreover, the codiffusion process has several advantages like a more efficient gettering effect and therefore an improvement of diffusion length [6].

Applying the same processing parameters, a decrease of the sheet resistance using the Al-P codiffusion process is cognizable (see Table 3) because of the mutual enhancement of the P and the Al diffusion. For comparison we additionally diffused reference wafers without Al at the rear side. From these results we conclude that with our codiffusion process, a lower alloying temperature is sufficient, still obtaining sheet resistance values of the same order as usually reached in standard phosphorous diffusion. The same observation was reported by Hartiti et al. [7].

Table 3: *Sheet resistance of P-diffused and Al-P codiffused wafers. The Al-P codiffusion leads to lower sheet resistance values.*

	alloying-temperature 800°C	**alloying-temperature 900°C**
with Al	**111.6 Ω/sq**	**29.1 Ω/sq**
without Al	**149.2 Ω/sq**	**38.0 Ω/sq**

Fig. 3 shows the LBIC (Light Beam Induced Current)-mapping of a codiffused 5x5 cm² Cz standard solar cell with a base contact grid. The light stripes represent the p^+-regions, i.e. the alloyed Al, whereas the dark regions are caused by the electrical active rear side emitter. The cell parameters are: J_{sc} = 32.6 mA/cm² (untextured, with SARC), R_{sh} = 2500 Ωcm², V_{oc} = 609 mV, η = 13.5 %. The metal-emitter contact length is 110 cm. A relative low fill factor of 68.6 % was due to not yet optimized front contact grid.

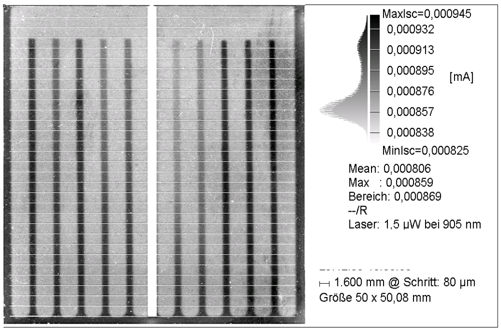


Fig. 3: *LBIC-mapping of a codiffused 5x5* cm^2 *solar cell. The light regions represent the alloyed* p^+*-fingers, whereas the dark regions are caused by electrical active rear side emitter.*

Résumé of processing steps - codiffusion

saw damage etching

cleaning

Al-evaporation

Al-P codiffusion

P-glass removal

deposition of front contact grid

sintering

Solar cell results:

We have successfully started to transfer this sequence to multicrytalline Si base materials and have also fabricated codiffused solar cells with interdigitated contact grids. These EWT solar cells reached shunt values up to 10000 Ωcm^2 and efficiencies of η = 12.8 % (with SARC) without steps for junction isolation. A recent study of conventional EWT solar cells can be found in [8]. It has to be mentioned that the J_{sc} values (Cz-Si: 25.4 mA/cm^2, mc-Si: 23.4 mA/cm^2 for flat EWT solar cells without ARC) are relative high due to the rear side electrical active emitter.

It is believed that codiffusion will assist the commercialization of promising solar cell devices with interdigitated doping regions by strongly simplifying their manufacturing process. As next steps of investigation we will try to understand in more detail the effect of codiffusion for junction isolation on the microscopic scale.

CONCLUSION

In this study different approaches have been investigated in order to obtain a rectifying junction without using conventional junction isolation steps (plasma etching, diffusion barrier,...).

The attempt to optimize the overcompensation method yielded shunt values lower than 600 Ωcm^2 (method 1).

The second approach, the Al-Si eutectic removal (method 2) led to a rectifying p^+n^+-transition. The shunt values were comparable with those of the codiffusion process, however this sequence involves additional steps for electrical isolation.

The codiffusion process (method 3) seems to be especially promising for novel cell designs with interdigitated doping regions such as conventional back contact POWER and EWT cells. The shunt values proved to be independent of the metal-emitter contact length as well as of the chosen parameter set. By using codiffusion three processing steps of the standard sequence (emitter formation, BSF formation, junction isolation) are carried out by one single high temperature step.

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