FORMATION OF A RECTIFYING P^+N^+-JUNCTION USING P-PASTE DURING AL/P-CODIFFUSION

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ABSTRACT: Aim of this study was the formation of a neighbouring rectifying p^+n^+-junction applying Al/P-codiffusion. Based on the Al/P-codiffusion using $POCl_3$-emitter diffusion in conjunction with evaporated aluminium this investigation initially tended to have more relation to industrial application. For that purpose $POCl_3$-emitter diffusion was replaced by screenprinting phosphorous-paste as well as evaporated aluminium was replaced by screenprinted Al. Usually, without additional arrangements cells with screenprinted emitter are short-circuit around the edges of the cell because non-printed regions of the wafer surface are also indirectly diffused via the gas phase.

Keywords: Al/P-codiffusion – 1, screen printing – 2, P-paste – 3

1 INTRODUCTION

In standard solar cells edge isolation is necessary in order to avoid excessive leakage currents from the emitter to the rear contact. Conventional aluminium base contacts form a highly doped p^+-BSF region. Without additional processing steps the transition between emitter and Al rear contact is non-rectifying. In conventional flat solar cells the shunt across the edges can be isolated e.g. by plasma etching or mechanical abrasion.

However, the development of novel cell designs with interdigitated grids, e.g. EWT cells [1] has made the problem more complicated, because additional processing steps were necessary to avoid these short-circuits. In the cell geometry mentioned above, the described shunts occur not only across the cell edges but also at the entire border of the interdigitated p- and n-type regions. Standard edge isolation cannot be applied, and therefore additional cost intensive processing steps were necessary, like the use of a diffusion barrier, plasma etching or locally milling off the rearside emitter [1].

The formation of a rectifying p^+n^+-junction using Al/P-codiffusion was investigated in [2]. The objective of this investigation was to replace the evaporated Al by a screenprinted Al-paste as well as to replace the $POCl_3$-emitter diffusion by a screenprinted P-paste. The implementation of an Al/P-codiffusion process using pastes would be interesting particularly for high volume production lines with inline automation.

By using P-paste for emitter formation, not screenprinted regions of the wafer surface were also indirectly diffused via the gas phase [3]. This means e.g. by fully covering the front side of a wafer with P-paste, after firing the wafers at high temperatures their rear sides are also n-type. Thus the problem of short-circuits between rear side emitter and alloyed rear contact is comparable to a $POCl_3$-emitter. In that concept leakage currents occur due to overcompensation of the n-type doping region by a metal.

2 EXPERIMENTAL

The used material was p-type mc-Si as well as Cz-Si. The wafer size amounted 5x5 cm^2.

After etching the wafers in a hot solution of NaOH and cleaning in HCl/HF Al was deposited on the rear side. The wafers were divided into two groups: One half with evaporated Al the other one with screenprinted Al on the rear. Cells with evaporated Al were fabricated as references in order to compare these results with codiffused cells using $POCl_3$-emitter diffusion [2]. The screenprinted and evaporated Al was deposited locally in form of a contact finger grid as well as with fully rear side coverage in order to examine the dependence of the shunt values from the metal-emitter contact length.

Afterwards half of each group was alloyed in an additional processing step (sequence 1, Fig. 1.). Wafers with evaporated Al were alloyed at 800°C in a tube furnace, wafers with screenprinted Al were fired at typical temperatures (> 800°C) in a belt furnace, i.e. for wafers of sequence 1 the BSF was formed before emitter diffusion. The BSF of the remaining wafers was formed while cofiring with P-paste (sequence 2).

After rinsing the wafers in a solution of HF P-paste was fully screenprinted on the front, dried and fired at different temperatures well above 900°C and with varying belt speeds. The emitter was formed in an IR belt furnace. Because of the wide range of sheet resistances the emitter contact had to be evaporated using Ti/Pd/Ag.

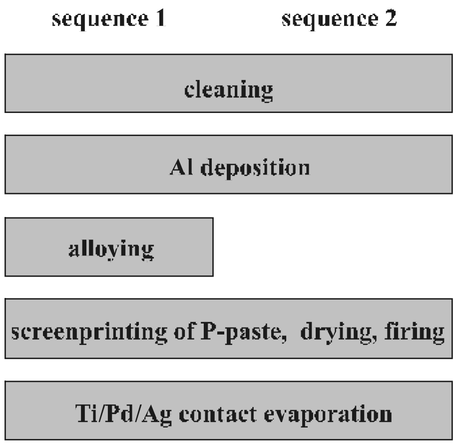

Fig. 1: Process flow of Al/P-codiffusion using P-paste for emitter formation

3 RESULTS

3.1. Rear side coverage

3.1.1. screenprinted Al

The Al-paste applied in this study is commercially available and used for standard screenprinting processes. After cofiring with P-paste at high temperatures (T > 900°C) and long cycles (more than 7 times longer as usual) cracks were induced at wafers with fully screenprinted Al-paste because of the large difference in thermal extension at extreme processing conditions. For locally alloyed Al-paste formation of little Al spheres along the contact fingers was observed as well as sporadically flaking of the fired Al grid. This occurs independently whether the screenprinted Al was fired in an additional processing step (sequence 1) or not (sequence 2).

Therefore, the used Al-paste is unsuitable for coprocessing together with P-paste due to the high firing temperature and low belt speed indispensable for emitter formation.

For future work the features of Al-pastes at extreme firing conditions must be investigated initially in a separate study. Proposals to improve the behaviour of the Al-paste while firing are e.g. to reduce the screenprinted Al thickness using a screen with another mesh or to vary the frit rate in the Al-paste [4].

3.1.2. evaporated Al

Al/P-Codiffusion with evaporated Al results in mean shunt values of about 1000 Ωcm^2 (Tab. 1) regardless whether the Al was separately alloyed in an additional processing step before screenprinting and firing the P-paste or not. The shunt values proved to be independent of the p^+n^+-contact length as well as independent of the used starting material (mc-/Cz-Si). The shunt values were also independent from the temperature gradient during firing, i.e. varying belt speed at constant temperature profile. The shunt values were averaged over a different number of mc-/Cz-Si cells as well as cells with different metal-emitter contact length, i.e. full/local BSF. This was reasonable because the individual shunt values of each group were approximately comparable. The p^+n+-contact length of cells with full BSF was 20 cm, whereas the metal-emitter contact length of cells with grid-like BSF amounted about 110 cm (cell area 25 cm^2).

Tab. 1: Shunt values of codiffused/overcompensated solar cells using screenprinted P-paste for emitter formation. The mean values were averaged over mc-/Cz-Si cells as well as cells with full/local BSF.

	best R_{sh} [Ωcm^2]	**mean R_{sh} [Ωcm^2]**
sequence 1	1630	1020 (7 cells)
sequence 2	1400	990 (5 cells)
P-paste + alloyed Al (references)	720	440 (3 cells)

To evaluate the shunt values of the codiffused cells of sequence 1 and sequence 2 presented in Tab.1 overcompensated cells were fabricated as references. There first the P-paste was screenprinted, dried and fired and afterwards the Al was evaporated and alloyed in a tube furnace. The emitter contact was also evaporated using Ti/Pd/Ag. The shunt value of the best cell (R_{sh} = 720 Ωcm^2) has clearly improved compared to standard overcompensation with $POCl_3$-emitter ($R_{sh} < 300\ \Omega cm^2$) [2].

3.2. Sheet resistance

Sheet resistances of wafers with screenprinted P-paste on the front and different coverage on the rear were compared. First the different rear sides were fabricated afterwards the front sides of each group were printed and fired in the same way.

Evaporated Al was separately alloyed in an additional processing step before printing and firing the P-paste, i.e. the BSF of the wafers of sequence 1 was formed before emitter diffusion.

Sequence 2 describes wafers with evaporated Al on the rear simultaneously alloyed while firing the P-paste on the front.

In addition R_{sheet} of wafers with one-sided P-paste and uncovered rear as well as wafers with double-sided P-paste were examined.

The distribution of R_{sheet} at a constant temperature profile and different firing durations of the P-paste is presented in Fig. 2.

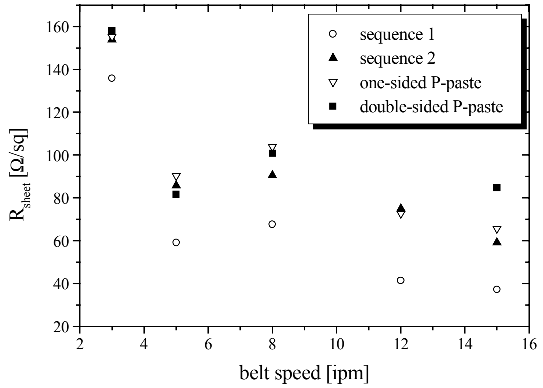

Fig. 2: R_{sheet} of wafers with differently treated rear sides at varied firing durations (T = const.).

R_{sheet} of sequence 1 is clearly lowest independent of the firing duration, i.e. BSF formation before emitter formation in a separate processing step results in an acceleration of diffusion kinetics [5]. This is remarkable because in sequence 1 the BSF is formed already before emitter diffusion, i.e. the Al should act actual only as a diffusion barrier.

However, sequence 2 describes the real Al/P-codiffusion by simultaneous formation of emitter and BSF in one single high temperature processing step. An acceleration of diffusion kinetics due to mutual influence of the dopant by generating point defects during the diffusion process [6] was also expected for sequence 2.

It is difficult to understand that R_{sheet} of sequence 2 is approximately comparable with the non-metalized groups. Definitely the distribution of R_{sheet} in Fig. 2 is reproduceable.

Furthermore a decrease in R_{sheet} with increasing belt speed is cognizable. Assuming the P-paste as finite doping source the trend of R_{sheet} can be explained by outdiffusion of phosphorous due to long cycles at extremely high temperatures (980°C).

3.2. Indirect emitter diffusion via gas phase

The LBIC (Light Beam Induced Current) mapping in the short wavelength range of the rear side of the cell shows at three sides sharply defined borders (Fig. 3). This separation is caused by the alloyed busbar on the top and the outer contact fingers on the left and right side. On the rear side of the wafer 3µm Al with comb-structure was locally evaporated and alloyed. Afterwards the front side was fully covered with screenprinted P-paste, dried and fired at temperatures well above 900°C. At the end of the contact fingers (bottom of LBIC-map Fig. 3) the electrically active n-type doping region is separated along defined angles due to the printout of the metal belt while firing the P-paste in the IR belt furnace. The rear side is completely diffused via the gas phase. However, the connection between the rear side emitter (the black region in Fig. 3) and the front side emitter is interrupt by laying the wafers on the belt.

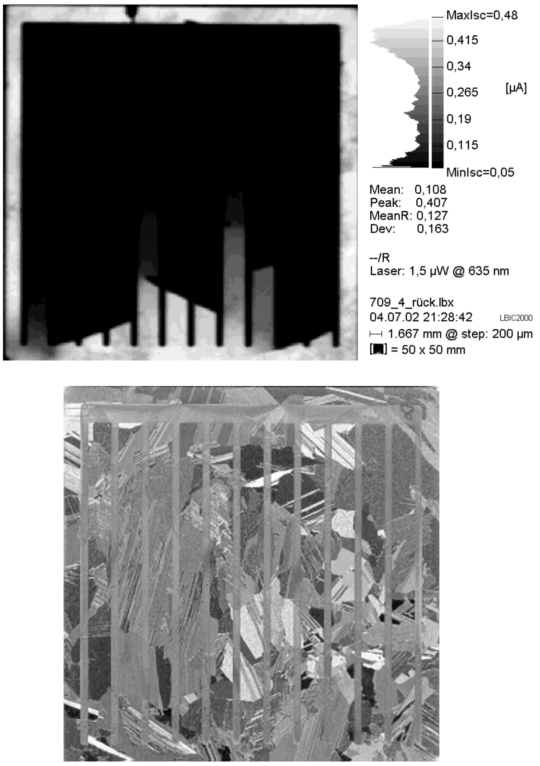

Fig. 3: LBIC measurement in the short wavelength range (635 nm) of the rear side of a codiffused mc-Si with comb-like BSF

3.3. Back Surface Field

On the basis of LBIC and IQE measurements in the long wavelength range adjacent mc-Si solar cells processed according to sequence 1 and sequence 2 (Fig. 1) were compared. Fig. 4 shows the improved IQE of the cell of sequence 2.

One obvious argument for the improved IQE in the long wavelength range of sequence 2 is the redundance of one additional high temperature processing step. Dependent on the quality and the applied processing sequence of the silicon wafers used this would have a benefiting effect on the material and the cell performance.

Another cause is the improved effectiveness of the Al/P-cogettering [7] resulting in an improved diffusion length. This is of importance especially for low-grade mc-Si. Applying sequence 1 there are two separate gettering steps first the Al gettering and afterwards an (Al)/P-gettering. The gettering effect of the Al in the second high temperature step is probably negligible because the BSF formation is already completed.

In addition the BSF formation of both sequences takes place under different conditions. In the first sequence the evaporated Al was alloyed in a tube furnace at 800°C for 30 min. However, in the second sequence the evaporated Al was cofired in an IR belt furnace for a short duration (< 4 min) at 980°C, i.e. the peak temperature during BSF formation is clearly higher. In addition BSF formation in a tube furnace is expected to be cleaner due to the use of quartz boats.

Which of all these arguments predominates is difficult to separate.

A comparison of the short wavelength IQE is useless because of the different emitter doping profiles at the same firing conditions caused by the different handling of the rear sides(Fig. 2).

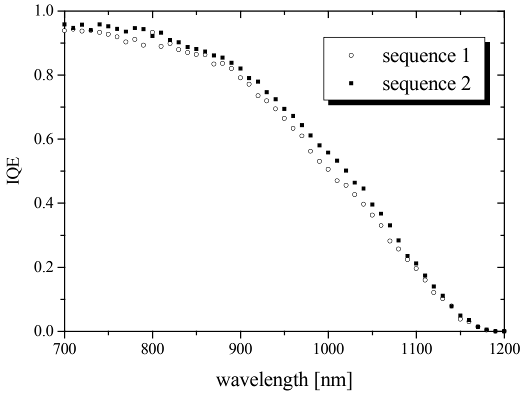

Fig. 4: IQE measurement of adjacent mc-Si solar cells with differently alloyed Al

4 REMARKS

Comparing Al/P-codiffusion using $POCl_3$-emitter diffusion [2] and screenprinted P-paste the obtained shunt values of the $POCl_3$-emitter diffusion are clearly higher up to 10000 Ωcm^2 [2]. However, additional LBIC measurements of cells with screenprinted emitter show that the relative low shunt values of about 1000 Ωcm^2 are determined by difficulties of handling during solar cell processing. The detected shunts are located not between the alloyed metal and the neighbouring emitter but locally at the wafer edges. Emitter diffusion in an IR heated furnace is after all a process of lower purity.

5 CONCLUSION

Al/P-codiffusion combining P-paste and Al-paste is not possible without additional investigations due to the extreme firing conditions indispensable for emitter formation using P-paste. Cracks were induced while cofiring wafers with fully screenprinted Al on the rear due to the big difference in thermal extension. For locally alloyed Al the formation of little Al spheres along the grid finger as well as flaking of the grid was observed.

Al/P-codiffusion combining P-paste and evaporated Al results in mean shunt values of about 1000 Ωcm^2 regardless whether the Al is additionally alloyed in a separate processing step before depositing and firing the P-paste or not. I.e. the separate alloying of the deposited Al (sequence 1) proved to be unnecessary. In addition the shunt values turned out to be independent form the metal-emitter contact length, independent from the used material (mc-/Cz-Si) as well as independent from the chosen parameter set while emitter formation.

The distribution of R_{sheet} at constant firing temperature and with screenprinted P-paste on the front by varying rear side coverage and varying duration of heating was investigated. Wafers with evaporated and alloyed Al on the rear before screenprinting and firing the P-paste showed the lowest R_{sheet} regardless of the firing conditions of the P-paste. Additionally a trend of increasing R_{sheet} with decreasing belt speed independent of the different rear side coverage could be observed.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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