LOCAL BACK SURFACE FIELD ON THIN SILICON LOW COST SOLAR CELLS

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ABSTRACT: In view of future industrial solar cell production a high efficiency process for thin multicrystalline silicon wafers is requested. Thin wafers are advantageous because the major cost factor in todays silicon photovoltaics is the silicon wafer. The industrial compatible firing-through PECVD (Plasma Enhanced Chemical Vapor Deposition) silicon nitride process was adapted to the demands of thin wafers with a thickness of 200 µm. New rear side schemes are needed to take into account the higher ratio of the diffusion length to the cell thickness and to overcome the bending of thin wafers with the standard full Al-BSF. A promising attempt is the realization of a local back surface field (LBSF) by passivating the back side with SiN_x and afterwards screen printing a square pattern of lines. The LBSF process was carried out using various coverage ratios and printing pastes. After evaporating Al as a back surface reflector cell efficiences of 12.5%were obtained, representing an increase of 0.6% absolute compared to the standard process. To exclude the influence of leakage currents resulting from the double-sided $POCl_3$ emitter diffusion the LBSF process was modified. The rear side emitter was compensated by evaporating Al and alloying to perform a BSF. Furthermore the PECVD silicon nitride was replaced by a LPCVD (Low Pressure Chemical Vapor Deposition) SiN_x to fulfill the requirement of no additional processing step. With this process sequence the fill factor losses could be minimized to 1-2% absolute.
KEYWORDS: Multi-Crystalline - 1: Back-Surface-Field - 2: - Screen Printing 3

1. INTRODUCTION

Since 46% of the total module costs are due to the wafer [1] there is a high potential for cost reduction. By reducing the wafer thickness more wafers per ingot can be obtained and the silicon resources are economized.

Because of the higher ratio of the diffusion length to the cell thickness the surface recombination at the rear side becomes one of the dominating factors limiting the efficiency of thin solar cells. The high surface recombination due to the metal contacts can be lowered by reducing the back contact area. This can be accomplished by printing a square pattern of lines at the rear side leading to a local back surface field (LBSF). As can be seen in the PC1D simulation in Figure 1 the grid has to be combined with a rear surface passivation to get a S_{eff} smaller than 3000 cms^{-1}.

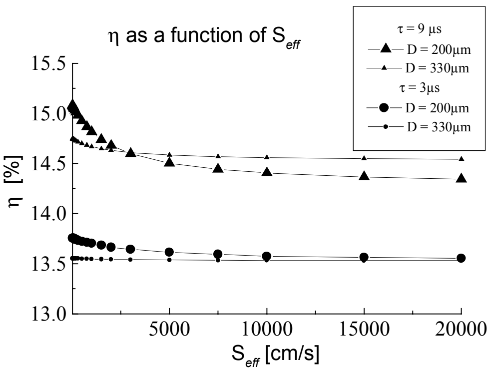

Figure 1: *PC1D simulation for the cell efficiency η as a function of the effective surface recombination velocity S_{eff} assuming a carrier lifetime of 9 µs resp. 3 µs and a wafer thickness of 200 µm resp. 330 µm.*

Furthermore, the bending of thin cells with an entirely metallized rear surface resulting from the difference in the thermal expansion coefficients of Si and metallization pastes (α_{Si}=7.6K^{-1}, α_{Al}=23.8K^{-1}) is avoided. This bending would lead to problems with automatic handling systems and on the stage of cell stringing for module fabrication. It was shown [2] that the yield of thin wafers within the industrial fabrication process depends mainly on the handling systems and operators.

Another advantage of an LBSF compared to the standard full Al BSF presently used in most industrial production lines is the lower consumption of expensive printing pastes.

2. EXPERIMENTAL AND RESULTS

2.1 LBSF solar cell process

The material processed were 100 cm^2 mc-Si wafers with a thickness of 200 µm supplied by Bayer. Figure 2 shows the LBSF solar cell process sequence. Initially the saw damage was removed in a solution of hot NaOH. The $POCl_3$ emitter diffusion resulted in a sheet resistance of 35Ω/sqr. After the etching of the phosphorous glas in hydroflouric acid a double-sided silicon nitride was deposited as ARC and surface passivation with a direct PECVD (Plasma Enhanced Chemical Vapour Deposition) plasma reactor. The next step was the screen-printing of the front grid with a shadowing of 8% and a square pattern of lines at the rear side with a coverage ratio of 20% or 30%. Co-firing the contacts in an IR-furnace overcompensates the emitter under the rear side grid forming an LBSF to the base. Processing was completed by mechanical p/n junction isolation with an automatic dicing saw.

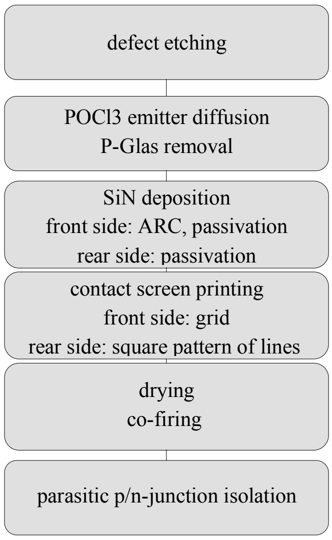

Figure 2: *The applied LBSF solar cell process is shown schematically.*

The results of this LBSF process are shown in Table 1. The reduction of the back contact area results in lower fill factors due to series resistances. The higher fill factor of the solar cells with an AgAl back contact can be attributed to the higher conductivity of the AgAl paste compared to the Al paste. In addition to the front side series resistances for thin LBSF cells the higher sheet resistivity, the back side lateral resistance and grid resistance must be taken into account [3]. The sheet resistivity ρ_S of the bulk (resistivity ρ = 1Ωcm) for a cell thickness of 200 µm is about 50 Ω/sqr. compared to 30 Ω/sqr. for 330 µm cells. A fit according to the 2-diode-model results for a back side grid with a coverage ratio of 20% and 30% in a lateral resistance R_{lat} of 3.0Ωcm^2 resp. 2.1Ωcm^2. Another problem are the leakage currents between the non-compensated n-layer at the rear side and the back contacts.

FF [%]		
covering ratio	printing paste	
	Al	AgAl
20%	65	68
30%	69	71
100%	73	74

Table 1: *Mean values of the fill factors of LBSF solar cells with different coverage ratios and printing pastes.*

Measurements of the internal quantum efficiency for an LBSF solar cell with a coverage ratio of 20% compared to a standard cell indicate the need for a back surface reflector for thin solar cells (Fig. 3). Nevertheless, a small improvement for long wavelengths shows the improved rear side passivation.

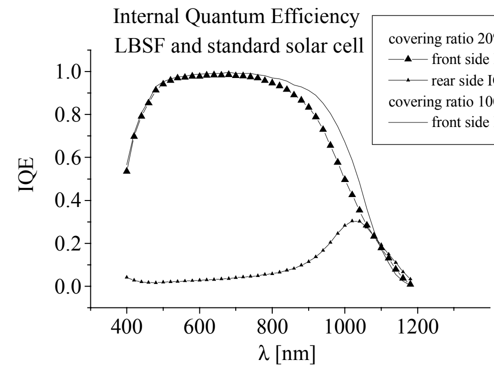

Figure 3: *Spectral response measurements showing the internal quantum efficiencies for the front and rear side of an LBSF solar cell with a coverage ratio of 20% and the front side of a standard solar cell.*

To improve the fill factors and short circuit current densities an Al layer was evaporated on the silicon nitride at the back side and sintered to perform a back surface reflector. In Table 2 the cell parameters of LBSF solar cells with an AgAl back side grid and a back surface reflector can be seen. This process sequence leads to an increase in J_{SC} for all applied coverage ratios. As the series resistance of the rear contact is negligible after sintering sof the evaporated Al the fill factor losses were reduced. Therefore the LBSF solar cell process leads for a coverage ratio of 20% and 30% to cell efficiencies η of 12.0% resp. 12.5%. This represents an increase in efficiency up to 0.6% absolute compared to thin cells with a standard full Al-BSF.

AgAl paste coverage ratio	J_{sc} [mA / cm^2]	V_{oc} [mV]	FF [%]	η [%]
20 %	28.0	579	74	12.0
30%	28.2	589	75	12.5
100%	27.3	578	76	11.9

Table 2: *Mean values of the cell parameters of LBSF solar cells with an AgAl back contact grid and an evaporated Al back surface reflector.*

2.2 LBSF process with a compensated rear side emitter

To exclude the influence of the non-compensated back side n-layer the process was modified as shown in Figure 4. Before the silicon nitride deposition the rear side emitter is overcompensated by an additional Al alloying step. The silicon nitride was deposited with a PECVD and additionally with a LPCVD (Low Pressure Chemical Vapor Deposition) reactor because the LPCVD reactor includes the possibility of a SiN_x deposition on both sides of the wafer at the same time and therefore no enlargement of the processing time [4]. Al paste was used for printing the back contact.

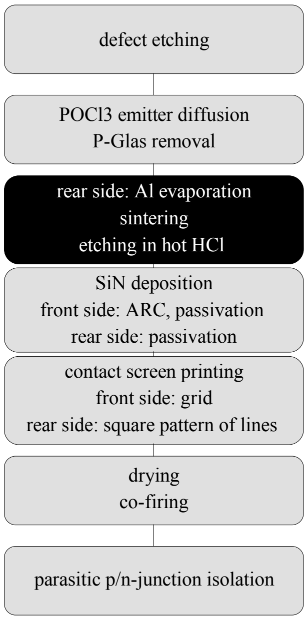

Figure 4: *The LBSF solar cell process with a compensated rear side emitter.*

In Table 3 the fill factors for this cell process are shown which are considerably higher than the ones obtained by the previous LBSF process (Fig. 2). Only minor fill factor reductions of 1-2% are visible as compared to the standard process with 100% coverage.

FF [%]			
coverage ratio	LBSF PECVD	LBSF evaporated Al-BSF PECVD	LBSF evaporated Al-BSF LPCVD
20%	65	71	70
30%	69	72	71
100%	73	73	74

Table 3: *Comparison of the fill factors (mean values) of LBSF solar cells with different coverage ratios and process sequences. The back side grid was printed with Al paste.*

An optimization of the firing-through PECVD SiN_x for thin solar cells with an emitter of 35 Ω/sqr. and a full Al BSF was carried out resulting in fill factors of 76-77% and 78-79% after sintering and tabbing. The best cell has a V_{oc} of 611 mV, a J_{sc} of 30.5 mA/cm^2, a fill factor of 79% and an efficiency of 14.7%. It is expected that this enhancement can be carried forward to the LBSF solar cells and reached for the firing-through LPCVD SiN_x process.

3. CONCLUSIONS

The firing-through silicon nitride process was modified for thin solar cells to take account of the higher diffusion length to cell thickness ratio and to avoid the bending of thin wafers within the standard process. Instead of the standard full Al-BSF a square pattern of lines was printed at the rear side leading to a local BSF. Due to series resistances and leakage currents the LBSF process on a non-compensated rear side emitter results in fill factor losses. To enhance the fill factors and short circuit current densities a back surface reflector was performed for the solar cells with an AgAl grid. This LBSF process leads for a coverage ratio of 30% to an improved cell efficiency η of 12.5% compared to 11.9% for the standard thin solar cell..

Furthermore, an LBSF process including an evaporated Al-BSF to compensate the emitter at the rear side was carried out leading to only minor fill factor reductions as compared to the process with a non-compensated rear side emitter.

Investigations on the dependence of the open circuit voltage on the bulk resistivity and furthermore the reduction of the wafer thickness down to 125µm are planned to be realized in the near future.

4. ACKNOWLEDGEMENTS

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