INDUSTRIALLY APPLICABLE METALLISATION WRAP THROUGH SOLAR CELL PROCESS RESULTING IN EFFICIENCIES EXCEEDING 16%

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ABSTRACT: Metallization Wrap Through (MWT) solar cells are back contact solar cells with a cell design that is particularly suited for large area cells. New interconnection technologies, applicable to back-contact cells, might be beneficial for the interconnection of thin wafers. As there is a trend in the industry to process both larger and thinner wafers, the development of a production process for MWT solar cells that can be transferred into an industrial environment is desirable. Our cell process for MWT cells is very similar to that of conventional screen-printed solar cells. Apart from minor adaptations, the additional effort is mostly only the formation of a limited number of holes with a laser. Large area (156 mm x156 mm) MWT cells with efficiencies up to 16.7% were processed. The cell process proved to be stable on a batch of over 80 cells, resulting in an average cell efficiency of 16.2%.

Keywords: Back Contact, MWT

1 INTRODUCTION

Metallisation Wrap Through (MWT) solar cells are back-contact solar cells with a design very similar to that of conventional screen-printed solar cells [1]. The collecting emitter and the contact fingers are located on the front side of the cell, while the busbars are shifted to the rear side. The electrical connection between the busbars and the fingers is established via laser drilled and metallised holes (see figure 1).

The MWT cell design offers several advantages compared to conventional cells. Most prominent is the gain in active cell area due to the missing shadowing of the busbars, which results in an increase in short circuit current. Furthermore, the removal of the highly reflective busbars enhances the optical appearance of the front side of the cell. This makes MWT cells particularly suited for the fast growing market of building integrated PV. Also, the cell design seems suited for large area cells, since the number of busbars can be increased without increasing shadowing losses. Thus, high currents, which are generated in large area cells, can be extracted more easily. Finally, with the contacts of both polarities located on the rear side, new automated pick-and-place technologies can be applied for cell interconnection [2].

The objective of our investigations was the development of an MWT cell that can be produced in an industrial environment.

2 Cell Process

The cell process used for the production of our MWT solar cells is shown in figure 2. It is very similar to the process used for conventional screen-printed solar cells. The process starts with the drilling of holes, through which the contact fingers will be connected with the busbars. The holes are formed by laser. Since there is a relatively small number of holes (about 200 for a 156 mm x 156 mm cell) a modern laser system can fulfill this task easily. The laser damage in the holes is removed in parallel to the saw damage resulting from wafering. Then an emitter (approx. 50 Ω/sq) is diffused in a $POCl_3$ diffusion. It is important that the holes are drilled before the diffusion to ensure that the emitter forms not only on the front and rear side, but also in the holes. Next, silicon nitride is deposited by plasma enhanced chemical vapor deposition (PECVD) on the front side of the cell. The metallization is realized by an adapted screen-printing process consisting of four printing steps. With conventional solar cells two screen-printing steps are commonly used for rear side metallization: Al-paste is printed on most of the rear side area. In addition solderable contact pads, mostly printed with AgAl-paste, are applied. In the case of MWT cells a third printing step becomes necessary as the emitter busbar has to be metallized with silver paste. Whether this additional step can be avoided by using the Ag-paste used for the busbars also for the p-type solder pads will be discussed later on. The application of the front contact grid requires a forth printing step. After screen-printing the cells are fired in an infra-red belt furnace. Finally the p- and n-regions are isolated with a laser. Since the isolation of the n-type busbar from the p-type region has to be on the rear side, the edge isolation is also done from the rear side

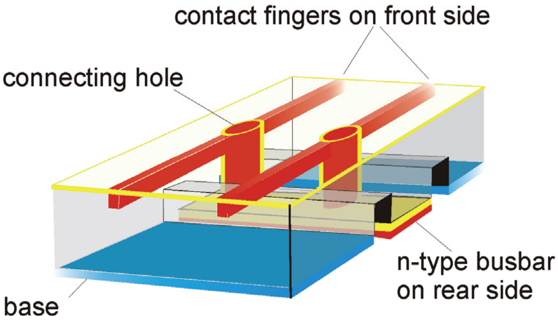

Figure 1: Schematic drawing of a MWT cell. Yellow: Emitter, blue: back surface field, red: n-type metal contact.

Thus the additional effort to process a MWT cell compared to a conventional cell is limited to the formation of a small number of holes and an additional

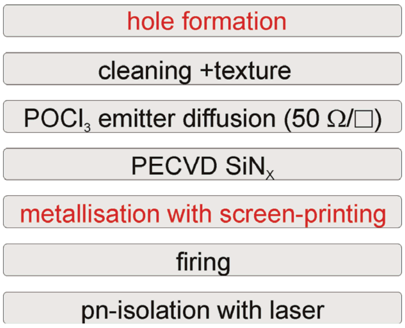

Figure 2: Process flow diagram used for the production of MWT solar cells

screen-printing step. The latter, however, can be avoided in principal.

3 CONTACT DESIGN

A MWT cell, which has the busbars shifted to the same position on the rear side as they would be on the front side, is not easily interconnectable. Tabs soldered to the emitter busbars will meet the neighboring cell at its emitter busbars instead of the base region. Several MWT contact designs solving this problem were suggested earlier [3],[4]. Three cell designs, shown in figure 3, were chosen for closer consideration: 1) a cell design with busbars, which do not extend to the full cell length, 2) a design with one busbar located at the edge of the cell and 3) a design similar to a solderable PUM cell [5].

To evaluate the different cell designs, their electrical properties were simulated using a previously described model [6]. For all cell designs the simulations resulted in a optimum of three busbars for a 156 x156mm cell. Further, the simulations indicate that neither the design with the shortened busbars nor the design with one busbar at the edge of the cell will result in a significant efficiency improvement compared to conventional cells. Only the solder version of the PUM cell promises superior cell efficiency. Unfortunately this cell design requires the application of an isolating lacquer between the n-type contact islands on the rear side or an alternative non-tabbing based interconnection. Nevertheless, the MWT cells mentioned below utilize a cell design similar to the solderable PUM cell.

4 CELL RESULTS

A large batch of MWT cell from 3-6 Ωcm 156 x 156 mm^2 semi-square Cz-Si was processed according to the sequence described above. For the removal of the saw damage an anisotropic etch was used, resulting in a random pyramid texture. The results are shown in figure 4.

The processing of the cells proved to be unproblematic. The laser drilling of the holes does not seem to influence mechanical stability significantly, as loss due to breakage was negligible. Also the distribution of cell results shows a standard spread and we consider the process to be stable.

The average cell efficiency was 16.2%, which is an excellent result for back-contact cells of 239 cm^2 cell area. Efficiency is limited by the fill factor, which is with 76.0% average slightly too low. By isolating the edges with a trench diced from the front side replacing the laser isolation from the rear, the fill factor can be improved by roughly 1.5% absolute, as verified for several cells. One of the best cells with an original efficiency of 16.4% and a fill factor of 75.8% improved to 16.7% efficiency and a fill factor of 77.2%. The fill factor is particularly high for both back-contact cells and large area cells. The power generated by the cell, however, slightly dropped after dicing the edges due to the loss in active area.

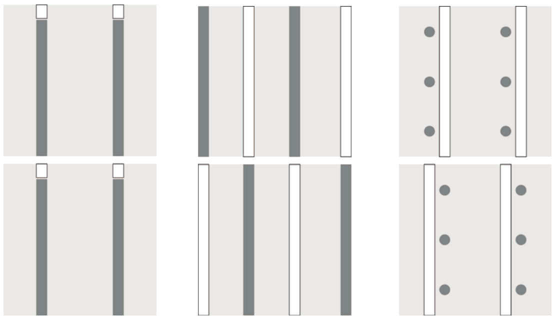

Figure 3: Different MWT contact designs. White: p-type solder pads. Dark grey: n-type busbars. Left: Cell design with busbars, which do not extend to the full cell length. Middle: Cell design with one busbar at the edge of the cell. Right: PUM like contact design.

	Laser rear side	**Dicing saw front side**
Area [cm^2]	239	233
J$_{sc}$ [mA/cm^2]	35.6	35.6
V$_{oc}$ [mV]	607.6	607.4
FF [%]	75.8	77.2
η [%]	16.4	16.7
P$_{max}$ [W]	3.92	3.90

Table 1: Cell results of the best MWT cell with the original pn-edge-isolation by a laser groove from the rear side and after the edges were removed with a dicing saw.

We believe that for this batch of cells efficiency is not limited due to problems specific for MWT cells (like cell geometry or a non-suited Ag-paste for busbar metallization). Further improvement will require mostly the same developments necessary for the improvement of conventional screen-printed solar cells like higher ohmic emitters and better rear side passivation.

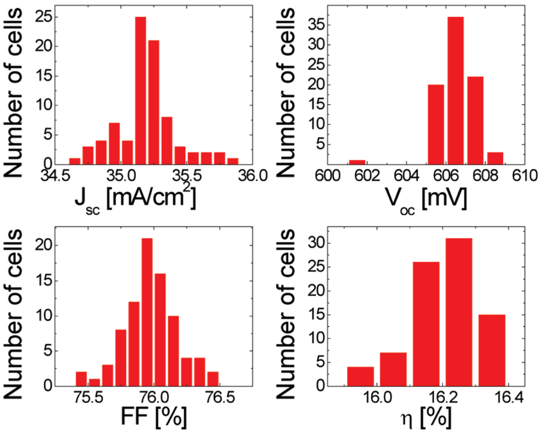

Figure 4: Cell results of a batch of 83 MWT cells (156 x 156mm^2) made from Cz-Si.

5 PROCESS SIMPLIFICATION

The batch of cells described above was metallized using four screen-printing steps: one step for the front grid and three printing steps on the rear side. On the rear side Al-paste is printed for the formation of a BSF. AgAl-paste was used to form solderable p-type contact pads. In addition the metallization of the rear side n-type busbars requires a non-conventionally firing Ag-paste. Using a conventional Ag-paste for the busbars would result in severe over-firing and shunting, as the paste is printed directly onto the emitter without a silicon nitride layer in-between.

In principal it is possible to avoid one printing step, if the solder pads for the p-type contact are printed with the same silver paste that is used for the metallization of the busbars (see table 2). In the following the effect of this simplification is investigated.

	Original	**Simplified**
front grid	Ag-Paste 1 on FS	Ag-Paste 1 on FS
busbars	Ag-Paste 2 on RS	Ag-Paste 2 on RS
p-type solder pads	AgAl-Paste on RS	
back surface field	Al-Paste on RS	Al-Paste on RS

Table 2: Printing sequences used for the metallization of MWT cells.

Two groups of MWT cells were processed in parallel from 156 x 156 mm^2 semi-square Cz-Si with a base resitivity of 3-6 Ωcm. For the first group a simplified metallization sequence was used with p-type solder pads and busbars printed with the same Ag-paste. The second group served as a reference using the original metallization with p-type solder pads of AgAl-paste. The average cell results of the two groups are listed in table 3.

	Original	**Simplified**
$\mathbf{J_{sc}}$ [mA/cm^2]	35.2 ± 0.1	35.3 ± 0.3
$\mathbf{V_{oc}}$ [mV]	609.8 ± 0.3	605.6 ± 1.0
FF [%]	74.6 ± 0.6	72.1 ± 0.5
η [%]	16.0 ± 0.1	15.4 ± 0.1

Table 3: Average cell results of 2 batches of 8 MWT cells. One batch was processed with a simplified metallization sequence with p-type solder pads of Ag-paste, which avoids one printing step.

Both metallization processes result in similar short circuit currents. The open circuit voltage, the fill factor and thus the efficiency differ significantly for the two processes. The average V_{oc} is more than 4mV lower for the simplified metallization. Since also the average fill factor is 2% lower for the simplified process, the average efficiency is reduced from 16.0% to 15.4%.

To understand this, it is necessary to realize that in our process the emitter is formed in a $POCl_3$ diffusion from the gas phase. This means that after the diffusion and before firing, there is emitter not only on the front side of the cell, but also on the rear. In particular, there is emitter under what will be the p-type solder pads. AgAl-paste and Al-paste both consume the emitter during the firing process, so that there is no more emitter under solder pads if they are made from AgAl-paste. If the pads are, however, made from the same Ag-paste with which the busbars are printed, this will not be the case. The busbar paste is a non-standard Ag-paste since it must not fire through the emitter to avoid shunting in the busbar region. Hence, for the simplified metallization there is still emitter under the p-type solder pads at the end of the process.

This emitter under the solder pad is short circuited with the base contact. Electrons diffusing to the rear side of the cell will be collected in the emitter. As the emitter is short circuited with the base the electrons will then recombine with holes. The surface passivation of AgAl-paste is poor compared to an Al-BSF. The short circuited emitter under the Ag-paste, however, leads to a complete depassivation of the surface (see figure 5). This is very likely the reason for the observed drop in V_{oc}.

The existence of an emitter under the p-type solder pad also affects holes in that region. Due to the band bending, the holes are repelled from the back contact. Thus, to be collected, the holes have to flow to the Al-BSF next to the solder pads. Due to an increased path length of the holes, the series resistance in the pad region is increased by 1.3 Ωcm^2 compared to the “non-busbar cell area” (assuming the contact geometry we used, a 300µm thick cell and a base resistivity of 3 Ωcm). The increased series resistance in parts of the cell will obviously reduce the fill factor.

It is important to note that the contact design used for the comparison describes a worst-case. We used a contact design with three p-type solder pads, which extend the full cell length. Currently the pads cover nearly 8 % of the cell area. By adjusting the cell design to smaller p-type solder pads the effect could be diminished greatly.

Further, the effect will be as articulated only for the special Ag-paste we use for busbar metallisation. Common Ag-paste will fire through the emitter, if it is printed directly onto the emitter without silicon nitride in-between and is fired with normal firing conditions. As in the case of AgAl-paste, all or the at least most of the emitter will be consumed thereby and cell performance will be similar.

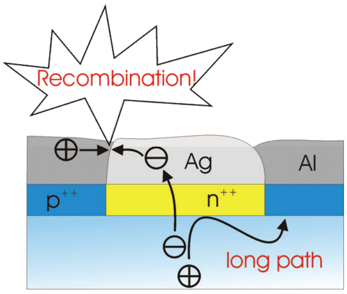

Figure 5: Schematic of a p-type solder pad printed with the same paste, which is used for the metallization of the emitter busbars. An emitter under the pads leads to a very poor surface passivation and to an increased path length for holes.

6 CONLUSIONS

We have developed a cell design for large area MWT cells, with which high cell efficiencies up to 16.7% (Cz-Si, 233cm^2) were demonstrated. The cell process used for the production of MWT cells proved to be stable on a larger batch of 83 cells, where an average cell efficiency was of 16.2% was achieved.

The possibility for a simplified process, which avoids one printing step, was investigated. The simplified process results in a loss in open circuit voltage and fill factor. Average efficiency of the cells processed with the simplified process reached only 15.4% compared to 16.0% for the reference group. Very likely the loss could be greatly reduced by using an adapted contact geometry with smaller p-type solder pads.

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