ADVANCEMENTS IN THE DEVELOPMENT OF BACK CONTACT CELL MANUFACTURING PROCESSES

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ABSTRACT: In this paper we report on investigations of different back contact solar cell designs and their suitability for large scale manufacturing. We assess challenges that arise in the processing and suggest new technologies that could be implemented. Based on small series of prototypes we identified several difficulties that have to be overcome in order to fully benefit from the various advantages back contact cells offer over conventional cells.
Keywords: Back Contact, Manufacturing and Processing, Laser Processing

1 INTRODUCTION

To stay abreast of the trend towards growing substrate sizes and the hereby entailed challenges in the manufacture of solar cells and modules, the development of industrially feasible back contact solar cell production processes will become very valuable.
Back contact solar cells offer various advantages over conventional solar cells. Apart from their pleasant optical appearance, which makes them well suitable for façade applications and building integration, they have the potential for higher efficiencies, mainly founded in reduced shadowing and resistive losses. They also facilitate an increase in the packing density in the module, as well as a reduction in module manufacturing costs [1].
The aim of this work is to evaluate back contact solar cells and to develop production technologies for the industrial manufacturing of low cost back contact solar cells. As candidates for the detailed investigation, we have selected three different device designs of back contact solar cells: Metallisation Wrap Around (MWA), Metallisation Wrap Through (MWT) and Emitter Wrap Through (EWT) solar cells. For these types of solar cells, different processing sequences based on screen-printing were determined and the major process technologies to be developed were identified.

2 MWA SOLAR CELL CONCEPT

Figure 1 depicts the MWA solar cell design that was investigated in this work. The emitter contact busbars are transferred to opposing edges on the rear side of the wafer and connected with the front contact fingergrid over the edges of the wafer. P- and n- contacts are separated through trenches on the rear side of the wafer.
A big advantage of the MWA cell design is that its processing sequence is very similar to that of a conventional solar cell. The processing starts with an alkaline texturing step which at the same times removes the as-cut saw damage. Afterwards the wafer is exposed to a gas phase $POCl_3$ diffusion creating the emitter (sheet resistance $R_{sh}\approx 50\Omega/sq$) and to a Low Pressure CVD silicon nitride deposition which serves as surface passivation as well as anti reflective coating. After screen printing and firing of both emitter and base contact processing is completed by the p/n-junction separation. With this processing sequence we achieved efficiencies of up to 15% on monocrystalline 100cm² Cz-wafers.

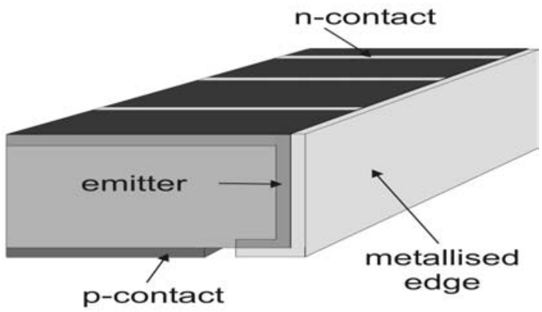

Figure 1: Schematic illustration of a Metallisation Wrap Around solar cell. The front fingers are connected to the emitter contact on the rear over two opposite edges. External p- and n-contact isolation was realised by isolating trenches.

Our model calculations show that this device design can lead to higher module efficiencies if appropriate interconnection schemes are applied [2].
In order to benefit from the transfer of the busbars to the rear of the cell it is vital to obtain a highly conductive emitter contact grid with narrow fingers to minimise resistive losses due to increased finger lengths.
Two additional main challenges arise in the large scale production of MWA solar cells. Whereas the p/n-junction separation of a conventional cell takes place at the wafer edges, usually performed with a plasma etch step, the MWA design necessitates the junction separation on the rear side of the wafer. We are investigating two methods that seem suited for this task: mechanical abrasion, using a dicing saw and laser ablation. At this point the mechanical abrasion seems to be superior to the laser ablation process using a Nd-YAG laser (λ=1064nm). Further investigations as to the use of short pulse laser systems as well as lasers with shorter wavelengths are pending.
The second challenge concerns the metallisation of the wafer edges. We have found that the shunt free edge metallisation using printable inks and a subsequent firing step is demanding in both finding optimal fire parameters as well as a reliable technology for continuous deposition of ink along the wafer edges. Currently the metallisation

ink is applied manually at the edges. Shunts at the wafer edge can first be caused by penetration of the metallisation paste through the emitter contacting the base. An appropriate paste can solve this problem. Secondly, silicon particles are chipped off during solar cell processing e.g. by wafer handling. During metallisation and firing, the base is directly contacted leading to the observed shunts (Fig. 2). This problem may be avoidable by a more sensitive wafer handling system.

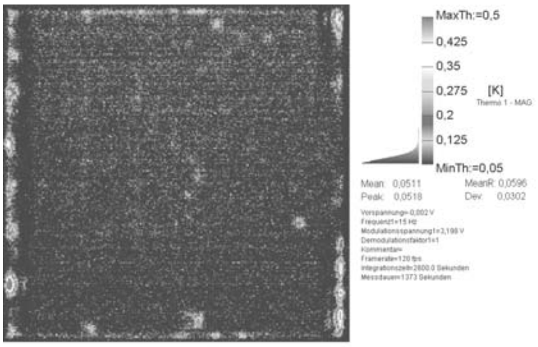

Figure 2: Thermographic image of a MWA solar cell. The lighter areas represent local shunts at the metallised edges, limiting fill factors and cell performance.

3 MWT SOLAR CELL CONCEPT

The MWT solar cell design resembles the conventional solar cell design very closely, the only visible difference being the transfer of the emitter contact busbars to the rear surface of the wafer. The electrical connection of these busbars to the frontside fingergrid is achieved through the insertion of laser drilled, metallised holes (Fig 3). The MWT solar cell allows for the reduction of the effective finger length without an increase in shadowing losses through the application of several busbars, thereby minimising resistive losses.

The processing sequence of the MWT cell design starts with the insertion of two laser drilled holes per emitter contact finger, corresponding to a two emitter busbar design. The following alkaline etch step applies a texturisation and removes the saw as well as the laser damage. After a $POCl_3$ gas phase diffusion forming the emitter (sheet resistance $R_{sh} \approx 50\Omega/sq$) and a subsequent plasma etch step to obtain a p/n-junction separation at the wafer edges, we deposited a Low Pressure CVD silicon nitride layer on the front side, both passivating the surface and serving as an anti reflective coating. In the last processing step both contacts are screen printed and fired which is then followed by the insertion of the isolating trenches to define the pn-contact regions on the back. With this processing sequence we achieved cell efficiencies exceeding 15% on monocrystalline 100cm² Cz-silicon wafers.

Processing MWT solar cells comprises the implementation of laser technology. Commercially available laser drilling systems have shown to reach drilling rates of up to 200 holes/sec. Although the necessary number of holes for an MWT cell varies with the grid design, i.e. number of fingers and busbars, current laser drilling systems should be fast enough not to slow down the cell production rate.

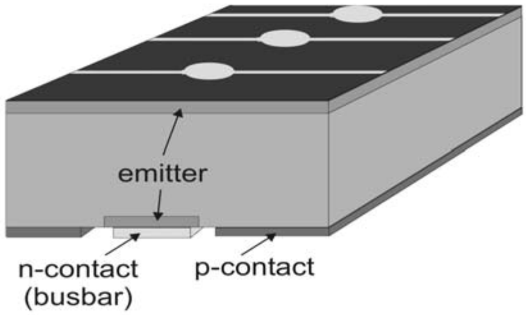

Figure 3: Schematic of a MWT solar cell. The frontside emitter contact finger grid is connected to the emitter busbars, located on the rear side of the wafer, through metallised holes. The design allows for a multiple busbar design without increasing shadowing losses.

As in the MWA design we investigated the possible use of laser ablation as a means for p/n-junction separation. The use of lasers would be especially desirable as it allows for emitter busbar designs on the rear surface, which do not extend as straight line from one edge to the other. This greatly bolsters the simple interconnection of MWT solar cells in the module fabrication process.

Presently the greatest challenge for reaching higher efficiencies lies in the finding of an appropriate set of inks for the emitter busbars, the frontside finger grid and the trough hole metallisation. Whereas on the front side the n-contacts must be fired through a silicon nitride layer, the n-contact regions on the rear surface have no silicon nitride coating. In our experiments we observed, that different inks have to be applied for the emitter busbar and emitter finger grid if co-firing is to be used, otherwise the cell may show shunting (Fig 4).

Current experiments are mainly concerned with the optimisation of the combination of metallisation inks and the corresponding fire parameters.

To achieve a reliable through hole metallisation highly accurate printing is required. Presently we are testing the usefulness of a multiple vacuum printing setup.

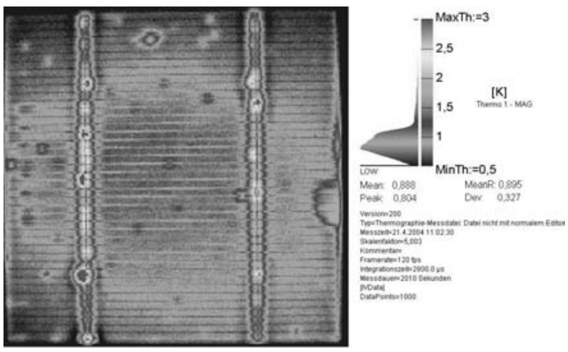

Figure 4: Thermographic image of a MWT solar cell. The cell shows shunting along the emitter busbars located on the rear surface of the cell if the same ink is used for frontside finger grid and rear side busbars. This is the major loss mechanism at the current stage of our cell development.

4 EWT CELL CONCEPT

The EWT cell design (Fig 5) features no metal contacts on the front side. The emitter contacts are transferred to the rear side of the wafer and connected to the frontside emitter through metallised, laser drilled holes [3]. Since both emitter and base contact are located on one side of the cell intricate interdigitation of the contact grids is required.

The most obvious advantage of the EWT cell design is the reduction of active cell area by less than 1%. In addition parts of the rear side are phosphorus diffused, increasing carrier collection probability.

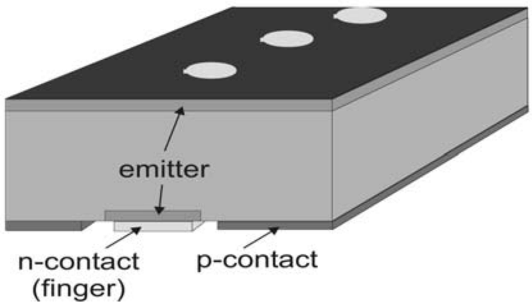

Figure 5: The EWT cell design has both emitter and base contact on the rear side of the cell, requiring interdigitation. The emitter contact is connected to the frontside emitter through metallised, laser drilled holes.

Manufacturing an EWT solar cell requires a more complex process than a conventional cell design does. We investigated a design involving a selective emitter process, reaching cell efficiencies over 16% on monocrystalline 100cm² Cz-wafers. [3]

After an alkaline texturisation step the wafer is exposed to a shallow emitter $POCl_3$ gas phase diffusion (sheet resistance $R_{sh}\approx 100\Omega/sq$). Afterwards a Low Pressure CVD silicon nitride anti reflection layer is deposited. We then inserted the laser drilled holes into the wafer, followed by an aqueous sodium hydroxide etch step to remove the laser damage. In order to achieve a subsequent p- and n-type region definition, a diffusion barrier was screen printed on the rear side of the wafer and fired. Then a second $POCl_3$ diffusion is applied (sheet resistance $R_{sh}\approx 10\Omega/sq$). In a last step the metal contacts are screen printed and fired.

Apart from the need for very accurate printing to avoid shunting of the cell and to achieve a reliable hole metallisation, an additional challenge lies in the laser drilling of a large number of holes. We are currently evaluating different laser drilling systems to determine the drilling rates and to assess the damage introduced into the wafer. First results suggest that the laser damage con presently not be considered a limiting factor for overall cell performance. As an alternative, also with the potential for higher efficiencies, we are investigating different masking methods to achieve the p- and n-type region definition on the rear side of the wafer.

5 CONCLUSIONS

We discussed three back contact solar cell designs that are suited for the industrial production and identified the challenges that arise. As back contact cells in general require additional process steps compared to conventional silicon solar cells, the necessary implementation of new technologies has to be thoroughly investigated. Although the integration of laser systems into existing production lines requires some effort, the technological challenges that lie in the large scale manufacture of back contact solar cells will soon be outweighed by their potential for higher efficiencies, especially for large substrate sizes, and the facilitation of the interconnection and higher packing density within the module.

6 ACKNOWLEDGEMENTS

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