17% BACK CONTACT BURIED CONTACT SOLAR CELLS

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ABSTRACT: In this study two back contact solar cell structures with buried contact metallisation are presented: the Metallisation Wrap Around (MWA) solar cell and the Metallisation Wrap Through (MWT) solar cell. The MWT solar cell has one laser-drilled via in each contact finger to transport the generated current to the n-type busbar on the back, whereas the front grid of the MWA solar cell is connected with the n-contacts on the back surface over two opposite edges of the solar cell. In the BCSC processing sequence the interconnections i.e. vias and edges are formed automatically during the electroless plating step which makes this metallisation technique especially suitable for back contact solar cells. The p/n-contacts on the rear of the solar cells are defined by mechanical abrasion using an automatic dicing machine. The best efficiencies obtained in this study are η=17.2% (cell area 25 cm^2) for an MWT solar cell and η=17.5% (area 25 cm^2) for an MWA solar cell using solar grade Cz-Si. The MWA solar cell concept was transferred to a cell area of 10x10 cm^2 and an efficiency of η=16.6% was reached.
Keywords: Back contact – 1: Buried Contacts – 2: Gettering - 3

1. INTRODUCTION

Placing the busbars of the emitter contact onto the rear side of a solar cell offers various advantages. The module assembling costs could be remarkably decreased due to the back contact design. Furthermore, the shadowing losses of the front grid are reduced leading to an improvement in cell efficiency. In addition the back contact design leads to a higher aesthetic appearance of the module which is an important advantage when dealing with solar architecture (e.g. facades).

In the last years various designs for back contact solar cells have been suggested for different electronic qualities of the silicon base materials and different metallisation techniques e.g. point contact solar cell [1], Emitter Wrap Through solar cells [2], [3], Metallisation Wrap Through solar cells [4], Metallisation Wrap Around solar cells [5]. These solar cells were either made by photolithography or screen-printing. Only for the EWT design, back contact solar cells were presented with metallisation made by electroless metal deposition.

In the present work the buried contact solar cell (BCSC) technique [6] was used to fabricate two different types of back contact solar cells: The Metallisation Wrap Through (MWT) solar cell and the Metallisation Wrap Around (MWA) solar cell. The process sequence to obtain the proposed back contact solar cells is very similar to the standard buried contact solar cell sequence.

2. CELL DESCRIPTION

Figure 1 shows a schematic illustration of the MWT and MWA cell concept. Both cells have a lightly doped emitter on the front side, which is essential for a high quantum efficiency in the short wavelength range. Most of the rear side is covered by an Al-BSF for surface passivation. The n-type metal fingers on the front side are connected to the busbars on the rear side of the cell. The MWT cells have one laser drilled via in each n-contacting finger to transport the current to the n-type busbar on the back surface. A very similar structure was already described by Van Kerschaver et al. [4] applying screen printed metallisation. The front grid of the MWA cells is connected to the busbar of the back surface over two edges

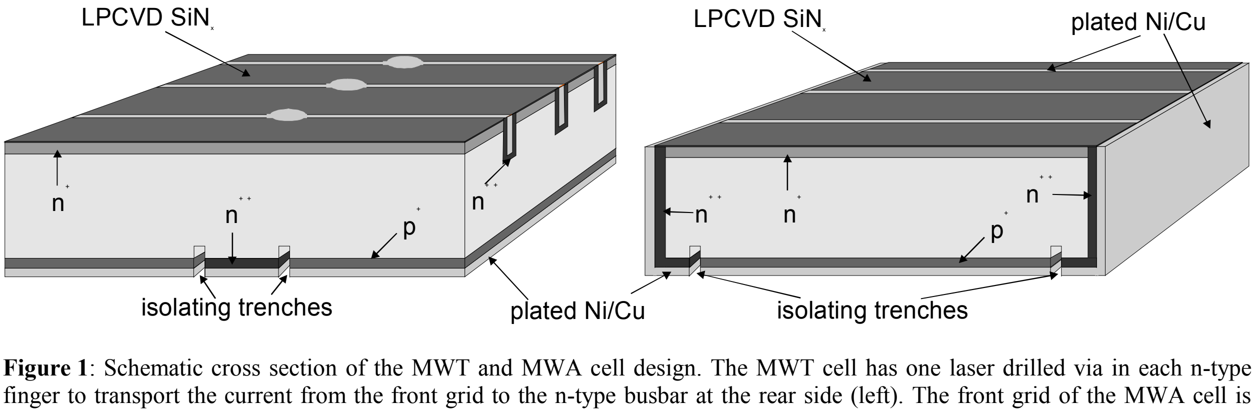

Figure 1: Schematic cross section of the MWT and MWA cell design. The MWT cell has one laser drilled via in each n-type finger to transport the current from the front grid to the n-type busbar at the rear side (left). The front grid of the MWA cell is connected with the n-contacts on the back surface via two opposite edges of the cell (right). The external p- and n-contacts on the rear of the cells are separated by mechanical abrasion using a conventional dicing saw.

of the cell. The concept of wrapped around electrodes was already investigated for space applications by Michaels et al. [5] using evaporated contacts.

The process sequence (Figure 2) takes advantage of the selective metal deposition during the electroless plating within the BCSC process. The front grid, the rear p- and n-contacts as well as the interconnections between the front grid and the n-busbars on the rear are metallised in the same plating step. The external p- and n-contacts were separated mechanically by thin dicing blades. Due to mechanical contact separation additional p/n-contact definition steps (e.g. deposition of masking dielectrics) are not necessary in the presented MWA/MWT processing sequence.

3. PROCESS DESCRIPTION

The process steps for the MWT and MWA cells are integrated in a P-Al co-diffusion buried contact process sequence as shown in Figure 2. The material used was 12.5x12.5 cm^2 pseudo-square solar grade Cz-Si with a resisitivity of $\rho \approx 1\ \Omega cm$. Processing started at the production line of BP Solar España in Madrid with a defect etch and alkaline texturing followed by $POCl_3$ emitter diffusion (sheet resistance R_{sh}=100 Ω/sq) and Low

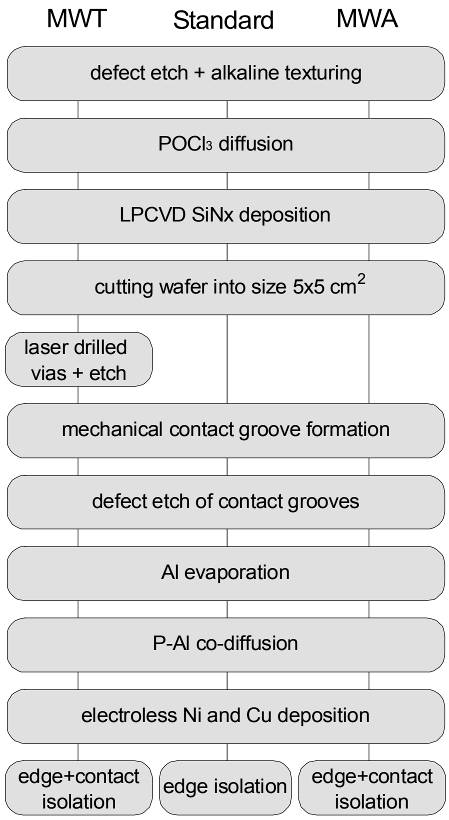

Figure 2*: Processing sequence of MWA and MWT solar cells with a cell area of 5x5 cm^2. The starting wafer size is 12.5x12.5 cm^2 pseudo-square. For comparison also the processing sequence of conventional BCSCs is given. Only a plasma etch of the edges to remove SiN_x has to be added to the process for MWA solar cells, when the initial size of the wafer is maintained during processing.*

Pressure CVD SiN_x deposition. The LPCVD SiN_x serves as antireflection coating, surface passivation as well as diffusion and plating mask. Processing continued at the University of Konstanz by cutting the wafers in a wafer size of 5x5 cm^2. This size was used for the first experiments. The MWT process continues by drilling the vias into the wafer with a NdYAG laser system. The vias are formed from the rear to the front surface resulting in a conical shape of the vias with a diameter of about 100 µm on the back and 30 µm on the front side, respectively. The laser damage was removed in a hot solution of NaOH which leads to a broadening of around 15 µm of the hole diameter on each side. The defect etch of the vias might not be necessary since the contact grooves have to be etched later in the process which will also remove the laser damage. In this first experiments we intended to ensure that the laser damage was completely removed.

The contact grooves of the MWT and MWA cells are formed by mechanical abrasion using 15 µm thin dicing blades mounted on an automatic dicing machine [7]. Each contact groove of the MWT cell is intermitted by a laser drilled via. The n-busbars on the rear (MWA, MWT) and front (standard) consist of several fingers with a distance of 100 µm. For the contact finger a spacing of 1.5 mm was chosen for all three cell types. The saw damage was etched in a hot solution of NaOH. Typical dimensions of the grooves were around 40 µm (depth) and 25 µm (width) after etching. Before the wafers passed through the P-Al co-diffusion they were cleaned in a solution of hot H_2SO_4/H_2O_2 (IMEC-clean [8]). Simultaneous diffusion of Al and P plays an important role in the processing sequence. In a single furnace step a full area Al- BSF is formed on the areas designated for the p-type contact and a heavy $POCl_3$-emitter ($R_{sh} \approx$10-15 Ω/sq) is diffused in n-type grooves, vias and edges. Additionally, the diffusion length of minority charge carriers can be increased by the gettering function of co-diffusion (see section 4.3). Before the wafers pass through this furnace step, a 2 µm thick Al layer is evaporated onto the rear side of the wafers using electron beam evaporation. At the same time the n-busbar regions on the back of the MWT/MWA solar cells are protected by shadowing masks, which is the only masking step in the whole process.

Commercial electroless Ni- and Cu-plating baths are used for selective metallisation. Since the chemical reaction occurs only on metal and semiconductor surfaces but not on dielectrics the SiN_x layer ensures that metal is not deposited on the front surface. Thus the front grid as well as the interconnections (vias and edges) and the back are metallised simultaneously during the plating step. Therefore this technique is especially useful for the fabrication of back contact solar cells since the interconnections are metallised without any further effort.

The external p- and n-contacts on the rear side of the cell have to be isolated. This is done by cutting about 30-50 µm deep grooves along the n-type busbars of the MWA and MWT solar cells. Additionally, edge isolation has to be done for all three cell types. Finally the busbars are tabbed (width of the tabs was 1.5 mm) to reduce series resistance losses.

The suggested processing sequence for the back contact BCSCs is almost identical to the processing sequence of conventional BCSCs. Only additional steps for the formation of the interconnections are necessary (laser drilling of vias for MWT, plasma etch of the edges for large area MWA).

4. EXPERIMENTAL RESULTS

4.1 IV-measurements

To show the feasibility of the suggested cell concepts first devices with an area of 5x5cm^2 were processed according to the sequence given in Figure 2. For comparison conventional cells were manufactured in parallel. The solar cells were characterised by their illuminated and dark IV measurements. The obtained illuminated IV-parameters of the three cell designs are given in Table I. For the MWA solar cell an efficiency of η=17.5% was measured, whereas for the MWT an efficiency of η=17.2% was reached. Both back contact solar cells led to a higher efficiency as compared to the conventional cell with an efficiency of η=16.9%. This is due to a gain of 3% relative in J_{SC} for the MWT and MWA cells. This can be explained by a non-existing shadowing loss of the front busbar. Open circuit voltages V_{oc} are similar for all cell types which is especially encouraging since often reduced V_{oc}'s and fill factors are observed in industrial type back contact solar cells. The fill factors of the MWT and MWA cells indicate that there was sufficient metal deposition in the vias and at the edges which is necessary for good interconnection of front grid and rear side busbar. The fill factor and the obtained shunt values (R_{sh}> 5kΩcm^2) indicate that the definition of the p/n-contact area was successfully realised by mechanical abrasion.

4.2 Plating results

In Figure 3 an SEM picture of a plated via is given. It can be seen that there was sufficient plating inside the via without any unplated areas. The via is not completely filled but the cross sectional area of the plated metal within the via is larger than the cross sectional area of the contact finger leading to a good conduction between front and rear.

4.3 P-Al co-diffusion

It is often observed that a thermal treatment with Al and/or P can lead to a gettering action and hence to an improvement of the bulk diffusion length L_B of minority charge carriers for different materials like Cz-Si and mc-Si. The measured high values of J_{sc} for all cell types indicate that a high bulk diffusion length was obtained after cell processing. For further verification, measurements of the spectral response and reflectivity were carried out to obtain the Internal Quantum Efficiency IQE. In Figure 4 the IQE of a conventional BCSC is given. The IQE in the long wavelength range was used to get information about the bulk diffusion length L_B. This was done by fitting the experimental curve using the programme IQE1D [9]. From this characterisation it can be concluded that the bulk diffusion length is in the range between 250 µm and 450 µm. This high value indicates that the suggested processing sequence with P-Al co-diffusion is capable to obtain high bulk diffusion lengths after cell processing on solar grade Cz-Si which is an important factor for high cell efficiencies. P-Al co-diffusion also leads to a gettering effect on mc-Si within the buried contact solar cell concept [10].

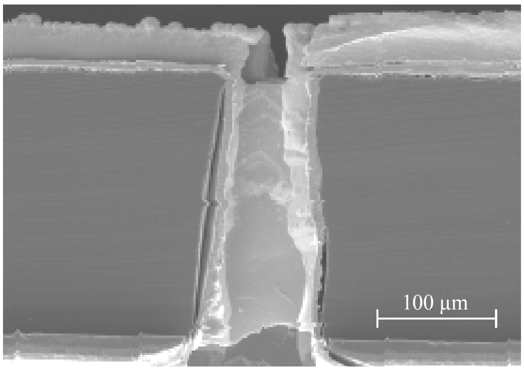

Figure 3: *SEM picture of a plated via. The thickness of the deposited metal in the via is comparable to the metal layer within the contact grooves. Therefore, a good interconnection between front and rear can be realised.*

Table I: *Illuminated IV-characteristics of back contacted MWA and MWT solar cells and reference cell. Cell area 5x5 cm^2.*

Cell design	J_{SC} [mA/cm^2]	V_{OC} [mV]	FF [%]	η [%]
Conventional	36.2	612	76.2	16.9
MWT	37.2	612	75.8	17.2
MWA	37.2	611	77.2	17.5

5. LARGE AREA MWA SOLAR CELLS

In the previous section it was shown that both back contact concepts are capable to obtain high efficiencies on medium cell areas (5x5 cm^2). It is desirable that the new cell designs can also be applied to larger substrates. For the MWT solar cell concept there are no obvious constraints when going to larger cell areas since the number of busbars can be increased without affecting the solar cell efficiency. For the MWA design the finger length to the collecting busbar at the rear will be enlarged for larger cell areas and

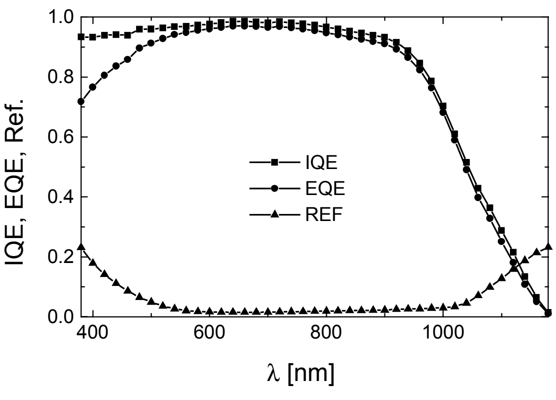

Figure 4: *Internal Quantum Efficiency IQE, External Quantum Efficiency EQE and reflectivity of a conventional BCSC with P-Al co-diffusion.*

hence the series resistance of the contact finger will increase. This will lead to a reduced fill factor and therefore to a lower cell efficiency. One possible solution of this problem is a reduced finger spacing. This will result in a slightly reduced J_{sc} due to enhanced shadowing losses by the finger grid.

To show the feasibility of the MWA solar cell concept for larger areas, model calculations were performed using the Two-Diode model. The parameters of I_{01}, I_{02} and R_{sh} were extracted from the experimental curves of the previous section. The contributions to the series resistance from emitter, busbar, contact and finger were calculated. These calculations were done for different line resistances of the finger metallisation. A standard buried contact finger will lead to a line resistance of R_{line}=500 mΩ/cm, whereas lower values can be obtained by cutting deeper contact grooves. From the calculated IV-curve, the solar cell parameters J_{sc}, V_{oc}, fill factor and η were determined. The results of the calculations are given in Figure 5 for a conventional cell (finger spacing 1.5 mm), and MWA cells with a finger spacing of 1 mm and 1.5 mm. A cell area of 10x10 cm^2 was chosen for these calculations. It can be seen that the fill factor and the efficiency of the MWA solar cell rely on good conducting fingers. Reducing the finger spacing from 1.5 mm to 1 mm will enhance the cell efficiency by at least 0.15%abs. For all investigated line resistances, the efficiency of the MWA solar cell with a finger spacing of 1 mm was higher as compared to the conventional BCSC.

After device simulations, MWA solar cells were processed according to the sequence given in Figure 2 with a cell size of 10x10 cm^2 and a finger spacing of 1 mm. An efficiency of η=16.6% (V_{oc}=614 mV, J_{sc}=35.9 mA/cm^2, FF=75.5%) was obtained for the best solar cell in this experiment. Unfortunately, the fill factor could not reach

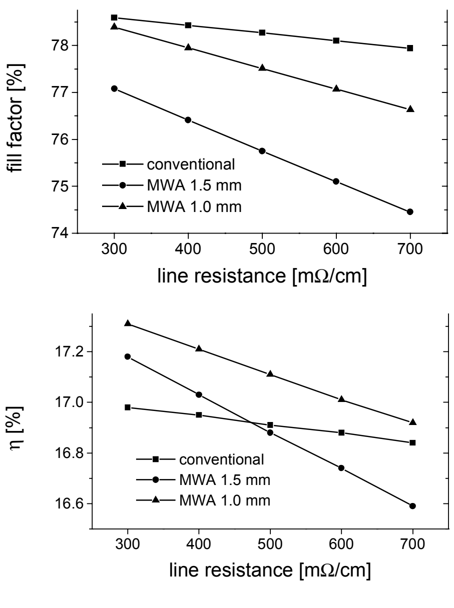

Figure 5: *Model calculations of fill factor and efficiency for a conventional solar cell and MWA solar cells as a function of line resistance of the finger metallisation. (Cell area 10x10 cm^2)*

the calculated value, which was due to poor plating of the contact fingers (R_{line}>700 mΩ/cm). But still the obtained efficiency is encouraging for large area back contact solar cells.

6. CONCLUSION

In this work two back contact solar cells with buried contact metallisation were presented, the MWT and MWA solar cell. The processing sequences for both cell designs are relatively simple and very similar to the standard industrial BCSC process. The implementation of P-Al co-diffusion led to a gettering action. Bulk diffusion lengths in the range of the cell thickness were obtained after this process step. The successful isolation of the p- and n-contacts on the back of the solar cell was realised by mechanical abrasion. The best efficiencies obtained in this work on a cell area of 25 cm^2 were η=17.5% for an MWA solar cell and η=17.2% for an MWT solar cell. Both efficiencies were higher as compared to an efficiency of η=16.9% of the conventionally produced BCSC. It was also shown that the MWA solar cell concept can be used for substrate sizes of 10x10 cm^2. On this size an efficiency of η=16.6% was demonstrated.

7. ACKNOWLEDGEMENTS

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