BACK CONTACT BURIED CONTACT SOLAR CELLS WITH METALLIZATION WRAP AROUND ELECTRODES

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ABSTRACT

We present results on back contact buried contact solar cells based on the Metallization Wrap Around (MWA) concept. In this cell design the current is conducted over metallized edges of the solar cell to the rear side busbar. The applied processing sequence is almost identical to the one of conventional buried contact cells and is based on p/n–contact isolation by mechanical abrasion. One major problem of MWA solar cells seems to be the long current paths in the fingers to the collecting busbar on the rear side. Therefore device simulations were carried out in order to find the optimum grid design for different cell sizes (10x10 cm^2 and 12.5x12.5 cm^2). The device simulations showed that the MWA solar cell concept leads to higher efficiencies as compared to conventional cells. Best efficiencies obtained in this study are η=17.5 % (cell area 25 cm^2) and η=16.6 % (100 cm^2) on Cz-Si. For mc-Si efficiencies of η=15.7 % (25 cm^2) and η=14.4 % (100 cm^2) were reached.

INTRODUCTION

Back contact solar cells offer various advantages compared to conventional solar cells. The commonly applied module assembling technique used for series interconnection of standard cells with tabs running from the front busbar to the rear contact of the next cell could be replaced by a technique where the cells are placed directly on a prepared back sheet containing the interconnection. This technique also seems to be better suitable for thin wafers. Additionally, back contact cells show lower shadowing losses as compared to conventional cells which will lead to a higher cell efficiency.

Numerous investigations were carried out to develop back contact solar cells with different device designs and metallization techniques: Metallization Wrap Around MWA [1-3], Metallization Wrap Through MWT [1,4], Emitter Wrap Through EWT [5,6], Interdigitated Back Contact IBC [7] and the Pin Up Module PUM cells [8]. Most of the work focused on the evolution of processing sequences which use industrial production techniques.

In the present work the buried contact metallization technique was used to produce solar cells with wrap around contacts. Only minor changes to the processing sequence of conventional cells are necessary in order to produce MWA solar cells.

MWA SOLAR CELL DESCRIPTION

In Fig. 1 a schematic illustration of the MWA solar cell design is given as it was used in this work. The selective emitter is realized by a lightly doped emitter on the front surface and a heavily doped one in the contact grooves. An Al-alloyed back surface field is formed at the rear side on areas designated for the base contact. The front surface is coated by Low Pressure CVD silicon nitride which serves as anti-reflection coating and surface passivation. The n-type fingers are connected to the rear side emitter contact over two opposite edges. The electrical connection between front and rear around the edges is formed during the electroless plating step applied for buried contact solar cells. Trenches are cut by mechanical abrasion to isolate the p- and n-contacts on the rear.

PROCESS DESCRIPTION

Fig. 2 shows the suggested processing sequence to fabricate MWA solar cells in a production environment. This is compared to a typical sequence for conventional cells. In the present work we were not able to carry out all process steps as indicated for the industrial sequence.

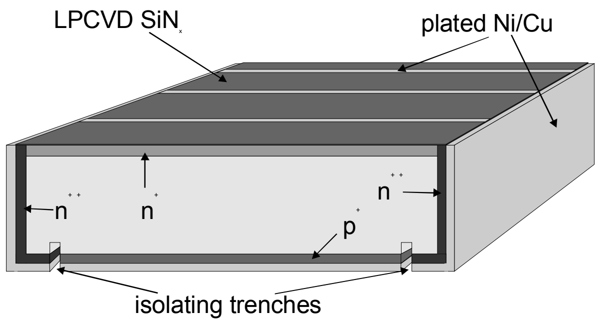

Fig. 1: Schematic illustration of a Metallization Wrap Around solar cell. The front fingers are connected to the emitter contact on the rear over two opposite edges. External p- and n-contact isolation was realized by isolating trenches.

Therefore a slightly modified process flow was applied and is given in the right part of Fig. 2.

Processing starts with front surface texturing either by alkaline texturing or mechanical V-texturing [9]. This is followed by a light emitter diffusion using a liquid $POCl_3$ source (sheet resistance $R_{sh}\approx100\ \Omega/sq$) and the deposition of silicon nitride SiN_x in a Low Pressure CVD system. These two process steps were done at the production line of BP Solar España in Madrid. The SiN_x which also deposits on the edges of the wafer has to be removed in order to metallize the edges during the electroless plating. In an industrial environment this can preferrably be done by plasma etching. Since we do not have a suitable plasma etching system in our lab, the wafers (initial size 12.5x12.5 cm^2) were cut into smaller wafer sizes (5x5 cm^2 or 10x10 cm^2) to obtain edges free of SiN_x. Processing continued with the formation of the contact grooves by mechanical abrasion using 15 µm wide dicing blades. The saw damage in the contact grooves was removed in a hot solution of sodium hydroxide leading to a width of about 25 µm and a depth of about 40 µm. In this study, a 2 µm thin layer of Al was deposited on the rear by electron beam evaporation. For the MWA solar cells, the areas designated to the emitter contact were covered by shadowing masks. Then the wafers were loaded into a conventional furnace for the P-Al co-diffusion. In this process step, the emitter contact

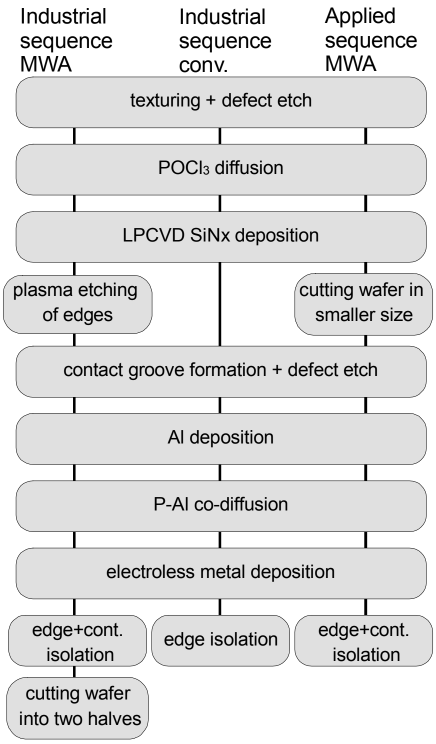

Fig. 2: In the left part the suggested processing sequence for large area MWA solar cells is given and is compared to the processing sequence of conventional cells. In the right part the applied processing sequence of this work is illustrated.

regions obtain a second heavy $POCl_3$-diffusion ($R_{sh}\approx10\ \Omega/sq$) and additionally the Al-BSF is formed in the same thermal cycle. Metallization was done by electroless deposition of Ni and Cu. Due to the selective character of this technique i.e. metal deposits on semiconductor and metal surfaces but not on dielectrics, the front grid as well as the edges and the rear side get metallized. For conventional solar cells processing is completed by edge isolation. In the sequence of the MWA solar cells, also the p- and n-contacts have to be electrically isolated. This was realized by an isolating trench formed by mechanical abrasion which was done in parallel with edge isolation. The obtained solar cell structure is given in Fig. 1: the contact is wrapped around two opposite edges.

An additional advantage of the MWA solar cell design can be taken if the cells are cut into two halves at the end of the process leading to a device with only one wrap around contact. These cells can be interconnected in a module as shown in Fig. 3. This arrangement was already proposed by Gabor et al. [2] for wrap around solar cells on string ribbon mc-Si. By using this kind of cell interconnection the I^2R loss in the busbar tabs of conventional modules can be significantly reduced, since the current path in the interconnection is only several millimeters as compared to the cell length in conventional modules (see also next section).

DEVICE SIMULATION

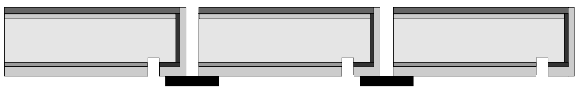

Fig. 3: Cell arrangement of MWA solar cells with one wrap around contact in a module. With this arrangement the I^2R power losses of the cell interconnection can be reduced.

Due to the long current path in the front fingers to the emitter contact on the rear side of the solar cell, the series resistance R_s of the contact fingers will increase for large area MWA solar cells. This will lead to a reduction of the fill factor and hence to a reduced solar cell efficiency. Therefore we performed device simulations to determine the optimum finger spacing leading to the highest cell efficiency. The calculations were performed within the two-diode model. The input parameters $J_{01}=1.4\cdot10^{-12}$ A/cm^2, $J_{02}=7\cdot10^{-8}$ A/cm^2, $R_{sh}=10000\ \Omega\cdot cm^2$ and $J_{sc}=34$ mA/cm^2 (corresponds to 35.8 mA/cm^2 when neglecting the grid shadowing losses) were taken from experimental data of conventional large area mc-Si solar cells processed in our lab. The series resistance R_s was calculated considering four contributions: emitter ($R_{sh}=100\ \Omega/sq$), tabbed busbar (line resistance $R_{bus}=0.8$ mΩ/cm), contact resistance in the front grid ($R_{cont}=2$ m$\Omega\cdot cm^2$) and contact finger. Since the series resistance of the contact finger is an important factor for MWA solar cells, the simulations were

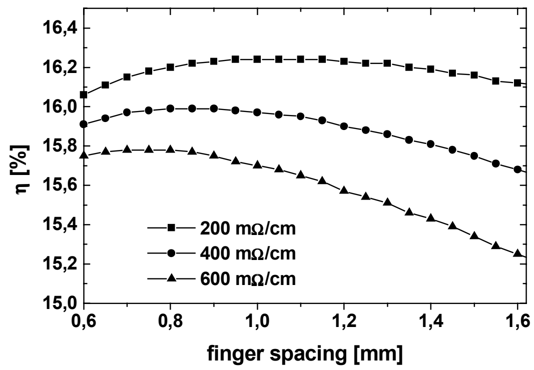

Fig. 4: Calculated cell efficiency as a function of finger spacing for three different line resistances of the contact finger for an MWA solar cell (cell area 12.5x12.5 cm^2).

performed by varying the line resistance between 200 and 600 mΩ/cm. Normally plated buried contact fingers lead to a line resistance of R_{line}=500 mΩ/cm, whereas lower values can be obtained by cutting deeper contact grooves. The model calculations also consider the shadowing losses of the front grid metallization: for the finger a width of 30 µm was taken, for the busbar tabs a width of 1.5 mm.

With these data the illuminated IV-curve was calculated and the solar cell parameters were extracted. In Fig. 4 the calculated efficiency is given as a function of finger spacing for an MWA solar cell (cell area 12.5x12.5 cm^2) for three different line resistances of the contact finger. It can be seen that for higher line resistances the finger spacing has to be reduced to obtain the highest efficiencies.

In Fig. 5 the optimum efficiency is given for MWA and conventional solar cells for cell sizes of 10x10 cm^2 and 12.5x12.5 cm^2. The efficiency of conventional solar cells was calculated for two different cases. The first case considered the standard setup used to measure solar cells with two probes per busbar to contact the cell. In this case the series resistance of the busbar is almost negligible. The second case takes the I^2R loss in the interconnection of the module into account (corresponding to one contact per busbar), where the series resistance holds a significant part and reduces the fill factor. This power loss reduces the cell efficiency and moves the data points towards lower efficiencies (see Fig. 5). As mentioned in the previous section this power loss nearly vanishes for the interconnection of MWA solar cells as given in Fig.2.

As can be seen in Fig. 5, for a cell size of 10x10 cm^2 the efficiency of the MWA is higher as compared to the conventional cell for all line resistances. When going to the cell size of 12.5x12.5 cm^2, the MWA cell exhibits a lower efficiency for higher line reistances. But this vanishes if the power loss in the module is considered. Therefore the MWA solar cell concept is superior to the conventional cell design even for large substrate sizes.

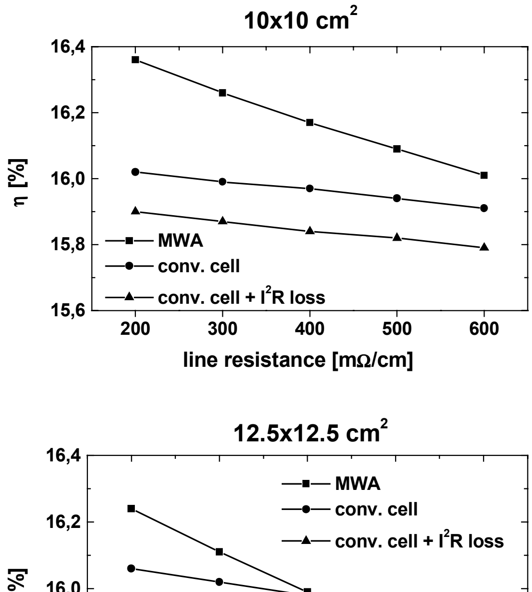

Fig 5: Modelled efficiencies of conventional and MWA solar cells for cell areas of 10x10 cm^2 and 12.5x12.5 cm^2 on mc-Si. For the conventional cells the efficiency was also calculated with the I^2R loss of the busbar tabs of module interconnection. These losses can almost be neglected for MWA cell interconnection as shown in Fig. 3.

SOLAR CELL RESULTS

In a first experiment MWA and conventional solar cells were processed according to Fig. 1 using solar grade Cz-Si with alkaline front surface texturing. The results of the illuminated IV-measurement are given in Table 1. For a medium cell area of 25 cm^2 an efficiency of η=17.5% was obtained as compared to η=16.9% for the conventional solar cell. The MWA design benefits from the non-existing shadowing loss of the front busbar leading to an enhanced J_{sc} of about 3%. For an MWA solar cell with a cell area of 100 cm^2 an efficiency of 16.6% was obtained with an optimum finger spacing of 1 mm.

In a further experiment multicrystalline Baysix silicon was used. The devices with medium cell area were mechanically V-textured, whereas the larger wafers were alkaline textured. In a previous investigation [9], we

Table 1: Illuminated IV-parameters of conventional and MWA solar cells on Cz-Si for different cell sizes.

Cell type	Cell size [cm^2]	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
Conv.	25	612	36.2	76.2	16.9
MWA	25	611	37.2	77.2	17.5
MWA	100	614	35.9	75.5	16.6

Table 2: Illuminated IV-results of conventional and MWA solar cells for different cell sizes on mc-Si. The front surface was either mechanically V-textured or alkaline textured.

Cell type	Text.	Size [cm^2]	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	η [%]
MWA	V-text.	25	35.1	598	74.9	15.7
Conv.	V-text.	25	34.1	599	76.0	15.5
MWA	alk.	100	32.8	590	74.2	14.4
Conv.	alk.	100	32.6	598	76.0	14.8

observed an efficiency gain of about 0.5 to 0.7 % abs. for V-textured cells as compared to alkaline textured ones. Additionally the wafers were subjected to a hydrogen passivation step in a Microwave Induced Remote Hydrogen Plasma (MIRHP)-system for 2 h at 375 °C [9]. The illuminated solar cell parameters are given in Table 2. For the medium cell area we obtained an efficiency of 15.7% for the MWA design, for the conventional cell an efficiency of 15.5% was measured. Again we observed an enhanced J_{sc} for the MWA cells.

In the experiment on large area MWA solar cells we tried to enhance the finger conductivity by cutting deeper contact grooves of around 80 µm which should lead to a reduced line resistance of the contact fingers. The depth of the contact grooves for the conventional cell was kept at about 40 µm. The illuminated IV-results of this experiment are also given in Table 2. The MWA solar cell shows a lower efficiency caused by a reduced fill factor and V_{oc}. By fitting the two diode model to the experimental dark IV-curve it was observed that this is due to a poor second diode of the MWA cell. This could be caused by an insufficient removal of the saw damage in the deep contact grooves.

CONCLUSIONS

In this paper we have suggested a processing sequence for large area back contact solar cells with Metallization Wrap Around electrodes. This processing sequence is almost identical to the one of conventional BCSCs, only additional steps for the removal of excessive SiN_x on the edges (plasma etching) and for the p/n-contact isolation (mechanical abrasion) are necessary. Device simulations showed that MWA solar cells have the potential for higher cell efficiencies even for large area substrates, if the cell arangement in the module is done as given in Fig. 3. In this arrangement the I^2R power loss of standard module interconnection can be reduced. The best efficiencies obtained are η=17.5 % (cell area 25 cm^2) and η=16.6 % (100 cm^2) on Cz-Si. For mc-Si efficiencies of η=15.7 % (25 cm^2) and η=14.4 % (100 cm^2) were measured.

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