LARGE AREA METALLISATION WRAP THROUGH SOLAR CELLS WITH THICKFILM METALLISATION

H. Knauss[1], P. Fath[1], W. Jooss[2], M. McCann[1], E. Rüland[1], S. Steckemetz[2]
[1]University of Konstanz, Department of Physics, PO Box X916, 78457 Konstanz, Germany
[2]Sunways AG, Macairestr. 3-5, 78467 Konstanz, Germany
Tel: +49-7531-88-2082, Fax: +49-7531-88-3895. Email: Holger.Knauss@uni-konstanz.de

ABSTRACT: Metallization Wrap Through (MWT) solar cells are back contact solar cells that can be processed with only a little extra effort compared to conventional cells. The cell concept is particularly suited for large area cells, which makes the concept attractive, since the size of the wafers processed by the industry is increasing. The MWT cells presented in this paper are produced with a process applicable in industry that uses screen-printing for metallization. Cell efficiency, which reaches 16% for the best cell, is limited by the fill factor. A model to explain low fill factors is presented. Using the model conclusions on the limits of the cell design are drawn.
Keywords: Back Contact, Modelling, Screen Printing

1 INTRODUCTION

Metallization Wrap Through (MWT) solar cells are back contact solar cells. This means that the external contacts of both polarities are located on the rear side of the cell. With the MWT design the collecting emitter remains on the front side of the cell (see Figure. 1). So do the grid fingers, which lead the current to holes through which the electrical contact to the rear side busbars is established. Increased short circuit current, due to the absence of shadowing from the busbars, gives potential for an increase in efficiency compared to a conventional cell design. Improved cell performance can be expected in particular for large area cells, as the number of busbars can be increased without additional shading loss. Thus high currents (over 12 A for a 20cm x 20cm cell) can be drained more easily.

In general, back contact solar cells are suitable for new planar interconnection technologies, e.g. pick-and-place in combination with pre-patterned back sheets. On the one hand such new interconnection technologies have the potential to reduce module assembly cost; on the other hand they might reduce stress on the cells during module production. Thus, back contact cell designs are also considered as well suited for thin wafers.

Compared to other back contact cell concepts, MWT cells seem well suited for industrial production. Requirements towards the starting silicon material do not change (in contrast to the IBC cell concept), the screen-printing metallization can be maintained expect for minor adjustments and only little additional processing is required.

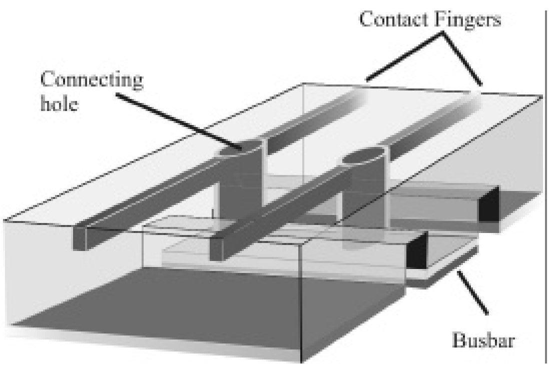

Figure 1: Schematic Drawing of a MWT solar cell. With this cell concept the collecting emitter and the grid fingers remain on the front side of the cell. The connection of the fingers to the busbar, which is located on the rear side of the cell, is established trough holes.

2 CELL PROCESS

Our MWT cells are processed in a very similar way to conventional screen printed cells. A process flow diagram is given in Figure 2. The first step is the formation of holes, which we do with an Nd:YAG laser. As there has to be an emitter in the holes to avoid a short circuit between the base and the emitter, it is crucial to drill the holes before the emitter diffusion is done. The laser damage generated thereby is removed in the same etch step as the saw-damage that results from wafering. This etching step can also be used to texture the wafer. The cleaning before the 50 Ω/Sq $POCl_3$ diffusion also includes cleaning in HCl and HF. The diffusion from the gas phase insures that an emitter is formed on the front and rear side as well as in the holes. Next, the pn-isolation at the edges is done using a plasma etch. Then silicon nitride is deposited on the front side of the wafer by PECVD. Next, isolation trenches are diced to isolate the busbar from the base region. In an industrial environment this would very likely be done with an appropriate laser. In principle a combination of busbar and edge isolation using a single laser step is possible. Edge isolation from the rear side of the cell, however, is known to lead to inferior isolation properties [1]. Thus it will very likely be preferable to keep edge and busbar isolation as two separate steps. The final state of the process is screen printing and firing. During metallization an additional (silver paste) screen-printing step is needed to form the rear side busbars. Thereby a reliable contact between the fingers and the busbar through the holes must be established. By minor adjustments to the standard equipment, a slight but evenly spread vacuum can be applied to the hole regions. Then the paste is sucked through the holes, which leads to a reliable through-hole metallization [2].

Compared to the process used for the production of screen-printed conventional cells, MWT cells require that a limited number of holes (approx. 100 for a 12.5 cm x 12.5 cm cell) must be drilled; a non-challenging

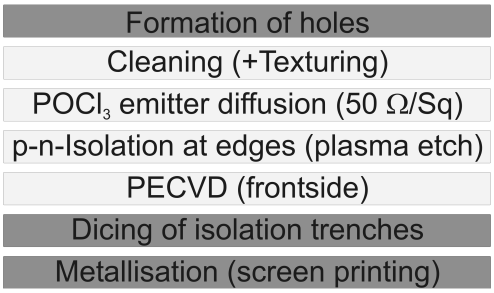

Figure 2: Process flow diagram for the production of MWT cells. The process is similar to the one for conventional screen-printed cells. The differences are marked with darker boxes.

task for modern laser systems. Further the pn-isolation of the rear side busbars requires an additional process step. Finally, the screen-printing has to be adjusted. Overall, however, the process appears to be manageable and does consist only of steps, which could be easily transferred to industrial production.

When optimising the process parameters the most time consuming task was to find a suitable combination of pastes. Silver paste is used to print the grid-fingers on the front side as well as for the metallization of the rear side busbars. The front fingers, however, are printed onto silicon nitride while the busbars are applied directly onto n-type silicon. Thus, firing conditions vary for the silver-paste on the front and rear side, so that different pastes should be used. A combination of an aggressively firing paste for the front side and a less aggressive firing paste for the busbars enables good contact of the front fingers while not over-firing the busbars.

3 CELL RESULTS

The cell parameters of our best cell made from 12.5 cm x 12.5 cm semi-squared Cz-Si are listed in Table 1. The short circuit current is high due to the absence of busbars on the font side of the cell. V_{oc} was measured to be 620mV. The very satisfying efficiency of 16.0% is limited by a low fill factor of 72.4%. Fill factor limitations are discussed below.

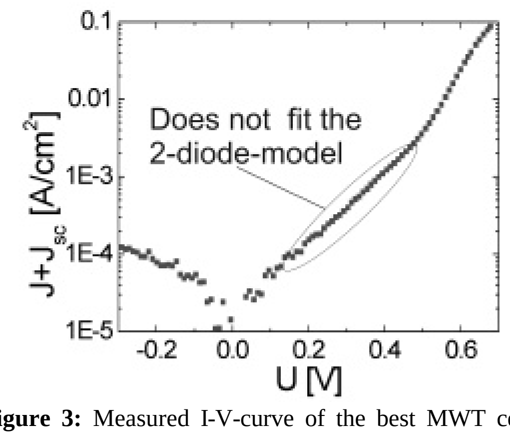

Figure 3: Measured I-V-curve of the best MWT cell. Between 0.2 and 0.5 V the curve shows an uncommon characteristic.

J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	h [%]
35.6	620	72.4	16.0

Table 1: Parameters of the best MWT cell (textured Cz-Si, 155cm^2).

The illuminated I-V-curve is displayed in Figure 3. For negative voltages and for voltages above 0.5 V the curve apparently shows common behaviour. Between 0.2 and 0.4, however, the curve has an unusual characteristic and does not fit the 2-diode model.

The MWT cells processed so far have busbars which extend to the full cell length. Such a cell design is not suited for easy interconnection [3]. The rear busbar design must be adapted before these cells are considered to be ready for production tests.

4 MODEL FOR MWT CELLS

There are two significantly different cell parts in a MWT cell: The busbar region and the rest of the cell. The busbar region has emitter on both sides of the cell, while the rest of the cell has, like a conventional cell, an emitter only on the front side and an Al-BSF on the rear. Therefore, for an MWT cell, the parameters of the 2-diode-model differ strongly in the two cell parts.

Holes generated in the busbar region can not be collected by the rear side emitter. They have to drift parallel to the cell surface in order to reach the Al-contact. The contribution to the series resistance is:

$$R_{series,Base} = \frac{1}{12}\frac{r\,d^2}{D},$$

where ρ is the specific resistance of the base, D is the base thickness and d is the width of the spacing of Al-contact in the busbar region. As the busbar and the isolation trenches have to fit in the spacing of the Al-contact d will not fall below 4mm – with our cell design d =5 mm. This significantly increases the contribution of the base region to the overall series resistance in the busbar region. Our realisation and a 300µm thick wafer leads to $R_{series,Base}$= 0.7 Ωcm^2 for 1 Ωcm and 4.2 Ωcm^2 for 6 Ωcm material. With a conventional cell this contribution would only be 0.03Ωcm^2 for 1 Ωcm silicon. Accordingly, as an inherent property of the cell design, series resistance in the busbar region tends to be high. This will become more apparent for high base resistivities.

The busbar region also has an unfavourable ratio between cell seize and the length of the pn-junction boarding the surface, which reduces J_{02}. Diced isolation trenches were found to increase J_{02} by approximately $3{\cdot}10^{-8}$ A/cm [4]. For our cells, this leads to J_{02}=$1.3{\cdot}10^{-7}$ A/cm^2. By using diffusion masks to create the pn-junction and by passivating the surface J_{02} could, however, be significantly reduced.

With electrically connected emitters on both sides of the cell J_{01} is also affected. For diffusion lengths much smaller than the cell width J_{01} can nearly be doubled compared to a conventional cell (assuming carrier are collected mostly at the front side). For high quality silicon (diffusion length > cell thickness) J_{01} can even be reduced [5] in the busbar region.

Finally, thermographic Lock-In measurements indicate that, due to non-optimal processing, there is an accumulation of shunts in the busbar region. Slight shunting can be detected a long the diced trenches. Further, the busbar pastes did tend to fire locally through the emitter due to over-firing. Recently, however, we found a paste, of which we believe that it avoids this problem entirely.

The other parts of the cell, excluding the busbar region, resemble a conventional cell. It appears reasonable to assume that in these regions the parameters of the 2-diode model are close to those of a conventional screen-printed cell.

Considering that an MWT cell consists of two different regions with very different properties, it is perhaps not surprising that the two-diode model is not appropriate. Instead we suggest considering MWT cells as a parallel interconnection of the poor busbar region with the rest of the cell.

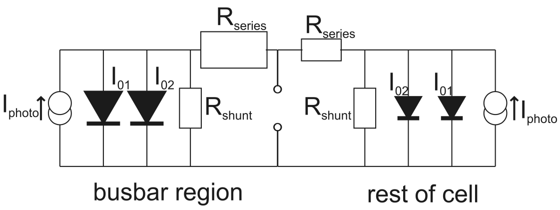

Figure 4: Equivalent circuit diagram used for calculating I-V-curves of MWT cells. The cells are described as a parallel interconnection of the busbar region and the rest of the cell. Both cell parts separately are assumed to fit the two-diode model.

5 SIMULATING MWT CELLS USING THE MODEL

Using the model described above the I-V-curve of a MWT cell on 3 Ωcm silicon was calculated. For a comparison, the simulated I-V-curve of a conventional cell made of the same material was also calculated and the results are displayed in Figure 5. The parameters used for the calculation are listed in Table 2.

The curves differ in particular between 0.3 and 0.5 V, where the MWT curve is bent upward compared to the conventional curve. For negative voltages the difference between the two cells is due to the reduced shunt resistance assumed for the busbar region. For voltages above 0.6 V the difference is due to the increased series resistance in the busbar region. Interestingly, this is also true for 0.3 to 0.5 V. It is not the poor second diode but the high series resistance that mainly shifts up the curve in this region.

	R_{shunt} [Ωcm²]	R_{series} [Ωcm²]	J_{01} [A/cm²]	J_{02} [A/cm²]
Busbar region	1000	2.6	$1.8 \cdot 10^{-12}$	$13 \cdot 10^{-8}$
Rest of cell	3000	0.86	$1.0 \cdot 10^{-12}$	$3.0 \cdot 10^{-8}$

Table 2: Parameters used to calculate the I-V-curves of a MWT and a conventional cell made from 3 Ωcm silicon.

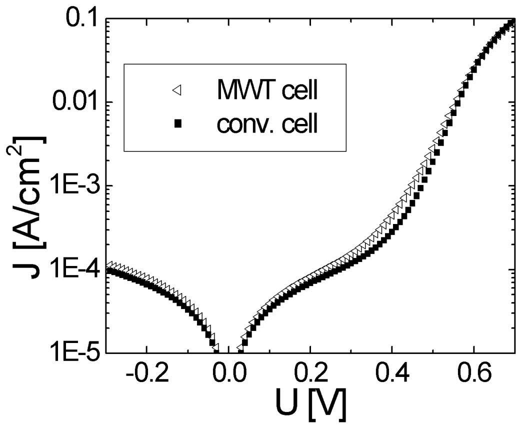

Figure 5: Simulated I-V-curves of a conventional and a MWT cell made of 3 Ωcm silicon.

Series resistance in the busbar region can easily be varied by using differently doped base material. I-V-curves of MWT cells with different base resistivities were calculated and are shown in Figure 6. Compared to the 3 Ωcm MWT cell we altered only series resistance, keeping J_{01} and J_{02} constant. Higher base resistivities clearly lead to a more significant deviation of the curves from the expected 2-diode model behaviour. Also the calculated influence on the fill factor is much larger than for conventional cells. Namely a drop of 3.1% absolute in fill factor for 6 Ωcm compared to 1 Ωcm MWT cells compared to only 0.9% for conventional cells.

To study the model MWT cells of 1 Ωcm and 7 Ωcm silicon were processed. The illuminated I-V-curves of cells with similar shunt resistance are displayed in Figure 7. The behaviour of the curves is in qualitative agreement with the simulation. The 7 Ωcm cells do not show two-diode model like behaviour.

6 DISCUSSION

Although the simulated and measured curves show qualitatively the same behaviour they do not match exactly. Partly processing problems, which originate from the use of a non-optimal combination of pastes, give reason for the remaining differences. The silver paste used for the busbars was not inactive enough, what lead to local shunts in the busbar area. Such shunts might have Schottky-like behaviour. In that case the I-V-curve would shift upwards between 0.1 - 0.4 V [6] where the agreement of simulation and measurement is still unsatisfying.

In addition the parameters used for the simulation might not fit reality. Reasonable values were assumed or in some cases values were derived from calculations. A direct access to the parameters of the separate sub-cells by measurements, however, is not possible. By adjusting parameters a better match of simulation and measurement can be reached. Due to the large number of parameters this approach appears rather daring.

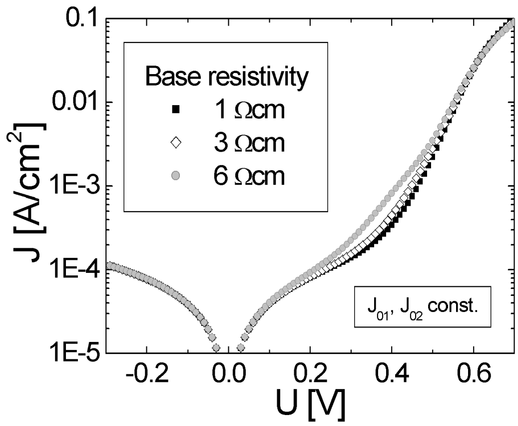

Figure 6: Simulated I-V-curves showing the effect of different base resistivities. Higher base resistivities lead to a more significant deviation from the two-diode model.

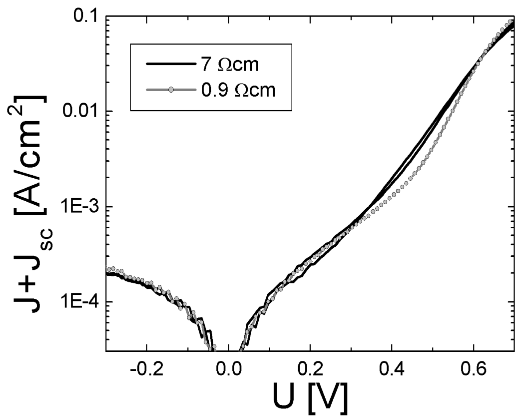

Figure 7: Illuminated I-V-curves of MWT cells made of 1 and 7 Ωcm material. The curves show qualitatively the behaviour predicted by the simulation.

7 CONCLUSIONS FROM THE MODEL

We believe that the model, which describes MWT cells as a parallel interconnection of the busbar region and the rest of the cell, is better suited than the two-diode model to explain the I-V-characteristic of the MWT cells.

Using our model the following can be concluded:

- The more similar the two cells parts get, the less relevant it is to treat them separately. The two cells will be more similar with narrower the busbar regions and lower the base resistivities.
- The Cz-Si currently used as a standard by the industry is typically specified with 3-6 Ωcm and is very likely not the best choice for the MWT cell concept.
- The model suggests that an increase in the number of busbars will not always be beneficial for the cell performance. Although additional busbars do not increase the shading losses, they do increase electrically poor areas.
- The developed model should be used to evaluate MWT-cell designs, which are easier to interconnect [3], [7].
- With an adapted cell design the model suggests that MWT cells do have the potential to exceed the performance of a conventional cell.

8 SUMMARY

The MWT cells processed have reached a good efficiency of 16.0%. Potential for further improvement lies in the optimisation of process parameters, in particular the paste used for busbar metallization. A model in which MWT cells are considered as a parallel interconnection of the busbar region and the rest of the cell was proposed. Experimental work supports the model. Optimisation of the cell design on the base of the model promises further improvement.

11 ACKNOWLEDGEMENTS

We would like to thank N. Gawehns, H. Haverkamp and T. Pernau for their kind assistance with solar cell processing. The underlying project of this report was supported with funding of the German “Bundesministeriums fuer Umwelt, Naturschutz und Reaktorsicherheit” under contract number (0329916A). The content of this publication is the responsibility of the authors.

12 REFERENCES

[1] A. Hauser et al, “Comparison Of Different Techniques For Edge Isolation”, Proc. 17th ECPVSEC, München, Germany, 2001

[2] E. Van Kerschaver et al, „Photovoltaic Façade And Roof Elements With Added Value By Use Of Back Contact Solar Cells“, Proc. PV in Europe, Rome, Italy, 2002

[3] E. Van Kerschaver et al, „Record High Performance Modules Based On Screen Printed MWT Solar Cells”, Proc. 29th PVSC, New Orleans, USA, 2002

[4] B. Fischer, “Loss Analysis Of Crystalline Silicon Solar Cells Using Photoconductance And Quantum Efficiency Measurements”, PhD thesis Univ. Konstanz, Cuiveller Verlag Göttingen, 2003

[5] E. Van Kerschaver et al, “Double Sided Minority Carrier Collection In Silicon Solar Cells”, Trans on Electron Dev, **47**, 2000

[6] F. Huster et al, “Shunts In Silicon Solar Cells Below Screen Printed Silver Contacts”, Proc. 19th PVSEC, Paris, 2004

[7] J.H. Bultmann et al, “Interconnection Through Vias For Improved Efficiency And Easy Module Manufacturing Of Crystalline Silicon Solar Cells”; Solar Eng Materials & Solar Cells 65, 2001