Improved efficiency and cost of ownership for p-type MWT cell and module technology

C.J.J. Tool, E.J. Kossen, I.J. Bennett, M.J.H. Kloos, W. Eerenstein
tool@ecn.nl
Energy research Centre of the Netherlands (ECN)
PO BOX 1, 1755 ZG Petten, The NETHERLANDS

ABSTRACT

In this study, we show the benefit of a combined cell and module design for MWT solar cells. At the module level this design results in a reduction of the module cost, while at the same time the power output is increased.

1. INTRODUCTION

The major goal of the PV industry nowadays is to lower the cost of solar photovoltaic electricity. This can be realized by either increasing the efficiency of the PV modules, or by reducing their production cost.

The vast majority of the market still consists of (p-type) crystalline silicon (x-Si) PV. In x-Si modules, x-Si solar cells are usually interconnected in strings by tabs soldered to the front side of one cell and the rear side of the adjacent cell. Due to the limited width of the tabs, such interconnection leads to additional resistive losses compared to the individual cells. A promising option to reduce the resistive losses in the tabs is by using an metal wrap through (MWT) concept, as shown in a recent review on this concept [1].

At ECN we developed an integrated solution for both the cell design and the module design to increase the solar cell efficiency, lower the production cost of the solar cells by limiting the amount of expensive Ag in the cell and at the same time reduce the resistive losses in interconnecting the solar cells.

The MWT cell design places all the contact points on the rear side of the cell. This is realized by bringing the emitter metallization via small holes through to the rear side of the cell. Compared to normal H-pattern processing, the only additional process step is drilling the vias through the wafer. This means that the process can easily be installed as an update in most modern x-Si cell production lines.

To fully benefit from the MWT design, we developed an interconnection based on a conductive foil. In this process, cells are not interconnected by soldering tabs to the cells, but by a conductive back-sheet (Figure 1). Cells are placed on the structured conductive back-sheet which connects the emitter contacts of one cell to the base contact of the adjacent cell and at the same time acts as the back- sheet of the module.

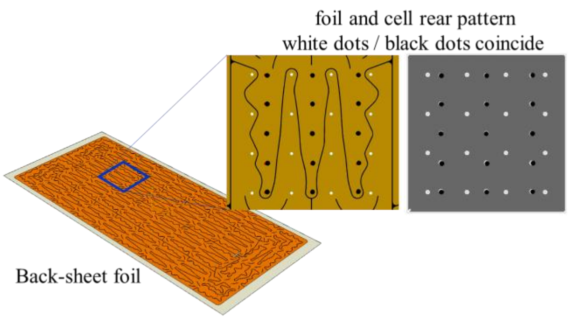

Figure 1: ***Integrated cell and module design. Dots of matching colors are connected using conductive adhesive.***

In this work we show the benefits of the MWT design, both at cell and module level. Besides the efficiency gains, we will also show the cost effectiveness of this integrated solution.

2. EXPERIMENTS

2.1 Experimental setup

In this work we performed 3 different experiments.

In experiment 1 we directly compared the efficiency difference for H-pattern and MWT modules.

The second experiment was a large scale test performed on an industrial process line. Over 2000 H-pattern cells and over 2000 MWT cells were processed. From these cells a total of 20 modules were manufactured to show that the lab scale efficiency gain can be maintained in production.

In the third experiment we included process improvements in the MWT process to increase the power output of the MWT module.

2.1. ECN baseline process flow

The ECN-baseline process flow consist of an alkaline random pyramid texture etch followed by tube diffusion using $POCl_3$ as the phosphorous source. Wafers are loaded back-to-back in the $POCl_3$ tube to maximize the loading and minimize the processing costs. After diffusion a combined glass removal and pn-junction isolation using wet chemical single side etch is performed. The sheet resistance of the emitter is about 70 Ω.sq. A remote MW-PECVD system is used to apply an ~80 nm thick single layer SiN_x anti reflection coating. Finally the metallization is applied by screen printing and the contacts are co-fired in an IR heated belt furnace. A schematic overview of the process sequence is given in Table 1.

The vias to guide the emitter contacts are made using laser drilling. The position of the laser drilling step in the process flow can be varied, depending on the exact process being used in the industrial production line.

Besides the vias and metallization patterns used, the H-pattern and MWT cells are processed using identical processes and process settings.

Table 1. ***H-pattern process flow***

Step	*Process*
1	random pyramid texture
2	$POCl_3$ emitter diffusion
3	PSG etch + Single Side Etch (SSE) parasitic junction removal
4	MW-PECVD SiN ARC deposition
5	contact printing (front and rear silver contacts + Al-BSF)
6	Co-firing metal contacts

3. RESULTS AND DISCUSSION

3.1 H-pattern vs. MWT pattern

In experiment 1, 200 standard full square 6” Cz wafers were divided into 2 groups of 100 cells each. One group was processed into H-pattern cells with a 2 busbar front metallization design. The other group was processed into MWT cells using identical processing.

After cell processing 60 cells from each group were selected and used to manufacture an H-pattern module using tabbing and soldering, and an MWT module using conductive adhesive and the conductive back-sheet as shown above.

In Table 2 the average IV characteristics for all the cells are given. Clearly seen is the significant efficiency increase for the MWT design. The current increase results from the lower metallization fraction on the MWT cell. Due to the lower metallization area, the recombination current below the metallization is also reduced[2]. This explains the (small) voltage increase.

Table 2. ***IV baseline scenario***

Pattern	N	Isc A/cm^2	Uoc V	FF %	Eta %	$IRev_{@-10V}$ A
H	93	9.05	0.625	76.4	17.8	0.10
MWT	91	9.22	0.629	75.8	18.1	0.57
rel. gain		1.9%	0.6%	-0.8%	1.6%	

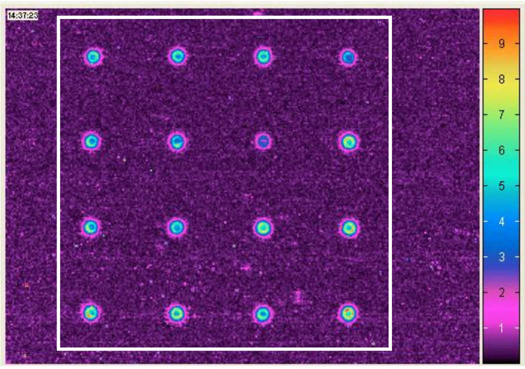

Figure 2. ***Vomolit scan of baseline MWT cell. White line indicates the position of the cell edge.***

The reverse bias leakage current is increased in the MWT cell design. From Vomolit[1] measurements (Figure 2) it is obvious that the leakage current increase is related to the via's. Although we expect that we will be able to overcome this increase, it has no impact on the reliability of the module. Van Aken et al. show that as the shunt effect is distributed over all 16 vias the thermal impact of the leakage current is much smaller compared to an H-pattern solar cells with a single shunt path[3]. Also, modules fabricated with solar cells with reversed bias characteristics comparable to the results shown above passed the IEC61730 hotspot tests[4].

In Table 3 the average IV characteristics of the H-pattern and MWT module are given. Included in this table is the relative gain of the MWT module IV characteristics compared to the H-pattern module.

The gain in Isc for the MWT module over the H-pattern module is smaller when compared to the gain at a cell level. This could be due to the smaller white area in the MWT module between the cells and at the edge of the module; the module area of the H-pattern module is about 3% larger compared to the MWT module.

Also the Voc gain for the MWT module is smaller at the module level than for the cells. This could be due to the different methods for contacting the MWT and the H-pattern cells during the cell IV-measurement. As both MWT and H-pattern modules are connected in the

[1] Vomolit: Voltage Modulated LockIn Thermography: while applying a (negative) voltage, the temperature of the cell is monitored by a sensitive IR camera. Temperature variations indicate ohmic warming of the cell.

same way the measurement method for the module does not affect the Voc.

The main benefit from the integrated MWT cell and module design can be observed from the reduced loss of FF. In going from cell to module, the relative FF loss is only 1%.

Table 3. ***IV cells and modules in baseline scenario***

Pattern	Isc	Voc	FF	Eta_{cell}	P
	A	V	%	%	W
H	8.83	37.69	71.0	16.2	236.3
MWT	8.92	37.83	75.0	17.3	253.0
Rel.gain	1.0%	0.4%	5.6%	7.0%	
CtM					
H	0.976	1.005	0.929	0.910	
MWT	0.967	1.002	0.989	0.957	

Comparing the H-pattern module with the MWT module clearly shows that the gain at module level for MWT is mainly due to the strongly reduced FF loss. This confirms the lower series resistance losses in the MWT conductive back-sheet compared to the H-pattern tabbed interconnection.

The final power output gain realized for the MWT design is well over 15 Wp absolute or a relative gain of 7.1%. Although this might be slightly overestimated because of the large FF drop for the H-pattern module, it indicates the potential of the integrated MWT cell and module.

3.2 H vs MWT in industry

To evaluate the industrial feasibility of MWT, in experiment 2 we have setup an industrial scale test. With the exception of via drilling, all cell processing has been conducted on an industrial production line developed for H-pattern processing. The via drilling was done at a test setup at a laser system manufacturer. In this test over 4500 cells were divided into 2 groups. One group was processed using the normal H-pattern process, while the other group was processed into MWT cells using the same process equipment. Only the metallization pastes used and the metallization patterns were changed for the MWT group.

From each group 600 cells were selected for module manufacture. The H-pattern modules were manufactured by the industrial partner, while the MWT modules were manufactured on the Eurotron pilot line for MWT modules with a conductive back-sheet at ECN. Due to the limited capacity of this pilot line it was decided to produce only 10 modules per group.

In Table 4 the IV characteristics of the cells and modules are summarized. For confidentiality reasons, the IV characteristics are given only relative to the IV characteristics of the H-pattern group.

Table 4. ***IV ratio cells and modules from industrial line***

	Isc	Voc	FF	Eta_{cell}
MWT/H ratio				
cell	1.017	1.003	1.004	1.025
module	1.035	1.010	1.013	1.058
CtM				
H	0.985	1.002	0.973	0.961
MWT	1.012	1.003	0.983	0.999

Compared to lab-scale processing, the gain in Isc and Voc is more pronounced in industrial processing. The background for this difference is not yet fully understood. However, this might be related to the problems in comparing IV characteristics of H-pattern and MWT cells[5]. As expected, the gain in FF in the industrial process is much smaller compared to the lab-scale process. We suspect the large drop in FF for the H-pattern module results from the lab-scale processing.

The overall efficiency gain at the module level is comparable for the industrial process and the lab-scale process. A relative efficiency gain of 5.8% has been realized. At an average module output of 250 Wp, this is equivalent to nearly 15 Wp.

3.3 MWT process improvement

In experiment 3 we used newly developed metallization pastes, optimized the emitter diffusion, firing condition and metallization for the MWT cells.

Because of the printing properties of the front silver paste we redesigned the silver metallization grid from a normal radial like configuration into an H-pattern 3 busbar lookalike configuration (Figure 3). To maintain the compatibility with the normal MWT contacting scheme, the busbar lookalike pattern has 5 vias per busbar.

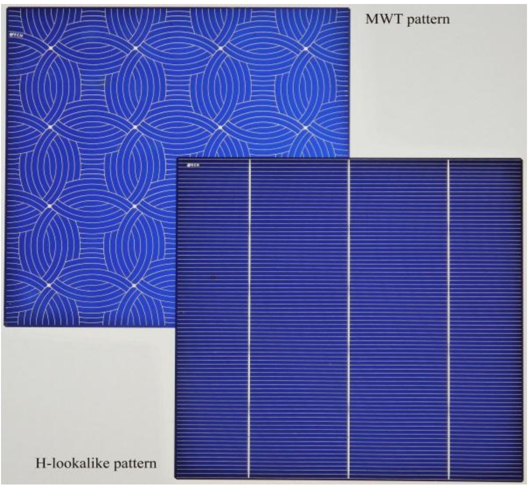

Figure 3: ***ECN's Circle MWT pattern (top left) and H-lookalike pattern (bottom right).***

In the improved process we increased the emitter sheet resistance to ~85 Ω.sq by lowering the diffusion temperature. Finally, we significantly reduced the front silver metallization area without a significant loss in FF. Due to the lower metallization area and the shallower emitter, both Isc and Voc are significantly increased while the FF is maintained due to the properties of the new paste.

In total 125 cells were produced using the new process settings, of which 60 cells were selected and manufactured into an MWT module.

In Table 5, the IV characteristics of all the cells and of the selection for the module are given. Also the absolute and relative module results are included in this table. Comparing these results with the results presented in Table 3 shows that the CtM ratio for this improved scenario is comparable, or even slightly better, than for the standard scenario. This proves that the higher cell output can be maintained at the module level. The module power increased from 253 Wp for the baseline MWT module to 260 Wp for the improved MWT process.

Table 5. ***IV cells and modules for MWT improved process***

Pattern	Isc A/cm^2	Uoc V	FF %	Eta_{cell} %	$IRev_{@-10V}$ A
Cell	9.26	0.632	77.4	18.6	0.37
Module	9.01	38.00	75.8	17.5	
CtM	0.976	1.004	0.989	0.967	

The updated process settings do not affect the reversed bias leakage current.

3.4. Cost aspects of MWT

In this chapter we will discuss the cost consequences of MWT. Because the actual cost will depend on specific choices made, we will not discuss the total MWT cost. Instead, we will discuss the differences between H-pattern and MWT module costs.

3.4.1. Cell costs

As discussed above, at the cell level no special equipment or processes are required for MWT processing with the exception of a laser system for via drilling. This laser will add about 250-350 k€ to the investment for a complete production line. The additional cost per cell due to this investment is very small.

Table 6. ***Paste consumption***

Pattern	Ag_{front} mg/cell	Ag_{rear} mg/cell	Al g/cell
H	175	40	2.0
MWT	170	42	2.0
$MWT_{improved}$	140	42	2.1

Table 6 compares the metal paste consumption for H-pattern and MWT cells as measured in the lab process. The observed reduction in front side silver paste can fully be explained from the lower metallization fraction in the MWT cells. At the rear side the silver consumption is slightly higher for the MWT-cells. This is partly because the silver pads in the H-pattern cell are minimized (6 pads per busbar), and partly because both emitter and base contacts are applied on the rear.

In the improved MWT process the silver consumption is reduced by 33 mg per wafer compared to the H-pattern process. At a Ag paste cost of € 750 per kg, this results is a saving of about € 0.025 per cell.

3.4.2 Module cost

The differences in cost between H-pattern and MWT modules are related mostly to the difference in module materials. In the MWT module, the conductive back-sheet and conductive adhesive replaces the back-sheet, tabbing and bussing used in an H-pattern module.

The projected price of the conductive back-sheet foil is approximately 10 €/m^2. This price is expected to be achieved by the start of 2013 using novel patterning techniques and a copper-base conductive back-sheet.

The price of the conductive adhesive is approximately 750 €/kg. The conductive adhesive has a reduced amount of silver and has been tested in damp-heat and thermal cycling to 2000 hours and 400 cycles respectively.

Calculations of the price per module show that the MWT module is approximately 2% more expensive than an H-pattern module with the same number of cells. This is compensated by an increase in power output of over 5% for the MWT module. This results in a cost reduction in €/Wp of 3% for the MWT module compared to the H-pattern module.

3.4.3 System cost

The MWT-module can be made smaller than a comparable H-pattern module as the cells can be placed closer together and the bussing is integrated in the conductive back-sheet. Therefore the power output per unit area is even larger than the difference in generated power.

As part of the balance of system (BoS) cost scale with area, the smaller MWT-module will result in additional savings at the system level.

Furthermore, MWT modules have been shown to generate a larger annual energy output, particularly at high irradiance[6], reducing the €/kWh costs.

3.4.4 Module cost outlook

Further cost advantages for MWT can be achieved by the use of thinner cells and reduction of the encapsulant thickness.

Thinner cells are compatible with MWT module production due to the low impact of the pick-and-place unit in the manufacturing line and due to the use of conductive adhesive for interconnection. The conductive adhesive is approximately 10 times less stiff than solder. This reduces the residual stresses on the cell after interconnection relative to a soldered interconnection. The conductive adhesive also has a lower processing temperature than solder, which further reduces the residual stresses and operational costs.

The absence of the tabs at the front and rear of the cells allows the use of a thinner encapsulant. In the current module design, an encapsulant with a thickness of 200 μm is used. Use of a thinner encapsulant will result in a reduction in the amount of conductive adhesive needed to make the interconnection as the conductive adhesive has to bridge the gap between the conductive back-sheet and the cells which is formed by the encapsulant.

Modules have been made with an encapsulant with a thickness of <100 μm. In doing so, the volume of the conductive adhesive is reduced by 70% compared to the standard thickness of the encapsulant. This will give a reduction of 2% in the module materials reducing the price of MWT modules compared to H-patern modules even more, whilst retaining the performance advantage of the MWT module.

We expect further cost reduction in the near further due to new developments in the rear foil and the conductive adhesive.

4. Summary and outlook

In this work we have clearly shown that the module power output can easily be increased by introducing ECN's integrated MWT concept. The higher power output for a 60 cells module of over 10 Wp is realized at lower module cost and smaller module size.

The MWT-cell can easily be installed as an upgrade to existing (modern) cell production lines. Therefore, upgrading to MWT cell production can be done at a relatively low cost.

We showed the results of preliminary work on increasing the conversion efficiency of the MWT-cells. Also, we showed that these efficiency improvements can be maintained at the module level. Because this upgrade of our MWT process started only recently we expect a further improvement in the power output of the MWT-modules in the near future.

REFEREENCES

[1] E. Lohmüller, M. Hendrichs, B. Thaidigsmann, U. Eitner, F. Clement, A. Wolf, D. Biro, R. Preu, *Photovoltaics International, **17**, 61-71,* (August 2012)

[2] R. Hoenig, A. Kalio, J. Sigwarth, F. Clement, M. Glatthaar, J. Wilde, D. Biro, *Sol. Energy Mater. Soll. Cells, **106**, 7-10,* (2012)

[3] M.J. Jansen, L.A.G. Okel, R.A. van der Schilden,

I.G. Romijn, B.J. Geerligs, B.B. van Aken, Improved heat dissipation for hot spots in MWT laminates, *this conference,* (2012)

[4] M. Späth, *personal communication*

[5] C. Meyer, K. Ramspeck, M. Zell, S. Krantz, J. Moschner, A. Metz, *Proceedings 26th EUPVSEC, Hamburg,* (2011)

[6] N.J.J. Dekker, M.J. Jansen, I.J. Bennett, W. Eerenstein, *Proceedings 27th EUPVSEC, Frankfurt,* (2012)

Acknowledgement

We kindly acknowledge Ferro, Dupont and MonoCrystal for making available their metallization pastes.