Towards a 300 W_P p-type HIP-MWT-Module – Simulation, Experimental Results and Costs

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ABSTRACT: In this work we are aiming at the goal of fabricating a cost-effective HIP-MWT module exceeding 300W. In order to accomplish this goal HIP-MWT (high-performance metal wrap through) silicon solar cells [1, 2] are fabricated on industrial PERC (passivated emitter and rear cell) precursors. Simulation of the optimal metallization layout for MWT based on measured parameters show cell efficiencies up to 21.5%. The consequentially fabricated HIP-MWT solar cells reach maximum efficiencies of 21.4%. The in parallel processed H-pattern reference cells reach maximum efficiencies of 21.2%. The cell efficiencies show a reduced advantage for MWT than in similar experiments, which is due to the tapered busbars of the reference cells allowing nearly the same short circuit currents. Anyhow, combined with a module interconnection based on back contact foils a cell-to-module (CTM) loss of 2 % is demonstrated which allows module power over 300 W_P. Due to a power advantage of about 15W in comparison to H-pattern modules the cost of ownership calculation shows a cost advantage of the HIP-MWT module of 3.2 %**.** Simulation, experimental results and cost calculation show an advantage for HIP-MWT technology over the H-pattern reference leading to the conclusion that MWT is a more cost-effective concept.
Keywords: HIP-MWT, module, cost of ownership

1 INTRODUCTION

Reaching higher output powers per module is a major goal of solar cell and module development. At the same time the cost per wattpeak has to be kept constant or should even be reduced. Applying the MWT concept on PERC solar cells (HIP-MWT [1, 2]) enables to achieve both at once. HIP-MWT solar cells not only allow higher cell efficiencies due to less shading by metallization on the front side; they also enable module interconnection based on conductive backsheets, which can result in lower cell-to-module losses. In contrast to standard H-pattern modules the conductive cross-section is independent of shading related losses.

2 APPROACH

As the cells are fabricated on partly processed PERC (passivated emitter and rear) wafers provided by Gintech the most crucial part in the process sequence of HIP-MWT solar cells is the metallization layout, which needs to be optimized as a trade of between series resistance losses and shading. For the optimization of the metallization layout we use the tool GridMaster developed at Fraunhofer ISE [4]. The via drilling process is inspired by the optimized metallization layout and can be carried out within the same laser system as the local contact opening leading to the same amount of process steps for HIP-MWT and H-pattern solar cells (s. Fig 1).

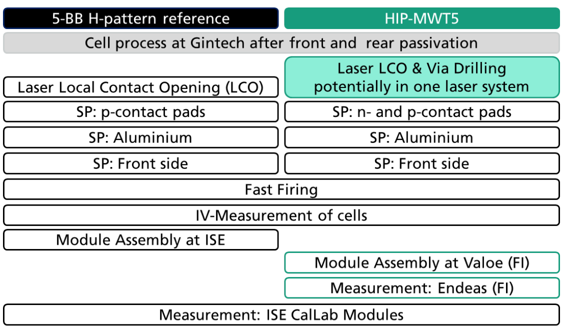


Fig 1: Process flow for 5 busbar H-pattern and HIP-MWT5 (5 pseudo-busbars) cell and module fabrication on industrial PERC wafers. The PERC wafers are processed until rear side passivation and front side anti-reflection coating at Gintech. The HIP-MWT module is build using a coated conductive backsheet to ensure the electrical isolation between the two polarities.

This optimized MWT metallization is applied on passivated wafers from Gintech. In parallel H-pattern cells are fabricated on the same wafers. Both cell types are assembled into 60 cell modules for direct comparison. To determine the cost-effectiveness of our 300W_P module approach a cost of ownership calculation of both cell and module concepts is applied employing SCost [4].

3 SIMULATION OF CELL EFFICIENCIES

The simulation of the cell efficiencies is carried out using GridMaster [3].

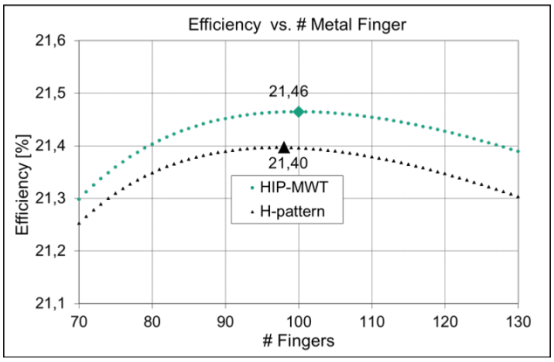


Fig 2: Simulation in GridMaster [3] of HIP-MWT and H-pattern cell efficiencies. The MWT5 metallization layout features 8 n-pads per contact row on the rear side. Further parameters for the simulation are: 50 µm printed finger width, pseudo-busbar width between 150 µm and 220 µm, via resistance of 2 mΩ, base resistivity of 1 Ωcm, thickness of 170 µm, sheet resistance of 100 Ωsq.

The simulation results presented in Fig 2 and table 1 show that HIP-MWT cells with efficiencies of up to 21.5 % are realistic. The j_{SC}-advantage of 0.3 mA/cm^2 for HIP-MWT cells in comparison to H-pattern cells is

opposed by the fill factor loss of 0.4 % due to the MWT metallization layout. The combination of both effects results in very similar cell efficiencies for both concepts. Nevertheless this simulation shows the situation only on cell level; the module interconnection of the H-pattern cells with 0.8 mm wide tapes will results in additional shading of 1.3 % reducing the j_{SC} of the H-pattern module and in additional series resistance losses within the tabs.
Considering the cell area of 243 cm^2 the simulated cell efficiency of the HIP-MWT cells translates to a cell power of 5.2 W; 60 cells theoretically provide 312 W_P allowing a rather high cell-to-module loss of 4 % while still enabling a 300 W_P module.

Table I: Simulated cell results of H-pattern and HIP-MWT cells

Simulated parameters	Eta [%]	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	R_S [Ohmcm^2]
HIP-MWT	21.5	663	40.4	80.2	0.53
H-pattern	21.4	662	40.1	80.6	0.45

3 EXPERIMENTAL RESULTS

3.1 Cell results

Based on the simulation described in chapter 2 H-pattern and HIP-MWT cells were fabricated on passivated wafers from Gintech. The cell layouts are shown in Fig 3. The enlargement of the HIP-MWT rear side shows one n-pad with surrounding aluminium (spacing 350 µm) and the alloyed LCO (local contact opening) lines. As the vias are largely filled with pad paste they are not visible in the image.

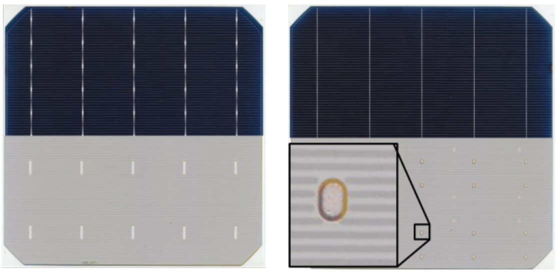


Fig 3: Image of H-pattern cell (left) front and rear as well as image of HIP-MWT cell (right) front and rear with a zoom of one n-pad. Detailed metallization parameters are listed in table II.

Table II: Input parameters GridMaster [3]

Input parameters	
Finger width	50 µm
Finger height	14 µm
Via resistance	2 mOhm
Spec. contact resistance	1.7 mOhmcm^2
Base resistivity	1 Ohmcm
Emitter sheet resistance	100 Ohm/sq.
# of n-pads for HIP-MWT	5 x 8
n-pad size for HIP-MWT	1.5 x 2.5 mm
# of vias for HIP-MWT	80
Front side shading HIP-MWT	4.4 %
Front side shading H-pattern	5.7 %

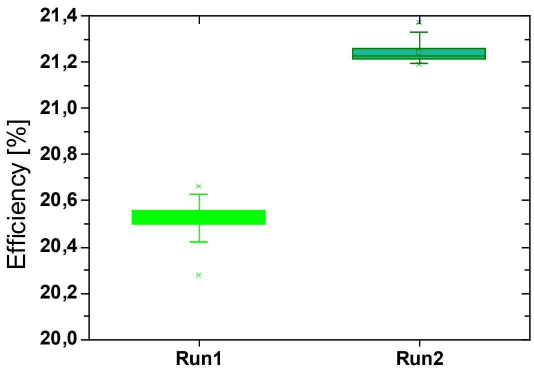


Fig 4: HIP-MWT cell efficiency results for first and second cell run. The open circuit voltage has improved 12 mV, the short circuit current 0.7 mA/cm^2 from first to second run due to the improved quality of the passivated wafers.

Fig 4 shows the cell efficiencies of the HIP-MWT cells conducted within two runs. For the first cell run passivated wafers with lower efficiency potential have been used. The metallization layout stayed the same in both runs, while the screen printing process was improved in run 2 leading to more homogeneous fingers. The improved passivated wafers in combination with the improved screen printing process result in a mean efficiency increase of about 0.7 %. The homogeneous fingers allowed to fabricate the second cell run with single screen print using only 75 mg of silver paste on the front side.
In parallel with the second HIP-MWT cell runs H-pattern 5 busbar cells with tapered busbars have been fabricated

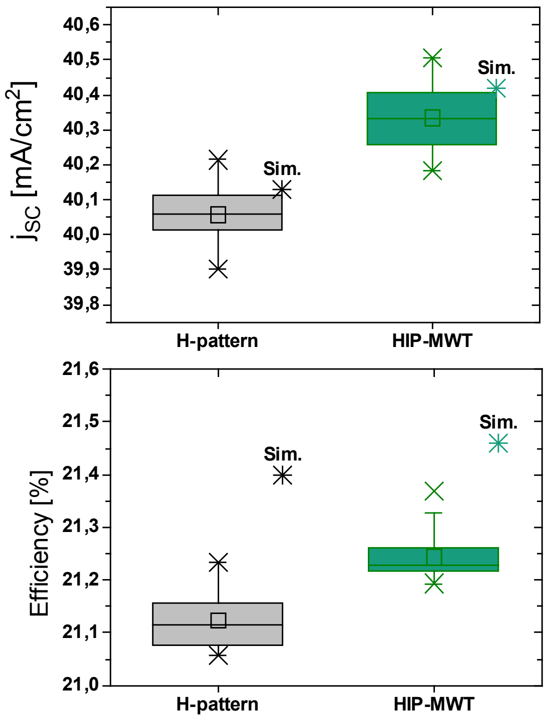
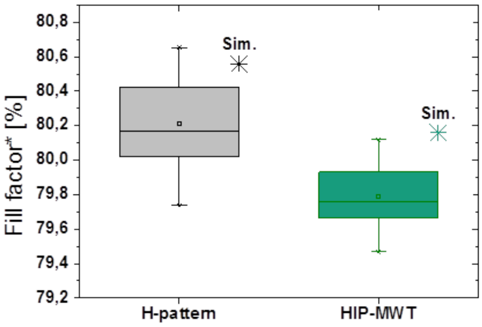


Fig 5: Experimental results of H-pattern (97 cells) and HIP-MWT (93 cells) for j_{SC} and efficiency (box plots). The stars represent the simulation results.

The experimental results of the H-pattern cells in direct comparison with the HIP-MWT cells are shown in Fig 5 also including the according simulation results (stars in graph). The experimentally achieved j_{SC}-values are in very good accordance with simulation results. The difference in the efficiency is caused by the fill factor, which is shown in Fig 6. The best solar cells achieve the simulated fill factors values. The deviation is caused by increased series resistance values, which is most likely caused by not perfectly homogeneous screen print. Overall the high fill factor values show, that a single step screen printing is sufficient. The overall deviation in efficiency is very small showing similar process stability for H-pattern and HIP-MWT cells.



* FF of HIP-MWT cells corrected based on GridMaster simulation

Fig 6: Measured fill factor values of H-pattern and HIP-MWT cells (box plots). The stars represent the simulation results.

3.2 H-pattern module results

Table III: H-pattern cell and module results as well as cell-to-module loss.

	I_{sc} [A]	U_{oc} [V]	P_{mpp} [W]	FF [%]	Eta [%]
60 cells	9.7^{Min}	39.4^{Σ}	307.5^{Σ}	$80.1^{\varnothing}$	$21.1^{\varnothing}$
Module @ ISE*	9.6	39.2	**287.7**	76.6	18.4
Cells-to-module loss	-1.3%	-0.5%	-6.5%	-4.4%	-12.9%

*measured at Fraunhofer ISE CalLab Modules

The 60 best H-pattern cells were built into a module at Fraunhofer ISE using 0.8 mm wide interconnectors. For the H-pattern module a moderate cell-to-module loss of 6.5 % in power was achieved. The j_{SC}-loss of 1.3 % corresponds directly to the additional shading due to the interconnectors on top of the tapered busbars.

3.3 HIP-MWT module results

Out of both HIP-MWT cells runs one HIP-MWT module each was build. The first HIP-MWT show the summed power of 297 W_p. The HIP-MWT module shows a power output of 291 W_P leading to a CTM of only 2 %. Of the second cell run with a mean efficiency of 21.2 % again the 60 best cells were built into a module by Valoe (see Fig 7). The 60 cells sum up to a power of 309 W_P. Unfortunately the contacting between cells and conductive backsheet has not been ideal resulting in a measured module output power of 282 W_P.

		P_{mpp} [W]
Run 1	60 cells	297^{Σ}
	HIP-MWT module*	291
	Cells-to-module loss	-2.0_{rel}
Run 2	60 cells	309^{Σ}
	Cells-to-module loss Run1	-2.0_{rel}
	Expected module Power	***303***
	HIP-MWT module**	282

* Measured at Endeas (FI)
** Measured at Fraunhofer ISE CalLab Modules

Fig 7: HIP-MWT module results of the first and the second run as well as the cell-to-module loss conducted from the first run.

The electroluminescence image (Fig 8) shows some inhomogeneity mainly caused by increased series resistance.

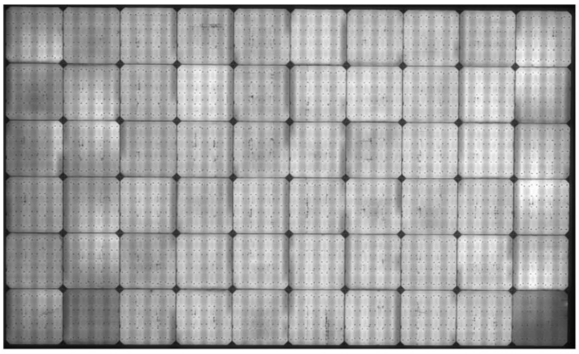


Fig 8: Electroluminescence image of the HIP-MWT module of run 2.

Nevertheless, if the same CTM as in the first run would have been realized a module exceeding the 300 W_P is achievable with the measured cell efficiencies.

4 COST OF OWNERSHIP CALCULATION

A bottom up Cost of Ownership (CoO) calculation is carried our using SCost [8] developed at Fraunhofer ISE. A combined cell and module production facility based in Europe on a green field site is taken as basis. The calculation in SCost is based on SEMI E35 CoO standard [11]. No capital costs are assumed; furthermore the calculation is carried out without inclusion of overhead costs for R&D (research and development) as well as SG&A (Selling, General and Administrative Expenses).

4.1 Cell production costs

The process sequence shown in Fig 1 is taken as basis for the CoO calculation of the cell production costs; these costs only include the production costs for the cells without the costs for the wafer. Furthermore the cell efficiencies of the experiment, shown in Table II are applied.

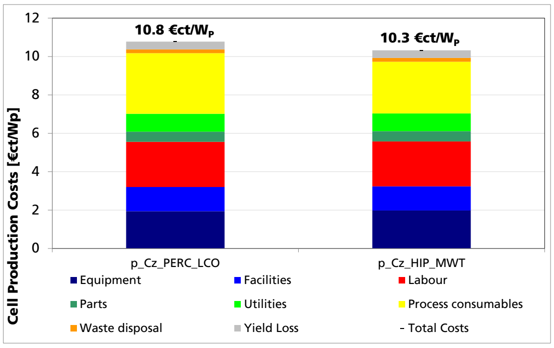


Fig 9: Cell production costs (without wafer costs) based on the Cost of ownership calculation carried out with SCost [8]. A silver price of 525 €/kg is taken from [7].

Fig 9 shows a cost advantage of 0.5 €ct/W_P for the HIP-MWT cells in comparison to the H-pattern cells. This advantage is caused by the higher cell efficiency of the HIP-MWT cells. In addition the HIP-MWT cell process uses 35 mg less silver paste on the front side (MWT: 75 mg; H-pattern: 110 mg), which is a large cost driver for solar cells.

4.2 Module costs

The cost of ownership calculation of the module production is based on the process sequence shown in Fig 10. Furthermore the achieved module output of 288 W_P of the H-pattern and the expected 303 W_P of the HIP-MWT module is applied. As over 70 % of the module production costs are material costs a detailed comparison of the module material costs is performed, see Fig 11.

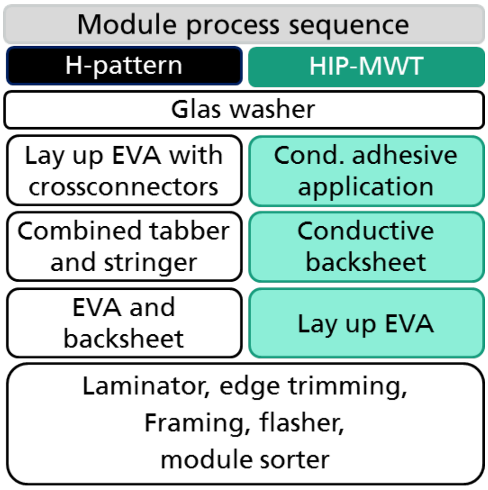


Fig 10: Process sequence for module assembly of H-pattern and HIP-MWT modules. The process sequence is taken as a base for the cost of ownership calculation.

The absolute module material costs are higher for MWT modules as the conductive backsheet with 10 € per module (6.25 €/m^2) is an additional cost driver. The lower costs for the conductive adhesive in comparison to the inter- and cross connectors of the H-pattern module partly revokes the costs of the conductive backsheet.

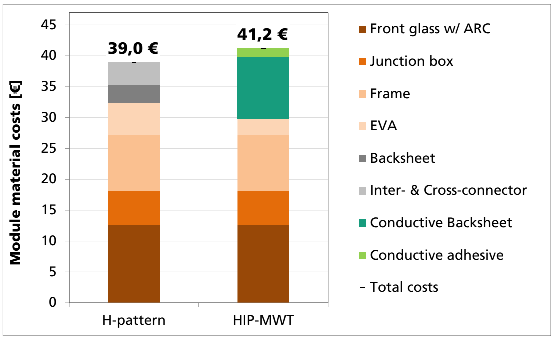


Fig 11: Module material costs of H-pattern and HIP-MWT modules. Front glass, junction box and frame are equal for both concepts. The costs for encapsulant of MWT is only 50 % of H-pattern as the rear EVA is included in the conductive backsheet. The largest cost factor for MWT is the conductive backsheet with 6.25 €/m^2. For the conductive adhesive a consumption of 2.3 g/module and a price of 600 €/kg is assumed.

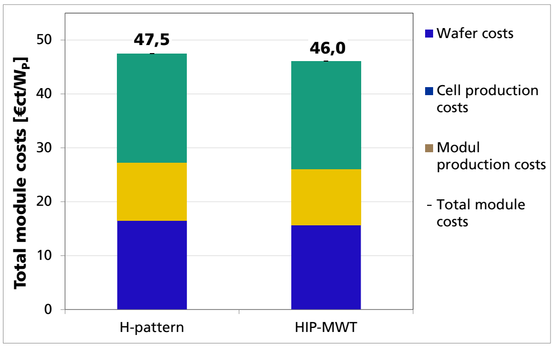


Fig 12: Total module costs subdivided into wafer, cell production and module production costs per wattpeak. Results are based on the Cost of ownership calculation carried out in SCost [4] using a wafer price of 79.09 €ct [8].

Fig 12 shows the total module costs for H-pattern and HIP-MWT subdivided into wafer, cell production and module production costs. In all categories the HIP-MWT technology shows a cost advantage over H-pattern due to the higher module output power: 0.8 €ct/W_P on wafer level; 0.5 €ct/W_P on cell level and 0.2 €ct/W_P on module level. Resulting in an overall cost advantage for HIP-MWT of 1.5 €ct/W_P translating to a relative cost advantage of 3.2 %.

5 SUMMARY AND CONCLUSION

With a cell simulation carried out in GridMaster the possibility of fabricating HIP-MWT cells with 21.5 % using passivated wafers from Gintech was displayed. In a first HIP-MWT run on passivated wafers with a lower efficiency potential a 291 W_P module was built. A cell-to-module loss of only 2 % in power is demonstrated. The second HIP-MWT cell run shows a mean efficiency of 21.2 % exceeding the first cell by 0.7 %abs.. In combination with 2 % CTM this opens up the possibility of manufacturing a p-type module with over 300 W_P. The second cell run also featured reference H-pattern cells and resulted in maximum efficiencies of 21.4 % for HIP-MWT cells and 21.2 % for H-pattern cells. The experimental results correspond well with the simulation. The best 60 cells of each concept were assembled into 60 cell modules resulting in 288 W_P for the H-pattern module. Due to challenges in the module assembly of the second HIP-MWT, a 300 W_P module is only theoretically shown.

Finally the Cost of Ownership calculation shows a cost advantage of 3.2 % for the HIP-MWT technology.

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