Further efficiency improvements of the n-type MWT Si solar cells using industrial processes

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ABSTRACT

The use of n-type silicon allows for high efficiencies: efficiencies up to 20% have been reported for industrial cells. MWT cells allow even higher cell efficiency due to reduced front metal coverage. The efficiency of MWT cells produced by industrial processes reproducibly exceeds the efficiency of front contact cells based on the same technology by 0.2-0.3%. Another advantage of back-contact MWT modules is the reduced cell to module fill factor losses. In a direct comparison, a 60 cell MWT module, based on integrated back foil, produced 3% more power compared to the tabbed module. Finally, simple process optimisations were tested to further improve the n-type MWT cell and module efficiency. A module made using MWT cells of 19.6% average efficiency resulted in a power output of 279 W.

1. INTRODUCTION

The majority of solar cell production is presently based on p-type crystalline silicon wafers using the very mature H-pattern grid technology. In contrast to traditional H-pattern cells, back-contact cells reduce the shading loss on the front side resulting in a current increase. Also, back-contacted cells permit cost and efficiency advantages at module level.

In parallel to the significant progress in cell architecture, R&D using n-type Si substrates and low-cost processing has taken place. N-type silicon solar cells represent an alternative to the standard p-type cells and can fulfil the objectives of low cost and high efficiency with only modest changes to the current wafer and cell production processes [1,2,3]. In order to further increase cell and module efficiencies and decrease cost, we have combined the n-type doped crystalline silicon with back-contact MWT solar cell technology [4] and developed high-efficiency n-type MWT crystalline silicon solar cells (n-MWT).

2. MWT FOR N-TYPE MATERIAL

MWT technology presents several advantages over the standard H-pattern cell technology. Apart from the current gain due to reduced front-side metallisation coverage, integration into a module is easier, as the cell is fully back-contacted. The mechanical stress induced on the cells by conductive adhesive based interconnection is low which results in reduced breakage. Consequently, thinner and larger cells can be interconnected without yield loss. In addition, the packing density can be significantly increased. The front side metal grid benefits from a small unit cell pattern allowing large cells. The cell interconnection can be optimised for low series resistance, since the constraints related to normal front-to-back tabbed interconnection (i.e., shading loss from the width of tab and stress on the cell) are absent [4].

2.1 Cell layout

The front and rear side metal grid patterns of the n-MWT cells are based on an H-pattern lookalike grid design, combined with the unit cell concept [6] as can be seen in Figure 1. We have chosen an H-pattern lookalike grid because it is well suited for a comparison of losses between n-MWT and n-Pasha cells (bifacial n-type cells where both sides are passivated and with H pattern contacts on both sides). Shading and resistance losses are balanced to optimise the power output of the n-MWT cells.

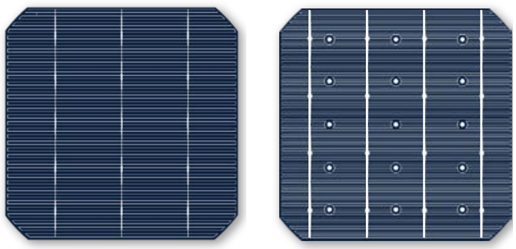

Fig. 1 Image of n-type MWT silicon solar cells with a H-pattern based unit cell design: front side (left) and rear side (right).

3. MWT AND PASHA CELLS

3.1 Experimental results

n-MWT and n-PasHa solar cells were prepared from 200 μm thick and neighbouring n-type wafers. Both groups were processed in parallel and received equivalent processing, where applicable. I/V data are presented in Table 1.

Table 1 I/V characteristics of n-Pasha and n-MWT cells, with comparable Jo and metallisation parameters, to illustrate the gains associated with MWT design.

	J_{SC} (mA/cm^2)	V_{OC} (mV)	FF (%)	η (%)
Average				
Pasha	38.4	638	79.1*	19.38
MWT	39.5	644	77.1	19.61
Best				
Pasha	38.5	638	79.2*	19.45
MWT	39.6	644	77.2	19.70

The Voc gain of 1% for the n-MWT cells is related to the reduced metal contact area to the emitter [7]. This reduced front recombination also results in some (relatively small) Isc gain.

Even though the FF is reduced, a resulting efficiency gain of 0.25% absolute is measured on the back-contacted cells compared to the H-pattern cell. Contributions to series resistance and FF losses are summarised in Table 2.

Table 2. Calculated contributions to Rse and FF loss of the n-MWT cells. 'fingers' is due to unintended difference in print resolution.

Source	$\mathbf{R_{series}}$	**FF loss**
metal via	0.2 mΩ	0.3%
busbars	0.6 mΩ	0.9%
fingers	0.2 mΩ	0.3%
increased I_{sc}		0.1%
Total	**1.0 mΩ**	**1.6%**

3.2 Reducing the series resistance

Several options exist to reduce the FF loss of n-MWT cells relative to n-Pasha cells. A straightforward option is illustrated in Fig. 2, when the number of via-holes increases, FF and Jsc increase due to the reduction of resistive and shading losses (dashed black and solid blue lines). [5] However, this increases the recombination, causing Voc loss (dotted blue line in Fig. 2). [5] From modelling we expect a maximum efficiency increase of 0.23%$_{abs}$ compared to the current number of vias.

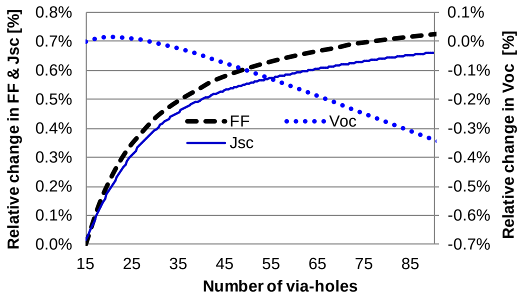

Fig. 2 Calculated relative FF, I_{sc} and V_{oc} changes as a function of the number of via-holes for n-MWT cells.

4. MWT v. PASHA MODULES

ECN's back contact module technology is based on an back foil with integrated Cu layer, on which the cells are contacted using a conductive adhesive. Compared to the tabs used for n-Pasha cells, a rear-side foil interconnection reduces the resistive losses by using more metal (larger cross section) and thus reduces the FF loss after interconnection.

n-MWT and n-Pasha module I-V parameters are presented in Table 3. The n-MWT module outperforms the corresponding n-Pasha tabbed module with a power gain of 8 Wp and a FF loss of only 0.8% which is more than 3 times lower than the FF loss for n-Pasha.

The reflectivity of the back-foils used for the n-MWT module is much lower than the standard TPT back-foil used for the tabbed module. Therefore, significant gain (on the order of 1%) in Isc is possible for n-MWT modules by employing high reflectance back-foils. The CTM Isc gain can be further optimised by adjusting the spacing between the MWT cells.

Table 3 average cell efficiency, power and FF loss for n-MWT and n-Pasha module.

	cell η	**P_{max} [W]**	**FF loss**
n-MWT	18.9%	273	0.8%
n-Pasha	18.6%	265	3%

5 LATEST N-MWT RESULTS

In addition to metallisation grid design optimisation, process improvements originally demonstrated on n-Pasha cell [7] were tested on the n-MWT solar cells. A batch of 60 n-MWT cells was prepared. The I/V data are presented in Table 4.

Table 4. I/V characteristics of n-type MWT cells.

	J_{SC} [mA/cm^2]	V_{OC} [mV]	FF [%]	η [%]
Mean	38.9	644	78.2	19.6
Best	39.1	646	78.5	19.8

Compared to the cells presented in section 3, the FF is improved by 1%$_{abs}$ and an efficiency of 19.8% was obtained. However, current and voltage measured for this batch are lower than expected. Internal quantum efficiency (IQE) data were compared to IQE of n-Pasha cells of the same efficiency but manufactured from a different ingot, using different processing parameters. The front-side IQE shows a lower response of the n-MWT cell at long wavelengths. Preliminary analysis, supported by modelling, indicates this decrease of IQE to be a due to a lower rear-side passivation. We expect to improve the rear side response of the n-MWT cells by more closely matching the processing parameters of the n-Pasha cells.

Interconnection of the n-MWT cells was done as described in section 4. For this n-MWT module, a back sheet with improved reflectivity was used. Incorporating cells with average efficiency of 19.6%, the module power reached 279 W with an absolute FF loss of 1.3%.

Despite an improved power, this n-MWT module shows a slightly higher CTM FF loss compared to the n-MWT module presented in section 4 which is possibly due to the use of a different conductive adhesive. Also, the module Isc turned out to be lower than expected, probably because of I_{mpp} mismatch of a few cells. With better I_{mpp} matching and the CTM FF-loss of Table 3, a module power above 285 Wp is possible.

6 CONCLUSION

We have developed a manufacturing process based on n-type monocrystalline Cz silicon wafers for MWT solar cells and modules, yielding a module power of 279 Wp with cells of 19.6% efficiency. With current density approaching 40 mA/cm^2 and open circuit voltages of 644 mV, the n-MWT solar cells outperform n-Pasha solar cells manufactured with a comparable process. In a direct comparison, an efficiency gain of 0.3%$_{abs}$ for MWT was achieved. Loss evaluation demonstrated a clear potential for series resistance and fill factor improvements. From an initial optimisation of the metal grid, a FF increase of 1%$_{abs}$ was achieved and a highest efficiency of 19.8%. Additional optimisation of paste properties and contacting layout as well as application of the optimum process parameters will allow the n-MWT cells to reach efficiency above 20%.

Performance enhancement at module level is obtained thanks to ECN’s back contact module technology based on conductive interconnect patterns integrated on the back foil. In a comparison between 60 cell n-MWT and n-Pasha modules, a power increase of 3% for the n-MWT module was obtained. A later experiment with improved cells (19.6% average) resulted in a module power close to 280 Wp. This module power gain can be increased further by better I_{mpp} matching and further optimisation of the back foil reflectivity and the cell packing density and by cell efficiency increases.

7 ACKNOWLEDGMENTS

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