EFFICIENCY IMPROVEMENTS BY METAL WRAP THROUGH TECHNOLOGY FOR N-TYPE SI SOLAR CELLS AND MODULES.

Wenchao Zhao[1], Jianming Wang[1], Yanlong Shen[1], Ziqian Wang[1], Yingle Chen[1], Shuquan Tian[1], Zhiliang Wan[1], Bo Yu[1], Gaofei Li[1], Zhiyan Hu[1], Jingfeng Xiong[1], N.Guillevin[2], B.J.B. Heurtault[2], B.B Van Aken[2], I.J. Bennett[2], L.J.Geerligs[2], A.W.Weeber[2], and J.H.Bultman[2]
[1] Yingli Green Energy Holding Co., Ltd, 3399 North Chaoyang Avenue, Baoding, China, E-mail: wenchao.zhao@yinglisolar.com
[2] ECN Solar Energy, P.O. Box 1, NL-1755 ZG Petten, the Netherlands

ABSTRACT: N-type Metal Wrap Through (n-MWT) is presented as an industrially promising back-contact technology to reach high performance of silicon solar cells and modules. It can combine benefits from both n-type base and MWT metallization. In this paper, the efficiency improvements of commercial industrial n-type bifacial Si solar cells (239cm^2) and modules (60 cells) by the integration of the MWT technique are described. For the cell, after the optimization of integration, over 0.3% absolute efficiency gain was achieved over the similar non-MWT technology, and Voc gain and Isc gain up to 0.9% and 3.5%, respectively. These gains are mainly attributed to reduced shading loss and surface recombination. Besides the front pattern optimization, a 0.1mΩ reduction of Rs in via part will induce further 0.06% absolute efficiency improvement. For the module part, a power output of n-MWT module up to 279W was achieved, corresponding to a module efficiency of about17.7%.
Keywords: Back contact, Bifacial, Metal-wrap-through, n-type, Silicon

1 INTRODUCTION

1.1 N-type bifacial Si solar cell

In the present photovoltaic (PV) industry, Si based solar cells are still playing a dominant role [1]. With the price of Si module per watt having dropped to less than 1 dollar per watt, grid parity has been realized in local areas, and the fabrication of solar cells with higher efficiency and lower cost (lower cost/watt) has become much more urgent and important than before. For the commercial Si-based PV market, the p-type silicon solar cell is still the mainstream, but compared with p-type, solar cells from n-type Si wafers have potentially higher efficiency thanks to advantages of n-type materials, such as higher minority carrier recombination lifetime [2,3], higher tolerance to impurities in silicon feedstock [4,5], low light-induced degradation of performance [6,7]. According to the prediction from the International Technology Roadmap for PV (ITRPV), the market share of n-type in mono crystalline Si PV production will be 30% in 2015 [8].

Up to now, there have been only 3 companies which realized the mass production of n-type Si solar cells with high efficiency: Sanyo, Sunpower and Yingli Solar. Sanyo is producing so-called HIT (Heterojunction with Intrinsic Thin-layer) cells. SunPower is manufacturing fully back-contacted (Interdigitated Back-Contacted, IBC) cells. In 2010, commercial n-type solar cells named PANDA cells were introduced by Yingli Solar. PANDA cells are bifacial N-type Si solar cells (239 cm2), which use conventional non back-contacted H-Pattern metal contact grids. So far, the best cell efficiency of 19.89% in production and 20% in laboratory has been reported [9].

1.2 MWT concept

Metal wrap through (MWT) technology, as one back-contact technology, has been regarded as industrially promising because of its high cost-effectiveness for increasing cell and module efficiency [10]. In MWT cells, the front metal grids will be wrapped through the via-holes to the rear side of the wafer, inducing reduced shading losses, and reduced surface recombination, and as a result the cell efficiency will be improved [11]. On MWT module part, the strategy of full back interconnection of the cells results in lower cell-to-module loss thanks to avoiding much of the resistive loss existing in the normal double-side interconnection of H-pattern solar cells with tabs [12,13]. In addition, the MWT technology can allow the use of thinner cells which will reduce cost directly.

Recent reports on combination of MWT techniques with commercial solar cells mainly focus on the p-type solar cells [14, 15]. The utilization of MWT on n-type materials will allow to achieve even higher cell and module efficiencies. Based on this, in collaboration with ECN, we have developed the MWT version of the PANDA cells, which are labeled as n-MWT cells.

In this paper we present the latest results on the efficiency improvements by integration of MWT concept on PANDA based materials, both for cells and modules.

2 N-MWT CELLS

To guarantee a good comparison, the n-MWT cells and PANDA cells were processed in parallel in Yingli's pilot line. Based on the normal PANDA cell process, steps such as texturization, BSF and emitter formation, and passivation, are the same. After the metallization of both sides by screen printing, the cells were fired in one single step in an IR heated belt furnace. The IV characteristics of n-MWT cells and PANDA cells were measured by using a corresponding chuck, under the same illumination condition in the same tester.

2.1 Design of front pattern

Figure 1 shows the difference of front design between actual n-MWT cells (4 busbars) and normal PANDA cells (3 busbars).

Compared with normal H-pattern PANDA cells, n-MWT cells allow more flexibility in pattern design. When the number of BB is larger than PANDA cells, n-MWT cells will possess more potential in pattern optimization (the collection of currents will be more flexible). Based on this basic concept, firstly we make a theoretical comparison.

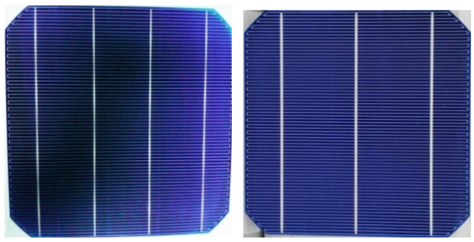

Figure 1: Images of the front side for an n-MWT cell (left) and a normal PANDA cell (right).

The influence of the front-side grid finger width (Figure 2) and their number (Figure 3) on the performance is shown. The performance is represented by overall-loss, which includes the FF-loss and shading-loss. (In Finger 2, the contact design of n-MWT is 4x4, and the PANDA cell is contacted by 8 probes per busbar).

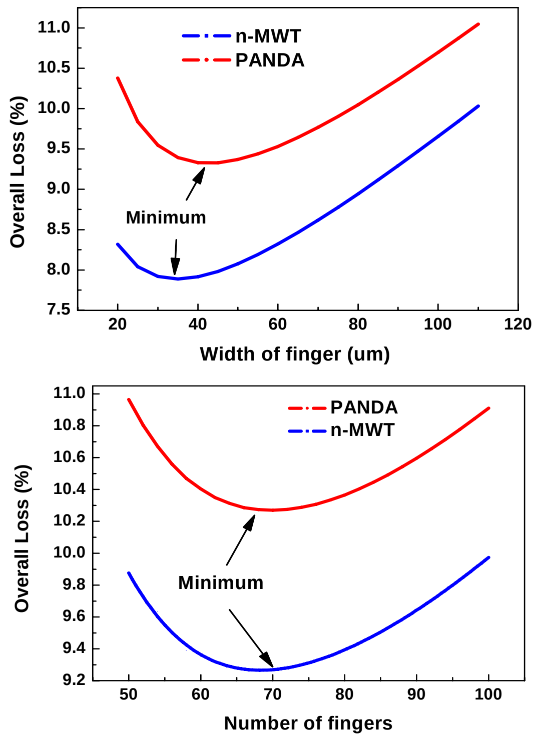

Figure 2: Calculated relationships between front finger pattern and the overall-loss, for both n-MWT and PANDA. (Top：width of fingers；Bottom：number of fingers)

From these two images, obvious improvements can be anticipated. The actual experimental results also confirmed that Voc and Isc improvements can be achieved by optimization of the front design..

In Table 1, the mean values of the main electrical parameters of the solar cells from 2 runs of experiments, with different MWT grid pattern for each run are given. Compared with Pattern1, Pattern2 possess narrower width of fingers.). The absolute efficiency gain has been up to 0.36%, and Voc gain and Isc gain are 5.7mV (0.9%) and 0.31A (3.5%) respectively. In addition paste consumption will be reduced in Pattern2.

		Uoc (mV)	Isc (A)	FF (%)	Eta (%)
Pattern1	PANDA	636.0	8.96	77.68	18.53
	n-MWT	639.8	9.14	77.02	18.85
	Delta	3.8	0.18	-0.66	0.32
Pattern2	n-MWT	641.7	9.27	75.96	18.89
	Delta	5.7	0.31	-1.72	0.36

Table 1: Comparison of electrical parameters for n-MWT cells (2 patterns) and PANDA cells (mean values of 30 cells, Pattern2 possess narrower width of front fingers than Pattern1)

According to the characterization results (including the measured parameters of grid patterns) combined with modeling (from PC1D), the Voc gain and Isc gain from shading-loss reduction for different n-MWT cells are investigated. (See Table 2).

	Voc gain (%)	Overall Isc gain (%)		
		reduced recombination (%)	enhanced light-absorption (%)	Other parts (%)
Pattern1	0.6	0.4	1.1	0.6
Pattern2	0.9	0.5	2.5	0.5

Table 2: Analysis of Voc gain and Isc gain of n-MWT cells over PANDA cells from two different MWT patterns

In our result, there is still 0.5% Isc gain from other parts, the reason for which is still under investigation. It should be noted that there are uncertainties in the measurements, which may be different for the MWT and Pasha chuck in our tester. The bifacial character of cells further complicates measurements (need to define reflectance underneath the cell). The cells have not been independently certified. Presently, hybrid PANDA-MWT cells [16] are being tested to increase accuracy of comparisons in this experiment.

We also investigate the influence from number of via-holes on improving cell efficiency.

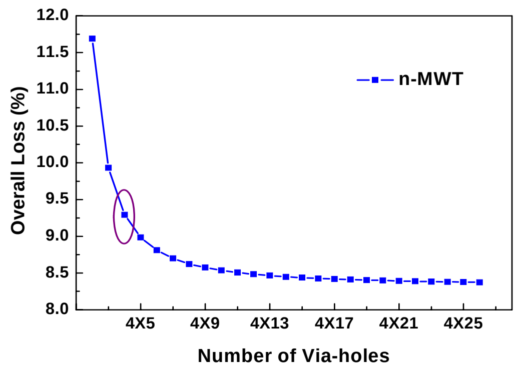

Figure 3: Influence of n-MWT via-hole number on the overall loss.

Figure 3 shows the calculated potential efficiency improvement obtained by increasing the number of via-holes. For the n-MWT cells with different via-hole numbers, the optimum design of the front side pattern, especially of the busbars, will be different. For simplicity, the busbar pattern is kept the same in this calculation. (The purple ring refers to the current number of via-holes.). From this curve, we can anticipate that by increasing the number of front pattern for n-MWT, higher efficiency can be achieved. But, in fact, the reasonable design of number of via-holes will be dependent on the cost of the module assembly.

2.2 Plug pastes

Besides the front pattern, compared with normal PANDA cell structure, the plug paste which connects the front metallization grid to the rear side through the via-holes will be another important difference. So, the plug paste will definitely become a factor influencing the final n-MWT cell efficiency.

In figure 4, two plug pastes with different conductivity were tested to investigate their influence on the FF and the efficiency of the n-MWT cells (during the test, the other process parameters are the same, including the same patterns and same pastes on the front and the rear)

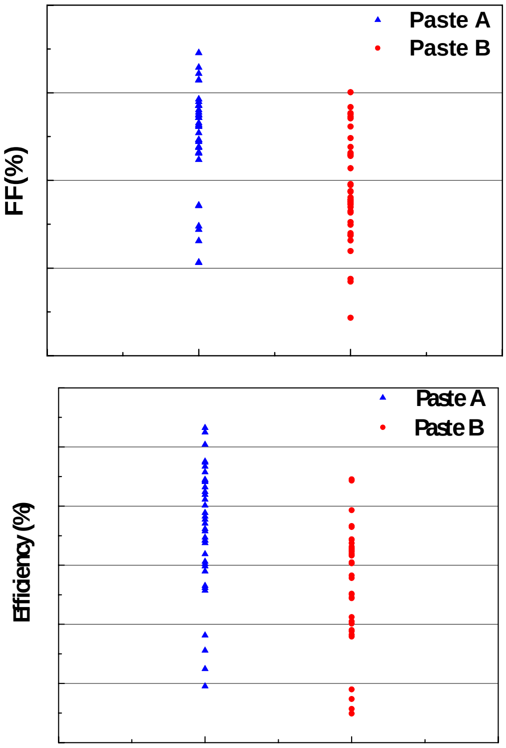

Figure 4: Relative distribution of FF (top, grid line separation is 0.5% of FF) and Efficiency (bottom, grid line separation is 0.1% of efficiency) as a function of Plug pastes

For Rs in the via part (Rs-Via, including the contact resistance of front paste with plug paste) of the two plug pastes, plug paste A has about 0.1mohm lower Rs-Via than plug paste B. As a result, absolute FF difference and efficiency difference are up to 0.4% and 0.06% respectively.

3 N-MWT MODULESs

Not only can the cell efficiency be improved by the MWT concept. On the module part, additional efficiency improvements can be achieved by optimization of back contact module technology.

At the module level, we use integrated backfoil for interconnection of the cells. Conductive adhesive (CA) was used to connect pads on the rear side of the cells with corresponding contacting points on the backfoil. In this connection method, the sheet resistance of the conductive foil is determined by the large cross-section of the patterned conducting Cu sheet in the foil, the typical cross-section of the Cu sheet is much larger than that of standard soldered tabs. As a result, less FF-loss from cell to module after cell encapsulation can be realized, which means more power output can be achieved. Furthermore, the CA will influence the FF loss from cell to module and the reliability behavior of the final modules. To improve the cost-effectiveness, different backfoils with electrical and optical optimizations have been evaluated.

Previously we have presented results comparing full size (60-cell) modules of H-pattern PANDA and n-MWT (using standard backfoil). The n-MWT module (M1) showed a relative power gain of slightly more than 3% over the corresponding PANDA module, resulting in a power of 273Wp [12] and a module efficiency of 17.3%.

In this part, we will show our latest MWT module results based on optimization from backfoil reflection and CA.

3.1 Optimization of Backfoil

One of the possibilities for improvement of MWT module performance is increasing the reflectivity of the MWT backfoil. Figure 5 shows the influence of backfoil on the spectral response (SR) of different n-MWT laminates. In this test, two different backfoils (labeled as Foil-A and Foil-B) were used, and n-MWT cells were first contacted to the integrated backfoil and subsequently laminated into 1-cell laminates. To make a comparison independent of fluctuations in cell performance, the SR data of the laminates were normalized by dividing them by the SR of the unlaminated cells.

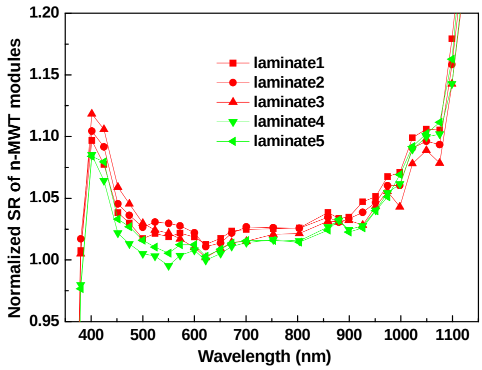

Figure 5: Influence of backfoil on SR of n-MWT laminates.(The green data from Foil-A; the red data is from Foil-B)

From this comparison, we can see that an increase in current is possible by improving the reflectivity of the backfoil especially in the wavelength range from short to middle (this increase is due to light scattering at the backfoil around the cell, via internal reflection in the laminate, into the cell).

3.2 Efficiency Investigation on Full-size module

Based on the optimization, recently, we made two new full-size modules (60 cells) based on the two kinds of backfoils and CA. The detailed comparison information is in Table 3

From this comparison, we can see, after replacing the Foil-A by the higher reflecting Foil-B, the Isc can be improved up to 2.7%. The highest power obtained for the n-MWT full-size module is 279 Wp, corresponding to an efficiency that can be 17.7%. It should be mentioned that the Isc improvement for Module3 (abbreviated as M3) is much lower than expected based on the advantage of Foil-B; EL image and shape of I-V curve show that probably a mismatch of Isc and Impp of a few cells are the reason for this. In future modules made from similar cells but without mismatch, if the current improvement is over 2%, then the Power output will be probably over 282W.

No	Pmax (W)	Foil	CA	Cell to Module	
				FF-change (%)	Isc improvement (%)
M1*	273	A	A	-0.7	1.5
M2	275	B	B	-1.4	2.7
M3	279	B	C	-1.3	1

Table 3 Comparison of different layouts for n-MWT 60-cell modules. *this module result has been reported in previous conference [12]. FF-change and Isc Improvement mean the absolute FF change and relative increase of Isc. Concerning the Isc change from cell to module it should be noted that the calibration cell and calibration module for module measurements both have uncertainties of about 2%.

From the FF-change comparison of these three n-MWT modules, CA will be an important factor. In fact for the point of cost-effectiveness, it is also playing an important role together with the backfoil.

4 CONCLUSIONS

In this paper, we investigate the efficiency improvements by MWT concept based on bifacial n-type Si solar cell (PANDA cells). By utilizing the flexibility of front pattern and plug pastes for n-MWT cells, the efficiency can be improved by over 0.3% absolute. For the module level, it is very important to optimize the reflectance of the backfoil to reach highest cell-to-module Isc gain. The cell-to-module FF-loss can be maintained around 1%. After testing the different combinations of materials for the n-MWT module, a 279W full-size module has been fabricated. Considering the potential improvement in current, such as from reducing the mismatch of Isc and Impp in selection of cells for modules, the power output of future modules from cells of the same efficiency should be able to reach over 282W.

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