

High-Efficiency N-type Si Metal-Wrap-Through Cells From Lab to Fab

N. Guillevin et al.¹ W. Zhao et al.²

¹ECN Solar Energy ²Yingli Green Energy Holding Co. Ltd.

Abstract

Metal-wrap-through (MWT) cell technology represents the smallest evolutionary step from mainstream Si PV production to high-efficiency rear-contact cell and module technology. The technology builds on standard “H-pattern front contact” cell technology by adding a small number (10-30) of via-holes to wrap the front metalization to the rear contacts for module interconnection. It increases the module efficiency by reduced shadow loss (~2-3 percent), reduced series resistance (~3 percent), and reduced module inactive area. Figure 1 shows a schematic layout of the MWT cell and module technology from ECN.

The advantages of the MWT technology are large: Apart from the increase in cell and module efficiency, the module manufacturing can be done with higher yield, a higher degree of automation and a much smaller equipment footprint. Also, the MWT technology reduces stress from the interconnection process and thus allows thinner cells, offering additional cost-reduction possibilities. Advances in mainstream H-pattern cell equipment and tech-

nology, such as selective emitter technology, can easily be incorporated in MWT.

The International Technology Roadmap for PV expects the share of rear-contact technology to take off rapidly in 2013-2014, and reach 40 percent in 2020. Several companies have already announced their intention to take p-type MWT cells to large-scale production this year.

With this in mind, several years ago, ECN began efforts to create an “MWT version” of its high-efficiency n-type cell technology.

n-type Cell Technology and the Panda Project

ECN typically develops cell concepts bottom-up, i.e., on full-size wafers, using industrial high-volume manufacturing (HVM) tools (or versions thereof with somewhat reduced throughput) and low-cost processes. This makes it somewhat harder to judge the performance ceiling of a cell design and process flow or establish benchmarks for process steps. However, the advantage of the bottom-up approach is that for transfer to industry, relatively little redesign of the process

flow must be done. Notwithstanding, usually some major points of attention remain, which cannot be so easily judged at a lab throughput of (at most) tens of cells per day; for example, mechanical yield, distributions of cell parameters, aspects of consumable costs, and process variations with very small effects, on the order of 0.1 percent change of efficiency. Also, input material specifications, such as ingot and wafer quality and purity requirements of chemicals, are more difficult to establish at low throughput.

Following the bottom-up approach, ECN has developed an n-type H-pattern front- and rear-contact cell technology (which we gave the acronym “n-PasHa”[1]). Compared to p-type Cz cells,

n-type Cz cells benefit from high bulk diffusion length and dielectric rear passivation (high internal reflection and low surface recombination) and thus have a much higher efficiency.

At ECN, breakthrough simple industrial process steps were developed between 2007 and 2009 that made such cells a potential industrial reality. In 2009 and 2010, the n-PasHa cell was successfully brought from lab (ECN’s pilot line) to fab (Yingli’s production lines) through the Panda project (a collaboration between Yingli Solar, ECN and Amtech Systems[2]). At the beginning of 2012, the annual throughput for Panda cells was 600M Wp; the average cell efficiency in production line is over 18.9 percent.

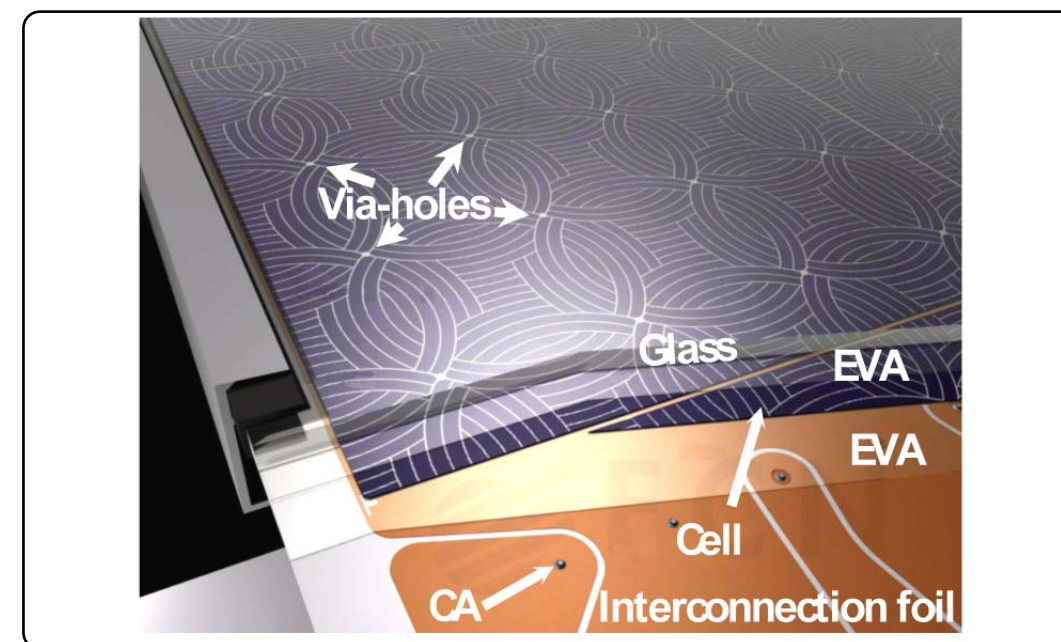


Figure 1 – Schematic 3D Cross Section of an MWT Module Manufactured Using the ECN Module Interconnection Technology

In September 2011, Yingli Solar, together with ECN and Amtech Systems, announced results of the industrialization project of ECN's n-type metal-wrap-through (n-MWT [1]) cell technology. As already illustrated by the successful industrialization of the n-PasHa technology, the collaboration within the Panda project – utilizing the synergy between a research institute, an equipment supplier and a major PV manufacturer – creates a fertile environment for the development and introduction to production of new-generation technologies such as n-MWT.

In the following sections, we will describe the sequence from lab development to pilot development of the n-MWT technology. In the final section, we will give an outlook for industrial production and further efficiency gains.

Technology Development: Lab Phase at ECN

At the start of the n-MWT development in the lab, ECN investigated and did

preliminary optimization of cost of ownership at cell level by designing and comparing several n-MWT cell process flows very similar to the industrial n-PasHa cell process.

The performance and estimated cost of the n-MWT cell processes were evaluated at lab scale. We selected the most suitable processes for industrialisation based on minimal changes to existing n-PasHa process equipment, minimal additional investment and footprint, maximum cell efficiency gain and expected yield of the additional process steps.

Within this process flow evaluation phase, characteristics of the n-MWT cell under reverse voltage bias also received attention, as this is very relevant for the reliability of modules in practical installations. MWT cells, because of their structure with emitter contact located on the rear side, could potentially have an increased reverse current compared to conventional two-side-contacted cell structures. However, as Figure 2 shows,

the n-MWT cells do not have (for suitable processing) a significant increase in reverse current compared to n-PasHa.

Also, in this phase, understanding of the cell losses, and application of loss analysis to optimize the MWT performance, played a key role. In this context, a direct comparison between the n-MWT and n-PasHa technologies was done. The results are described below.

Current Performance of n-MWT on Lab Scale

Details of the peak performance of n-MWT cells processed at ECN are presented in Table 1. The peak efficiency of n-PasHa cells, processed in parallel using our high-efficiency industrial process,[2] is presented for comparison. Both n-MWT and n-Pasha cells were processed from identical material (neighboring n-type Cz wafers of 239 cm² and 200 μm thickness).

The front- and rear-side metal grid patterns of n-MWT cells, illustrated in Figure 3, are based on an H-pattern look-alike grid design. As the module interconnection of MWT cells does not involve a tab soldering process, the front- side busbars can be significantly slimmed down compared to n-PasHa cells. As a result, the short circuit current density J_{sc}, due to

reduced shading losses, and the open-circuit voltage V_{oc}, due to reduced front metal contact-related recombination, are significantly higher compared to n-PasHa (+2.8 percent and +1 percent, respectively, as shown in Table 1).

However, the resistance in the narrow busbars is larger, which affects the total series resistance and leads to about 2 percent loss in fill factor (FF). We are working on ways to significantly reduce this fill factor loss. But even at these relatively low FF values, a total efficiency gain of 0.25 percent absolute is measured for the n-MWT cells. By correcting FF for the overestimation mentioned in Table 1,[1] the efficiency gain of MWT over n-PasHa cells becomes 0.3 percent absolute. By optimization of the front metal grid and cell contact layout, the shading and resistance losses can be balanced to further increase the cell efficiency compared to n-PasHa.

Technology Development: Pilot Validation and Development

The MWT technology was transferred to Yingli and implemented in pilot operation. Development continued in parallel in the ECN lab and Yingli pilot. In a short period, Yingli also obtained the efficiency

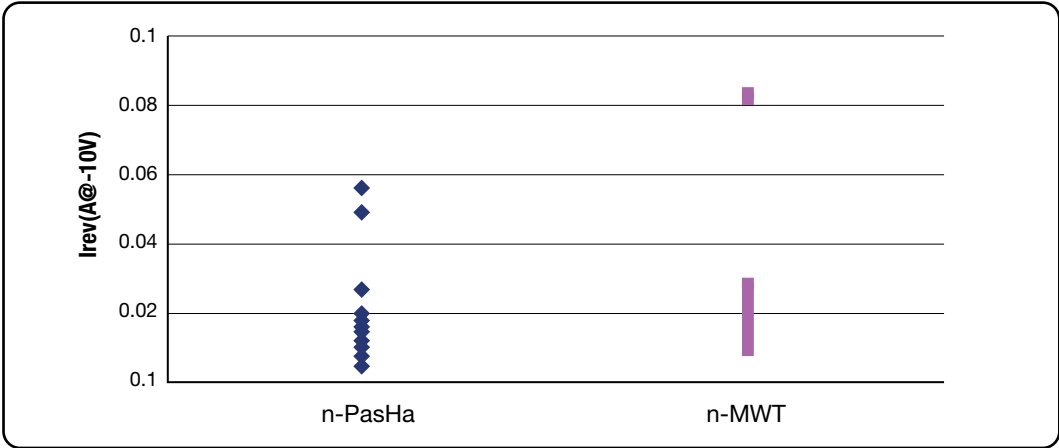


Figure 2 – Comparison of I_{rev} Between n-PasHa and n-MWT

	J _{sc} (mA/cm ²)	V _{oc} (mV)	FF (%)	η (%)	Rse (mΩ)
PasHa	38.50	638	79.20*	19.45	4.4
MWT	39.62	644	77.20	19.70	5.7

Table 1 – I/V characteristics of n-type MWT and n-type PasHa cells measured at ECN (class AAA solar simulator) illustrating the gains associated with the MWT technology. An ESTI calibrated cell was used as a reference. Cells were mounted on a reflective chuck. The Rse is obtained from a fit to the two-diode model. The J_{sc} has been corrected for spectral mismatch. *FF overestimated by approx. 0.2% absolute due to measurement method.[1]

gain of 0.3 percent absolute over n-PasHa. Thanks to the higher throughput in the pilot line, far better statistics could be obtained on, for instance, yield, impact of ingot specifications and I_{rev} . Further adjustments of process flow were done. The joint development project also resulted in an increased incentive for materials and equipment suppliers to modify their products for this cell and module process.

In this phase, the module process development and reliability testing were also introduced. Since the p-MWT and n-MWT cells are interconnected with identical module technology, this aspect was left out in the lab phase. An important aspect of MWT technology is the choice between using tabs or integrated conductive back foil for interconnection. To interconnect MWT cells, soldered wide tabs on the back side, together with a suitable isolation process, can be used with very small FF loss, similar to integrated back foil. The integrated back foil allows, in our

opinion, for more optimal HVM, meaning higher throughput, higher yield and smaller footprint. Even though the integrated back foil is very suitable for HVM, it is presently a bottleneck for pilot operation or small-scale mass production. In particular, the cost of integrated back foil is still relatively high, and as long as this is the case, it limits the cost benefit of integrated MWT technology. However, partly driven by developments in p-MWT module manufacturing, many suppliers of sheet material have become active, and quoted costs and cost forecasts show MWT module technology to be more competitive.[5] The same is true for other aspects of MWT module technology based on integrated back foil, such as the cost of the conductive adhesive or alternative interconnection technology.

The performance of the first 60-cell n-MWT module, interconnected on integrated back foil as in Figure 1, was evaluated against a corresponding n-PasHa

tabbed module. As shown in Table 2, the n-MWT module outperforms the n-PasHa module with a power gain of 8 W. A cell-to-module FF loss of only 0.8 percent (more than 3 times lower than for n-PasHa) results in a cell-to-module efficiency loss reduction by a factor of 2 for n-MWT compared to n-Pasha.

The reflectivity of the integrated back foil used for this first n-MWT module was much lower than the standard back foil used for the n-PasHa tabbed module. Therefore, an additional (and significant) J_{sc} gain is possible for n-MWT modules by employing high-reflectance back foils. Also, further J_{sc} gain is possible by optimization of the spacing between the MWT cells. Module reliability tests are ongoing. We note that p-type MWT modules based on integrated back foil have already repeatedly obtained IEC certifications, and passed test criteria well beyond IEC requirements,[5] proving the concept to be robust.

Outlook: Production and Further Increase of Efficiency

The pilot operation phase generally is composed of at least two stages. In the first stage, the preferred process flow will

be selected and the process windows will be narrowed to the point that full-scale production equipment can be selected, and tests and validation of, for instance, laser processing or module manufacturing, can commence. In the next stage, refining of process windows and optimization of performance can continue, while production equipment is being installed and full-scale production ramped up.

As for the n-PasHa technology, which is constantly improved by the collaboration between ECN, Yingli Solar and Amtech Systems, efficiency and future production costs of the n-MWT technology are continuously optimized. For example, as described in reference [3] it is expected that the efficiency gain over n-PasHa can be increased to above 0.5 percent absolute by increasing the number of via-holes, together with optimizing the front-contact grid design; thus, efficiencies well above 20 percent can be obtained. Of course, this must be balanced with the cost of interconnection and cell-to-module losses.

In addition to improvements specific to n-MWT cell processes, optimization of almost all n-Pasha cell processes can direct-

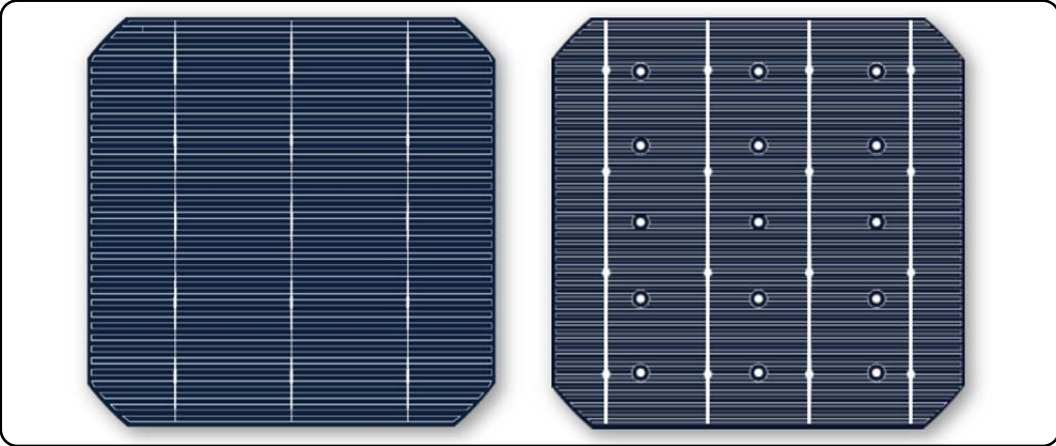


Figure 3 – Image of n-type MWT Silicon Solar Cells With an H-Pattern-Based Unit Cell Design: (left) Front Side; (right) Rear Side

	Pmax (W)	Absolute cell-to-module FF loss	Absolute cell-to-module η loss*
n-MWT module	273	0.8%	0.6%
n-Pasha module	265	3.0%	1.2%

Table 2 – n-type MWT and n-type Pasha module power, FF and η loss from cell to module. Measurements performed on a class A multi-flash tester according to the international standard IEC60904-9. *Loss calculation based on aperture area module efficiency corrected for spectral mismatch.

ly be transferred to the rear-contact cell processes. For instance, recently, the quality of the back surface field was enhanced, resulting in a considerable efficiency boost of the n-PasHa cells.[4] Current and voltage gains of more than 1 percent were achieved at ECN, and process improvements are about to be tested at Yingli. We expect that application of the improved BSF process to n-MWT will yield similar gains in both voltage and current, which means efficiencies over 20 percent using industrial technologies are within reach.

Conclusion

The cell efficiency gain, together with the extra module performance enhancement over n-PasHa arising from the significantly reduced cell-to-module efficiency loss, clearly make the n-MWT technology a good candidate to further improve the cost and performance of the firstly developed Panda technology.

With the further development of MWT technology, especially MWT module technology, the cost-effectiveness of MWT will become more prominent. According to current results on MWT technology, development of MWT will be an important part of Yingli’s R&D roadmap in the next few years. Eventual implementation of MWT in Panda will depend on cost-effectiveness of the approach.

Acknowledgments

We gratefully acknowledge the support and collaboration of Tempres Systems in this work.

References

1. N. Guillevin et al. 26th EU-PVSEC, 2011, 2BO.8.2
2. A. Burgers et al. 26th EU-PVSEC, 2011, 2DO.2.1
3. N. Guillevin et al. CPTIC, China, 2012
4. I. Romijn et al. CPTIC, China, 2012
5. W. Eerenstein et al. CPTIC, China, 2012 ■

About the Authors

ECN Solar Energy

- N. Guillevin – Researcher, Solar Energy
- L. Geerligs – Senior Researcher, Solar Energy
- B. Heurtault – Researcher, Solar Energy
- B. Van Aken – Researcher, Solar Energy
- I. Bennett – Researcher, Solar Energy
- M. Jansen – Researcher, Solar Energy
- L. Berkeveld – Researcher, Solar Energy
- A. Weeber – Senior Manager, Solar Energy
Si-PV Device Architecture
- J. Bultman – Business Development Manager,
Solar Energy

Yingli Green Energy Holding Co. Ltd.

- Wenchao Zhao – Researcher
- Jianming Wang – Researcher
- Ziqian Wang – Researcher
- Yingle Chen – Researcher
- Yanlong Shen – Researcher
- Zhiyan Hu – Director of Technology
& Manager of R&D
- Gaofei Li – Deputy Manager, R&D
- Jianhui Chen – Researcher
- Bo Yu – Manger, Module Design
- Shuquan Tian – Researcher
- Jingfeng Xiong – Vice President, Technology