

## AN OVERVIEW OF MWT CELLS AND EVOLUTION TO THE ASPIRE CONCEPT: A NEW INTEGRATED MC-SI CELL AND MODULE DESIGN FOR HIGH-EFFICIENCIES

I.G. Romijn, A.A. Mewe\*, M.W.P.E. Lamers, E. Kossen, E.E. Bende, A.W. Weeber  
ECN Solar Energy, P.O. Box 1, 1755 ZG Petten, The Netherlands

\*Corresponding author: Phone: +31 224 564323; Fax: +31 224 568214; email: mewe@ecn.nl

### ABSTRACT:

At ECN, we are developing several different cell concepts to reduce the €/W<sub>p</sub> costs of crystalline silicon solar cells by increasing the efficiency on thin and large solar cells. Our metallization wrap through (MWT) concept PUM reduces the shading losses from the front side by 3%, which results in a gain in J<sub>sc</sub>. Furthermore, the cells are fully back contacted and easy to implement in a module. Another way to improve efficiencies, especially on thin wafers, is to replace the full aluminum BSF at the rear side by a more appropriate passivating layer like silicon nitride in combination with partial rear metallization. In this paper we present the development at ECN from standard H-patterned cell processing towards a combination of the two concepts mentioned above: our rear side passivated PUM cell, the ASPIRe cell. The proof of concept of the ASPIRe cell will be given. Compared to PUM reference cells, ASPIRe cells have reached higher J<sub>sc</sub> and V<sub>oc</sub>, although the FF still remained behind. The highest efficiency obtained so far for ASPIRe cells is 16.4%, and methods to improve the FF by changing the rear side Al pattern are shown.

Keywords: multi crystalline, metal-wrap-through, back contact, bifacial

### 1 INTRODUCTION

To remain competitive in the future, wafer-based solar cell manufacturers will have to reach high efficiencies on thin and large cells. These cells should be easy to implement into a module, or, ideally, an integrated cell and module concept should be developed. Back-contacted cells like Metallization-Wrap-Through (MWT) are easier to implement into a module than the conventional H-pattern cells with contacts on both sides since the contacting can be done completely at the rear side.

However, processing of (very) thin and fragile MWT cells using a full area Al back surface field (BSF) will reduce the cell efficiency due to a non optimal passivation and optical confinement of the rear [1-7]. Furthermore, the use of such MWT cells will still cause problems for module assembly due to the increased bowing.

To overcome this major drawback, we have introduced a new MWT concept ASPIRe: **All Sides Passivated and Interconnected at the Rear**. The ASPIRe cells are based on our existing MWT PUM cells [8-10]. The emitter metallization is led to the rear side via 16 holes in the wafer, while the front side metallization is changed into a symmetric pattern around these holes. A similar pattern is now also applied on the rear side. The rear side of this cell is passivated with a single silicon nitride layer (SiN<sub>x</sub>) and local metallization is applied. Better rear surface passivation and better optical confinement results in higher efficiencies. Furthermore, the cell warping is reduced to 0 and the lower Al consumption will reduce the cell manufacturing costs considerable.

When local Al contacts are used at the rear side, a challenge is to obtain good fill factors while keeping optimal rear surface passivation. Less metallization at the rear, for instance by using narrower aluminum lines, will decrease the FF, but improve (lower) the rear surface recombination since the passivation by a silicon nitride layer is superior to that of the local fired through Al contacts. More metallization at the rear will have the

opposite effect, higher FF but worse rear surface passivation. At ECN we have developed a 2D simulation program to optimize the rear side metallization pattern while keeping the metallization fraction constant, such that the rear surface passivation remains the same [11]. As for the front side of PUM cells, the modular design on the rear side of the ASPIRe cells allows more freedom in the pattern design compared to the standard H-pattern design a better balance between the FF and rear side passivation can be achieved.

### 2 METALLIZATION WRAP THROUGH CONCEPT

In the past, several back contact solar cell concepts have been developed for multi or mono crystalline silicon solar cells. Most commonly known are the interdigitated back contacts (IBC), emitter wrap through (EWT) or metallization wrap through (MWT) cells [12-18]. Compared to IBC or EWT, the processing of MWT cells is relatively simple, and can be applied on both low and high material quality.

For IBC cells the emitter is only applied at the rear side. In this case the material quality should be high to prevent too much bulk recombination. For EWT cells the emitter is applied on the front side, and led to the rear via a large number of holes in the wafer. This means in principle lower material quality can be used compared to IBC cells. The metallization in both (IBC and EWT) cases is only applied at the rear side. For MWT cells the emitter is applied on the front side as well as in the holes, thus also lower material quality can be used. Compared to EWT, the conduction in the holes of MWT cells is high because of the application of metal inside the holes. This means a limited number of holes will be sufficient to enable a good FF for MWT cells, making the processing easier than for EWT.

In the past, several institutes have worked on MWT cell concepts [8-10,14-18]. Already 10 years ago, IMEC reported their MWT concept, using cells made

on 100 mm<sup>2</sup> wafers [12,13]. The front busbars were replaced by laser holes while the amount of front Ag fingers was kept intact. The cells could be contacted into a module in a conventional way: strings were made using tabbing material interconnecting the emitter and base busbars on the rear side.

More recently, researchers from ISE reported on MWT cells made in a similar way on mc-Si material [15]. Forty eight laser-drilled holes replaced three busbars on the front side. Again, contacting into a module was done in a conventional way by soldering strings on the busbars on the rear side. An efficiency gain of 0.6% was reported for tabbed and laminated MWT cells compared to standard solar cells.

At previous conferences, ECN introduced the MWT-PUM technology. Unlike the MWT concepts mentioned above, this is a completely integrated cell-and-module concept [8-10].

The front side metallization pattern is shown in figure 1. This pattern is symmetric around 16 holes through which the emitter metallization is led to the rear side of the wafer.

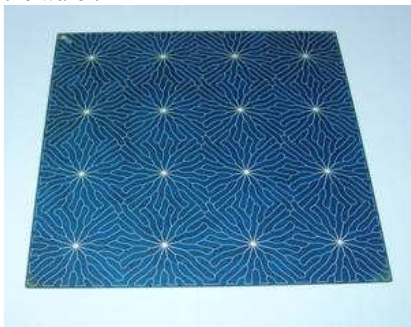


Figure 1: PUM front side

The emitter and base contacts are no longer the usual busbars, but evenly spaced dots on the rear surface. This enables a more homogeneous layout of the front fingers resulting in lower shading losses and a higher FF when the cells are connected into a module. Interconnecting the cells into strings is no longer necessary. The cells are placed into a module by simply picking and placing them on a conducting foil where the emitter and base contacts are directly soldered or glued [8,19]. With this MWT-PUM technology, an efficiency gain of 0.6-0.8% absolute has been demonstrated on full module size due to lower metallization coverage and less resistance losses after interconnection [9,10]. Moreover, the modular metallization pattern around the holes makes it very easy to adapt the PUM concept to larger cell sizes without loosing in the FF.

### 3 PROCESS DEVELOPMENTS TOWARDS ASPIRE

#### 3.1 Different cell concepts

Figure 2 shows four different cell concepts that are currently under investigation at ECN.

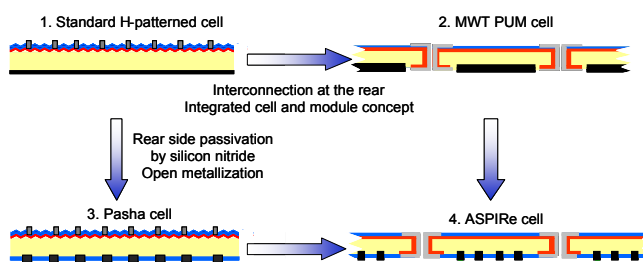


Figure 2: different solar cell concepts

1. The first one is the well known 'standard' H-patterned mc-Si solar cell with a full aluminum rear surface. This cell concept is used by almost all PV manufacturers since it is quite straightforward and enables reasonable cell efficiencies. The standard H-patterned concept relies on both front and rear contacting into strings for module manufacturing. When the wafers become too thin, the cells will start to bow after the high temperature 'firing' step due to differences in thermal expansion. This, especially in combination with the stringing of cells into modules, will increase the chance of breakage for thinner and larger wafers.
2. To increase the current, and enable all rear side interconnection of the solar cells, the so-called 'PUM' MWT cells were developed at ECN [1,14]. The emitter contacts are led towards the rear through 16 holes (for 156x156 mm<sup>2</sup> sized cells). The front metallization is modular in design around the holes and there are no busbars necessary, reducing the metallization (shadowing) fraction by 2-3%. Furthermore, the complete rear side interconnection enables simple 'picking and placing' of the cells into a conducting foil [17], which reduces the chance of breakage considerably during module manufacturing.
3. To reduce the bowing and increase the efficiency of solar cells, the full aluminum rear surface has to be replaced by a better passivating rear surface layer with open rear metalization. At ECN we successfully tested SiN<sub>x</sub> passivating layers on the rear side of standard H-patterned solar cells [1]. A gain in  $J_{sc}$  of ~ 3% relative has been realized for 125x125 mm<sup>2</sup> wafers showing the potential of this concept.
4. Combining the two new ECN cell concepts, we arrive at the ASPIRe cell concept: All Sides Passivated and Interconnected at the Rear (figure 3) In this cell, the advantages of all rear side interconnection and reduction of shadow losses are combined with those of a passivated rear surface with open Al metalization. This concept will enable both higher efficiencies and easier module manufacturing [1].

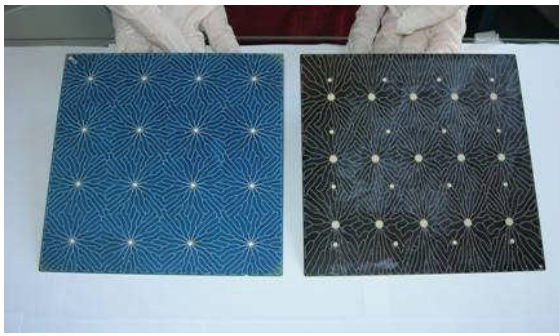


Figure 3: ASPIRe front and rear side

In the next paragraphs, the optimization of the PUM concept, and the development and optimization of the ASPIRe cell concept are described in more detail. The development towards the rear side passivated solar cells is already extensively discussed in previous publications [1].

### 3.2 H-pattern towards PUM

The processing of the PUM cells is very similar to the standard H-pattern processing, except for the laser drilling of the 16 MWT holes, the application of a different metallization pattern including printing Ag inside the holes, and hole isolation after the co-firing step. The flow charts of the two cell types are shown in figure 4, with the additional steps for PUM indicated in red italics.

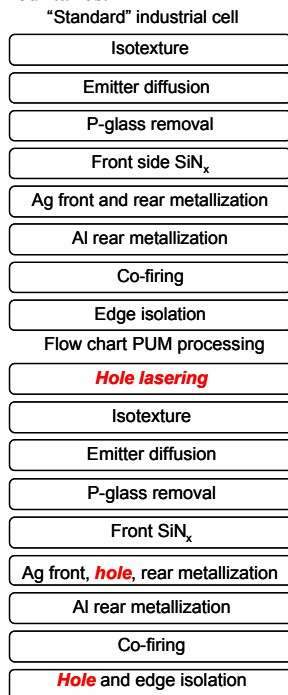


Figure 4: flow charts of a 'standard' and a PUM cell

The comparison between H-pattern cells and PUM cells is to be treated with delicacy. The only reliable comparison – especially with respect to the fill factor - can be achieved after interconnection or lamination of single or more cells. In previous publications, we have shown [9,10] that after interconnection and lamination PUM results in about 0.6-0.8% higher absolute efficiency than conventional H-pattern modules. In figure 5, modules of standard H-pattern cells and PUM cells are shown, together with the IV results.



	$I_{sc}$ (A)	$V_{oc}$ (V)	FF	$\eta$ (%)	$P$ (W)
H pattern	7.66	22.3	.720	15.2	123
PUM	7.86	22.3	.733	15.8	128

Figure 5: comparison of standard H-patterned and PUM cells on module level

Recently, PUM processing has been improved even further. The processing of the metallization inside the holes has been optimized, yielding a much more stable processing and fill factor. Instead of applying metallization only on the edges of the holes, a 'plug' paste was used which completely fills the holes. The improved FF is shown in figure 6. The reference group has been processed in the 'old' way. The plug paste clearly improve both the absolute value (by 1.4% absolute) and the standard deviation of the FF. The  $J_{sc}$  and  $V_{oc}$  values for the PUM cells processed with the plug paste are similar to those of the reference group, which resulted in an improved efficiency of 0.2% absolute compared to the reference. The more stable and higher FF can ascribed to a more constant amount of conducting paste that is printed in the hole, as the hole is always filled completely. More details can be found in the poster presentation and paper 2CV.5.55 [20].

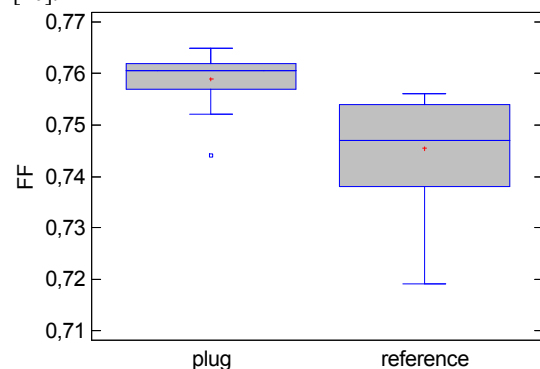
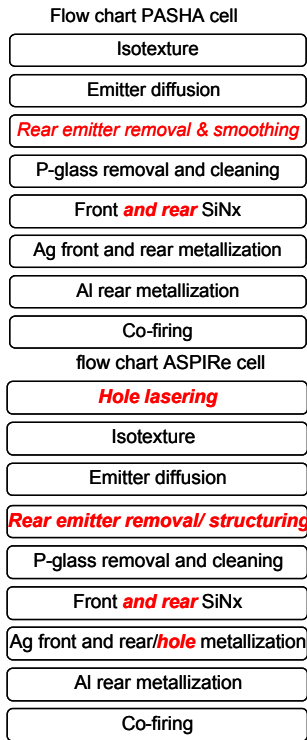


Figure 6: FF for groups of neighboring PUM cells. The reference group has been processed in the 'old' way.

### 3.3 PUM towards ASPIRe

Processing our rear side passivated solar cells – either H-patterned or MWT ASPIRe– is again very similar to the standard mc-Si H-patterned or PUM cell processing. In figure 7 the flow diagrams for our H-patterned open rear side cells (PASHA) [1,21] and ASPIRe are shown.



**Figure 7:** flow charts of the rear side passivated cell concepts PASHA and ASPIRe. Steps that differ from the standard H-pattern processing are indicated in red italics. Note that for neither concept laser isolation is needed after the co-firing step.

After diffusion, the rear side emitter is removed and the rear surface is polished to enable better surface passivation by the silicon nitride. A single SiN<sub>x</sub> layer, which is optimized for maximal passivation is applied on the rear side, after which the ‘standard’ anti-reflection coating is applied on the front side. Metallization is applied on the front and the rear side, and inside the holes for ASPIRe, after which the contacts are formed in a single firing step. In the case of ASPIRe, special care has to be taken that the emitter contact inside the holes and on the rear surface do not cause any shunts. As can be seen from the flow diagrams, no additional laser processing is necessary for the isolation.

#### 4 PROOF OF CONCEPT AND OPTIMIZATION OF ASPIRE

##### 4.1 IV results of different cell concepts

At the previous conference, we already presented 125x125 mm<sup>2</sup> bifacial cells with an increase of almost 3% relative in J<sub>sc</sub> compared to full Al reference cells. The optimization towards larger (156x156 mm<sup>2</sup>) Pasha cells is still ongoing [19].

The first ASPIRe cells were processed in January 2007. At the Milan conference the first results were presented, with cell efficiencies up to 15.9% on 160 μm thin material. On thinner (130μm) material, unfortunately of lower quality, 15.5% efficiency has been reached.

Recently several batches of wafers, all of 156x156 mm<sup>2</sup> and 180 μm thin neighboring material, were processed into ASPIRe cells. At this point, the rear side pattern of the ASPIRe cells is not optimized yet. Especially the series resistance in the aluminum lines

results in a lower FF. For the ASPIRe cells discussed in this paragraph and shown in table 1 and figure 8, we exclude the influence of the high series resistance by shorting the rear aluminum lines. In this way a better comparison can be made between the cell parameters of PUM and ASPIRe. Of course, a real comparison should be made on module level [10].

The first two batches yield an average efficiency of 15.8% and 15.6%. PUM reference cells had a higher average efficiency of 16.0, mainly due to a higher FF (see table 1) even though the rear aluminum of the ASPIRe cells has been shorted. This indicates that also other aspects of the rear ASPIRe pattern like aluminum line distance and line width should be optimized further.

By applying a better and more homogeneous texturization on the ASPIRe cells, average efficiencies of 16.1%, with a maximum of 16.4% were reached on a third neighboring batch. The results of the PUM and ASPIRe cells are summarized in table 1.

cell	J <sub>sc</sub> (mA/cm <sup>2</sup> )	V <sub>oc</sub> (mV)	FF (%)	Eta (%)	J <sub>sc</sub> *V <sub>oc</sub>
PUM avg	33.7	616	77.1	16.0	20.8
max	33.8	619	77.3	16.2	20.9
ASPIRe 1	33.6	616	76.3	15.8	20.7
max	33.7	617	76.7	15.9	20.8
ASPIRe 2	34.5	616	73.5	15.6	21.3
max	34.7	619	74.3	15.9	21.5
ASPIRe 3	35.1	618	74.4	16.1	21.7
max	35.4	622	75.1	16.4	22.0

Table 1: Average and maximum IV results for the ASPIRe and PUM solar cells. Average values were taken over 10 (ASPIRe 1) or 7 (ASPIRe 2 and ASPIRe 3) cells.

##### 4.2 Discussion of IV results

As can be seen from table 1 and figure 8, the J<sub>sc</sub> and V<sub>oc</sub> considerably improved for the subsequent ASPIRe batches. This is partly due to a more controlled processing as we gained more experience with ASPIRe processing over time. For a larger part, this is due to a decreased line-width for the rear side Al pattern in batch 2 and 3 compared to batch 1. The total coverage of rear side Aluminum decreased from 17-20% in the first batch towards ~10-12% in the second and third batch. To enable this, both the line width in the printing screen was decreased and a better firing through aluminum paste was used. However, while the FFs for the first batch were reasonable good (although still lower than those of the PUM reference) for the second and third batch the values are lower. The decrease in line-width causes a higher R<sub>series</sub> on the rear side which is directly reflected into the FF.

While the FF drops, J<sub>sc</sub> and V<sub>oc</sub> increase for narrower aluminum lines. This can be seen when ASPIRe batches 1 and 2 are compared. This is expected, since the passivation obtained with the silicon nitride coating is better than the passivation by the fired through local Al back surface field (BSF).

For group 3, a better texturization was used on the front side. Besides yielding both a higher J<sub>sc</sub> and a higher V<sub>oc</sub>, also the FF improved probably due to a more homogeneous surface.

Detailed analysis on the PUM and ASPIRe cells, such as IQE and PC1D analysis, should still be done.

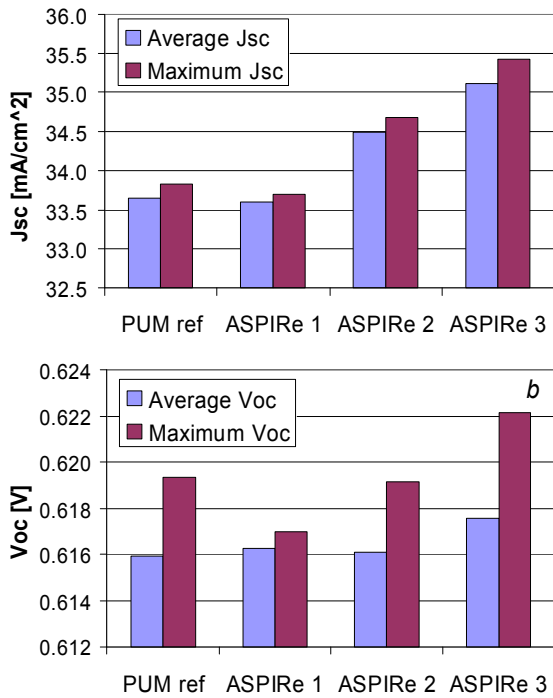


Figure 8:  $J_{sc}$  (a) and  $V_{oc}$  (b) of the different PUM and ASPIRe cells

#### 4.3 Further optimization of ASPIRe

The main bottleneck to obtain higher efficiencies for the ASPIRe cells is optimizing the FF and the rear side passivation ( $J_{sc}$  and  $V_{oc}$ ) at the same time.

A first, important, step is to improve the conductivity of the lines/fingers of the rear side pattern. In this way the FF can be improved without changing the metallization fraction on the rear side. Research on this topic is currently ongoing at ECN.

To optimize the rear side metallization pattern, by using for instance shorter lines to the rear contact points while keeping the metallization fraction the same, a 2D cell simulation program is being developed at ECN. The first calculations resulted in 4 new rear side patterns for the ASPIRe cells. The reference pattern 1 has 15 base contact points, and around 13% metallization. Pattern 2 and 3 have 25 base contact points, with 15% and 23% metallization. Pattern 4 and 5 have 64 base contact points, again with 15 and 23% metallization. The  $V_{oc} \cdot J_{sc}$  and FF results for ASPIRe cells using the different rear side aluminum patterns are shown in figure 9a and 9b. In this case, the IV and FF results are shown without shorting the rear aluminum fingers, to better see the effect of the changes in the pattern. Note that these ASPIRe cells were made on wafers of lower material quality than those described in paragraph 4.1 and 4.2

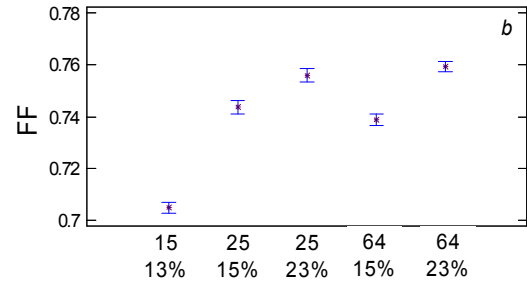
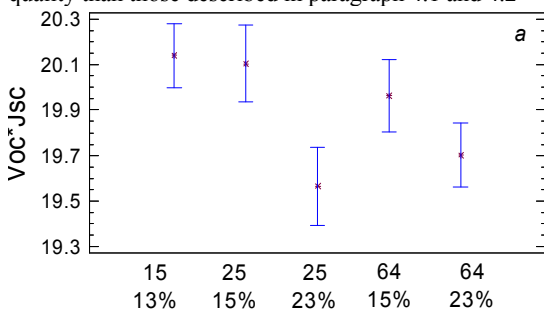


Figure 9:  $V_{oc} \cdot J_{sc}$  (a) and FF (b) results for different rear side patterns of the ASPIRe cells. On the x-axis the number of base contact points and the metallization percentage are mentioned. Pattern 1 is the original pattern, 2-5 are the newly calculated patterns

Even though the metallization fraction didn't increase a lot between pattern 1 and 2, the FF improved by more than 3% absolute while  $J_{sc} \cdot V_{oc}$  remained similar. This resulted in an efficiency gain of 0.8% absolute (more than 5.5% relative). The highest average efficiencies were obtained for pattern 2 (reasonable FF and good  $J_{sc} \cdot V_{oc}$ ) and 5 (lower  $J_{sc} \cdot V_{oc}$  but good FF), as can be seen in figure 10. Further optimization of the ASPIRe rear side metallization pattern is ongoing.

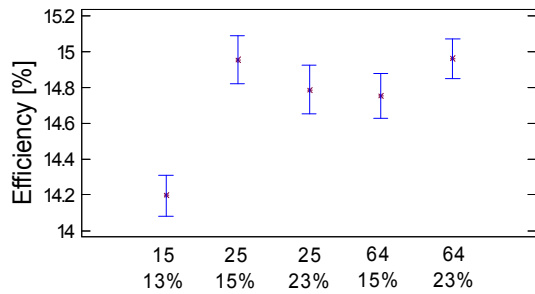
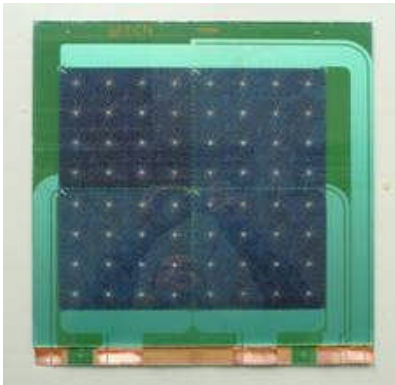


Figure 10: Efficiencies for ASPIRe cells with different rear side patterns. On the x-axis the number of base contact points and the metallization percentage are mentioned.

Additional efficiency gain will be achieved by improving the formation of the local BSF below the aluminum lines. In that case, a higher metallization fraction (like pattern 3 or 5) could be allowed and still result in high  $V_{oc} \cdot J_{sc}$ . Achieving a FF of 77% while keeping  $J_{sc}$  and  $V_{oc}$  the same, will result in efficiencies of 17 % for ASPIRe cells similar to those in batch 3.

## 5 MODULE MANUFACTURING

The ASPIRe cells will be interconnected into modules, either by soldering or by gluing the rear contacts onto conducting foils. A first batch of 130  $\mu$ m thin ASPIRe cells has been interconnected successfully into a module using the new ECN pilot line for rear contacting cells into modules [19]. Although the efficiencies were not optimal yet, the yield was 100%, no breakages occurred for the ASPIRe cells. To test the strength of the interconnection of ASPIRe cells into a module, either by soldering or by gluing, the ASPIRe cells have been tested in our climate chambers. The first 2x2 laminates of 160  $\mu$ m thin ASPIRe cells have been made and are currently being tested in our climate chambers (figure 11).



**Figure 11:** 2x2 laminate of 160  $\mu\text{m}$  thin ASPIRe cells for climate testing

## 6 CONCLUSIONS

In this paper we presented the development at ECN from standard H-patterned cell processing towards our rear side passivated PUM cell, the ASPIRe cell. The ASPIRe cell combines the properties for enhancing efficiencies of the MWT PUM concept and the PASHA cell concept. Proof of concept for the ASPIRe cell concept has been given, and several batches of ASPIRe cells were processed. Efficiencies similar to the PUM cell were reached. The highest efficiency obtained so far for ASPIRe cells is 16.4%. A first optimization of the aluminum rear side pattern was performed for ASPIRe, yielding 3% absolute higher FF for the same  $J_{sc}$  and  $V_{oc}$ . In the future, this pattern will be further optimized towards values of 77%, and efficiencies of 17% for ASPIRe cells will be within reach.

## 7 ACKNOWLEDGEMENTS

This work was financially supported by the FP6 European Crystal Clear project (EC contract SES6-CT-2003-502583) [22] and by the Dutch Senter Novem project StarFire (EOS-ES program project IS063024) [23]. All project partners are gratefully acknowledged for their helpful discussions and fruitful collaboration. Solland Solar Energy BV is acknowledged for using the front side metallization pattern of the ASPIRe and PUM cells

## 8 REFERENCES

- [1] I. G. Romijn et al., proceedings 22<sup>nd</sup> EPVSEC, Milan, September 2007; proceedings 21<sup>st</sup> EPVSEC, Dresden, September 2006
- [2] C. J. J. Tool et al., Solar Energy Mat. and Solar Cells 90, 2006, 3165-3173
- [3] L. Janssen et al., Progress in Photovoltaics: Res and Appl 15, 2007, 469-475
- [4] M. Hofmann et al., Proceedings 21<sup>st</sup> EPVSEC, Dresden, September 2006
- [5] G. Agostinelli et al., Proceedings 21<sup>st</sup> EPVSEC, Dresden, September 2006
- [6] P. Choulat et al., Proceedings 22<sup>nd</sup> EPVSEC, Milan, September 2007
- [7] M. Kaes et al, Proceedings 22<sup>nd</sup> EPVSEC, Milan, September 2007
- [8] J. H. Bultman et al., Proceedings WCPEC-3, Osaka 2003

- [9] P.C. de Jong et al., Proceedings 19<sup>th</sup> EPVSEC, Paris, 2004, 2145
- [10] A. W. Weeber et al., Proceedings 21<sup>st</sup> EPVSEC, Dresden, September 2006, 605; IEEE WCPEC-4, Waikoloa, Hawaii, mei 2006
- [11] E. E. Bende et al., proceedings 33<sup>rd</sup> IEEE Spec. Conf., San Diego, USA, 2008
- [12] [www.sunpowercorp.com](http://www.sunpowercorp.com)
- [13] [www.adventsolar.com](http://www.adventsolar.com)
- [14] E. van Kerschaver, et al., Proceedins 2nd World Conference on PVEC, Vienna, 1998, 1479
- [15] E. Van Kerschaver, et al., Proceedings 29th IEEE PV Spec. Conf., New Orleans, USA, 2002, 78
- [16] H. Knauss et al, Proceedings 31<sup>st</sup> IEEE, Orlando, USA, 2005
- [17] F. Clement, et al., Proceedings 22<sup>nd</sup> EPVSEC, Milan, September 2007
- [18] [www.photovoltech.be](http://www.photovoltech.be)
- [19] M. Spath at al, Proceedings 33<sup>rd</sup> IEEE Spec. Conf, San Diego, USA, 2008; This conference
- [20] A. A. Mewe, this conference
- [21] I. Cesar, this conference
- [22] G. Beaucarne et al., this conference
- [23] M. N. van den Donker, this conference