29th European Photovoltaic Solar Energy Conference and Exhibition,
Amsterdam, the Netherlands, 22-26 September 2014

AN OVERVIEW OF DEVELOPMENTS IN FOIL-BASED BACK-CONTACT MODULES

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ABSTRACT: Back-contact modules made using a conductive back-sheet foil have a number of advantages over conventional H-pattern modules including a higher power output, compatibility with very thin cells and efficient and high yield manufacturing. In this paper, we present the results of efficiency and material optimisation for cost reduction when using metal-wrap-through (MWT) cells. This includes the use of an aluminium conductive back-sheet, a thinner encapsulant for reduced conductive adhesive consumption and an increased number of vias in the cell. Experimental and modelling results show that the cell and module performance can be improved at a reduced module costs (4% lower than current cost of MWT modules) whilst retaining reliability.
Keywords: Metal wrap-through cell, back-contact module, cost reduction

1 INTRODUCTION

ECN has developed an integrated module technology for back-contact cells, in particular MWT cells, using a conductive back-sheet foil based on a copper conductor. The adhesive is cured during the lamination process resulting in a low-stress interconnection making the module technology suitable for very thin cells. The modules have been shown to reduce cell to module losses when compared with conventional modules resulting in 5% higher power output. MWT modules have proven to be reliable in climate chamber testing and IEC certification has been achieved by several partners [1-4]. Manufacturing equipment is available which has a very high level of automation. The first industrial production has recently started [5].

Large scale industrial implementation of this module technology requires availability of the materials at low cost, in particular the conductive back-sheet and the conductive adhesive. The cost of the back-sheet is partially related to the processing used to pattern the foil and partly to the cost of the copper conductor. The cost of the conductive adhesive is dominated by the silver content.

In this article a number of strategies for reducing the cost of back-contact modules will be presented including the use of aluminium as the conductor, reduction of conductive adhesive consumption by reduction of the encapsulant thickness and increasing the number of vias in the cell to improve current collection. Experimental and modelling results will be used to show that it is possible to improve the efficiency of the back-contact module at a reduced cost making the technology more than competitive when compared to conventional modules. This module technology is also suitable for thin wafers and other back contact concepts such as IBC, allowing for even further efficiency enhancements, cost reductions and future developments.

2 CURRENT DESIGN OF BACK-CONTACT MODULES AND MWT CELLS

The back-contact module technology developed by ECN uses a conductive back-sheet foil and conductive adhesive for interconnection of back-contact cells (see Fig. 1). The conductive back-sheet foil consists of a sheet of copper laminated to a PET-PVF laminate as used in conventional modules. The copper is patterned to match the contact pattern on the rear side of the MWT cells. During the module manufacturing process, the conductive back-sheet foil is fixed to a vacuum carrier after which conductive adhesive dots are stencil printed at positions corresponding to where the contact pads of the cells will be positioned. Next, a sheet of perforated EVA is placed on the back-sheet with the openings in the EVA corresponding to the position of the conductive adhesive dots. The conductive adhesive dots have a height greater than the EVA thickness. The cells are then placed on the stack, so making contact with the conductive adhesive. The stack is finished with a second sheet of EVA and a glass sheet. The stack is then inverted and laminated to cure the adhesive and EVA in one step.

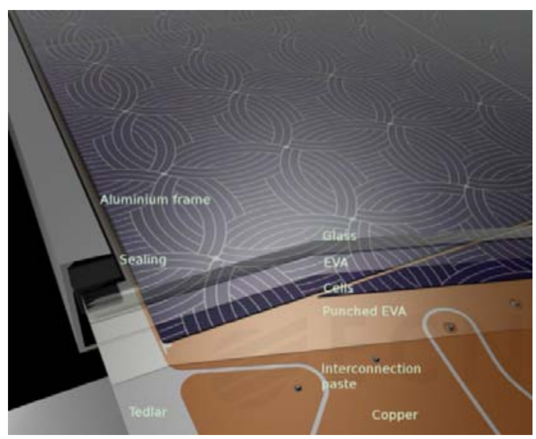

Figure 1: Cross-section through a back-contact module showing the patterned copper layer in the conductive back-sheet, the interconnection paste (i.e. conductive adhesive), the EVA perforated at the position of the interconnection paste and the MWT cells

The present design of the MWT cell consists of a 4x4 grid of vias that connects the front metallisation grid with contacts on the rear of the cell. The vias are made with a laser. The rear of the cell is contacted by 3 rows of 5 contact points positioned between the front contacts. The front side metallisation pattern is optimised for the highest conductivity with lowest coverage area. This balances the fill-factor and current generation of the cell. The performance advantage of this cell relative to conventional cells has been shown for both p-type multicrystalline cells [6] and for n-type mono-crystalline cells [7]. Typically an absolute improvement of 0.1% to 0.3% in cell efficiency is measured.

3 REDUCTION OF BACK-CONTACT MODULE COSTS

3.1 Use of aluminium in the conductive back-sheet

Replacing the copper layer in the conductive back-sheet with aluminium has the potential to reduce the overall cost of the module by over 2%. The difficulty of aluminium is the presence of a native oxide on its surface making the contact resistance to the conductive adhesive unacceptably high. ECN has implemented a cold-spray technique by which copper particles are applied to the aluminium surface at high speed breaking through the oxide and making contact to the bulk aluminium [8]. The conductive adhesive then makes contact to the copper with a low contact resistance (see Fig. 2).

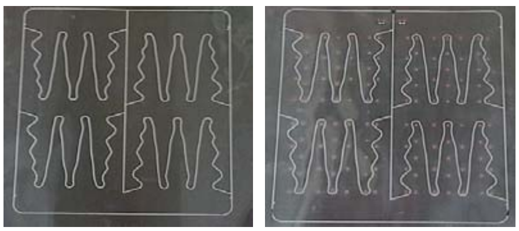

Figure 2: Left, an aluminium based conductive back-sheet patterned for a 4 cell module and right, the same foil with copper contacts applied by cold-spraying

A number of mini-modules containing 4 cells were manufactured using aluminium conductive back-sheet foils with a copper cold-spray contact where the conductive adhesive is applied. These modules were characterised and subjected to climate chamber testing according to the IEC61215 standard with characterisation at intervals during testing.

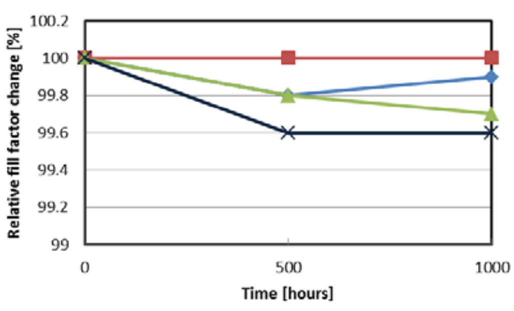

Figure 3: Damp-heat test results for mini-modules. The black line shows the reference module with a copper foil. The green line is a copper foil with copper cold-spray contacts. The red and blue lines are both aluminium with copper cold-spray conductive back-sheet foils. All foils show limited degradation up to 1000 hours in damp-heat (85%RH/85°C)

The results show a similar cell-to-module loss for modules using both copper and aluminium based conductive back-sheets. Characterisation using EL and DLIT shows uniform current transport with no hot-spots in the modules. Climate chamber testing also showed little difference in performance of the modules (see Fig. 3 for an example of damp-heat results). The copper thickness deposited on the aluminium back-sheet foil for these modules was in the order of 20 µm. A second series of foils was manufactured with a copper thickness of just 5 µm. This was found to be sufficient to not affect the contact resistance between the conductive adhesive and the foil. Climate chamber testing of modules made with these foils showed improved performance in thermal cycling results with no degradation after 300 cycles. This is thought to be due to the copper coating being a single layer with this layer not being damaged in any way by the application of further layers.

Further work on aluminium based conductive back-sheet will focus on optimisation of the cold-spray process for further cost reduction and scaling up of the process for manufacture of fill-size module using this process.

3.2 Reduction of conductive adhesive consumption

To allow the conductive adhesive to make contact between the foil and the cells, the encapsulant between the cells and the foil is perforated as described above. The current thickness of the encapsulant used in back-contact modules is 200 µm. This puts a restraint on the minimum height of the printed adhesive dots: they need to be higher than the encapsulant to ensure good contact between the cells and foil. The current stencil used for printing the conductive adhesive has a thickness is 400 µm. The stencil thickness also determines the lower limit of the adhesive dot diameter, presently 1.7 mm. By using a thinner encapsulant, a reduced adhesive height and diameter can be printed whilst still making good contact to the cell and the foil.

An EVA encapsulant was acquired with a thickness of 100 µm and a stencil was made with a thickness of 200 µm. The diameter of openings in the stencil was chosen to be 1 mm based on the ratio of the opening diameter and the thickness of the previous stencils and the viscosity of the adhesives. The reduced thickness of the stencil and opening diameter results in a 70% reduction of adhesive volume per dot printed. Mini-modules with four cells were manufactured using both 200 and 100 µm EVA with their respective stencils. The average cell-to module fill-factor loss for the two different module types was shown to be similar with a relative loss of between 2 and 3% (see Table I).

EVA between cell and foil	EVA between cell and glass	Fill-factor loss
200 µm	200 µm	-2.7%
100 µm	100 µm	-2.8%

Table I: Comparison of average cell to module fill-factor loss for modules made with standard and thin encapsulant. The modules with the thin encapsulant contain a 70% lower volume of conductive adhesive and show the same fill-factor loss. The loss is in line with previous four-cell modules

This is a typical value for mini-modules and indicates that good contact is made between the cell and the conductive foil through the conductive adhesive. Electroluminescence (EL) and dark lock-in thermography (DLIT) images of the modules confirm this result with uniform illumination for the modules made with the thin encapsulant (see Fig. 4).

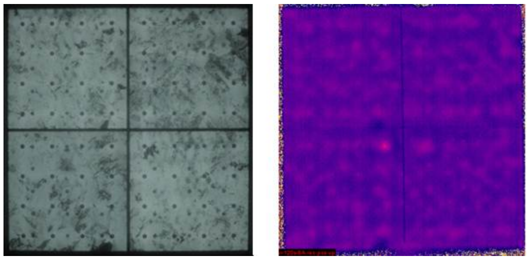

Figure 4: Left, EL image and, right, DLIT image of a four-cell module make with 100 µm thick encapsulant with a reduced volume of conductive adhesive. The images are uniform in colour and similar to images obtained from module made with 200 µm encapsulant and standard volume conductive adhesive contacts

For the current cell design, a reduction in conductive adhesive volume of 70% is estimated to result in an overall cost reduction of close to 2% for the complete module. Further savings are expected by reduction of the silver content in the adhesives. This has been steadily reduced over the past five years from above 80% to the current value of below 20%.

3.3 Increased number of vias in MWT cell

An additional advantage of using an adhesive dot with a reduced volume is that the cost penalty of increasing the number of contact points per cell is limited. Increasing the number of contact points, and so vias, in the MWT cell results in a reduction of current transported through each via. This allows for a reduction in the width of the fingers in the front side metallisation and so a saving in metallisation consumption.

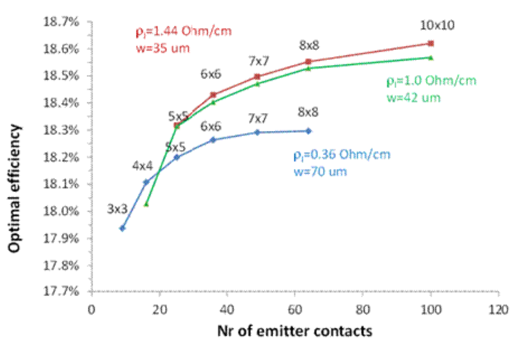

Figure 5: Modelling results for efficiency of MWT cells with an increasing number of vias with different finger widths and line resistances for the front side metallisation. The efficiency of the cell always increases with an increasing number of vias. Higher efficiencies can be achieved with narrower fingers for a higher number of vias

The cell efficiency for an increased number of vias in the MWT cell was modelled for three different line resistances. It was found that increasing the number of vias always results in an increase in the efficiency of the cell independent of the line resistance (see Fig. 5). The narrower (42 and 35 µm) metallisation print shows a higher efficiency for more than 4x4 vias when compared to the current print (70 µm) due to a reduction in shading of the cell. The model was elaborated to include the cost of the conductive adhesive based on the reduced volume as described above. An optimum in €/Wp for the module could be found depending on the line resistance. The results also showed that by moving to a line width of 42 µm, a potential saving of up to 4% could be achieved in module costs in combination with a 6x6 or 7x7 via configuration in the cell (see Fig. 6).

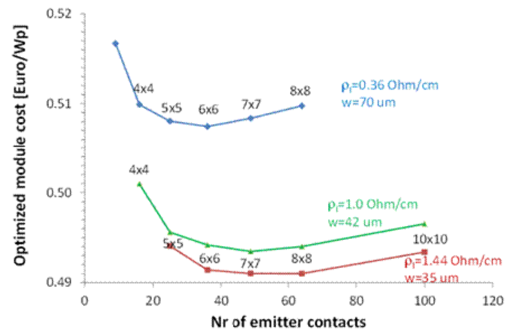

Figure 6: Optimised module cost for MWT cells with an increasing number of vias with different finger widths and line resistances. The reduced adhesive volume is included in these calculations. A cost reduction of close to 4% is predicted by going to a 6x6 or 7x7 via configuration in combination with a reduced finger width

To demonstrate the calculated advantage of MWT cells with an increased number of vias, two series of cells were manufactured using ECN's baseline processes and neighbouring wafers. One of the series was manufactured with 16 vias (4x4 pattern) and a total of 31 contacts with a line width of approximately 70 µm; the second was manufactured with 36 vias (6x6 pattern) with a total of 81 contacts with a line width of approximately 40 µm. The pattern on the front side of the cells was screen printed with the pattern optimised for the respective line widths and number of vias. Mini-modules consisting of four cells were manufactured with these cells. These modules were characterised by IV tracing and EL to determine differences in performance. The results are shown in table II.

Module code	Pattern	Isc	Voc	FF	Cell eff.
A2040	6x6	9.515	2.618	75.27	19.62
A2042	4x4	9.449	2.601	74.92	19.26

Table II: Results of mini-modules manufactured with cells containing 36 (6x6 pattern) and 16 (4x4 pattern) vias. The module efficiency increases by 1.9% by use of cells with an increased number of vias. This is in line with the calculate improvement as shown in Fig. 5

The results show an relative improvement of 1.9% in cell efficiency in the module. This is primarily as a result of a higher short circuit current due to the lower metallisation coverage on the front of the cell. The fill-factor of the module is also higher. This is due to the increased number of contacts to the conductive back-sheet improving current transport from the cell. The efficiency improvements correspond to the modelled improvements as shown in Fig. 5. Combining these results with the reduced thickness encapsulant, and consequently reduced volume of the conductive adhesive paste, will results in the modelled cost reductions as shown in Fig. 6. This will make the back-contact module technology competitive with conventional module technology and also with alternatives such as multi-busbar and multi-wire technologies.

4 CONCLUSIONS

The work presented in this paper summarises a number of strategies for reducing the cost of back-contact modules made using MWT cells. Each of the approaches described contributes significantly to an overall cost reduction of the module. For both the aluminium conductive back-sheet and reduced conductive adhesive consumption, similar performance and reliability are observed when compared to the current back-contact module build. The reduced conductive adhesive consumption allows a further cost optimisation by increasing the number of vias in the MWT cell as shown through modelling. An overall cost saving approaching 10% should be possible by combining the three approaches. This would significantly increase the competitiveness of back-contact modules with MWT cells when compared with conventional modules. The resulting back-contact module could be manufactured at a lower cost whilst achieving a higher power output and high reliability.

In addition, due to the low temperature processing used, further cost reduction could be realised by reducing the wafer thickness of the cells. Modules have been made with cells with a thickness of less than 120 µm with no cell breakage. The module technology is also suitable for incorporation of the next generation of back-contact cells including interdigitated back-contact (IBC) and heterojunction cells.

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