SELECTING OPTIMAL INTERCONNECTION METHODOLOGY FOR EASY AND COST EFFICIENT MANUFACTURING OF THE PIN UP MODULE

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ABSTRACT: Rear contacted solar cells are successfully glued onto an interconnection foil which also serves as the environmental barrier at the rear of the module. Resulting fill factors are similar to cells connected with strips that are soldered and glued. Glued cells are interconnected and laminated in a single step, which reduces labor to a minimum, reduces stress on the cells, and therefore could increase process yield. Considering these advantages, this concept has the potential to interconnect very thin cells without additional stress on the cells.

Keywords: Crystalline silicon - 1: Module - 2: Interconnection - 3

1. INTRODUCTION

An important focus of the PV industry is on increasing process yield. This is extremely important because of the high cost of base materials. One of the limiting process steps is the interconnection of solar cells into a string. This is due to the applied soldering process that is operated at the edge of what is possible. The reason is that there is a need for thick (> 0.15 mm) and narrow (< 2 mm) interconnection material to conduct the large currents and to reduce shadowing losses at the front side. However, stress in the soldered joint due to the difference in thermal expansion coefficients of the strip and silicon limits the thickness of the strips. A maximum thickness of about 0.1 mm is allowed to avoid this stress.
A new trend in the industry is to go to larger and thinner wafers. The first modules with cells of 400 cm2 are on the market, and cells with thickness of less than 300 micron are becoming the standard. In five years, the industry expects to work on wafer thickness of less than 200 micron. Solution of the above described interconnection issue becomes crucial in order to be able to accomodate for large currents and thin wafers that will be common in a couple of years.
Thick and narrow interconnection material is not required when the material is only at the rear of the cell. This is the case for back-contacted solar cell designs where the emitter and base contacts can be reached from the rear. Using this concept, the width of the interconnection material is not limited because the strips do not cause any shadowing.

In [1], we have introduced a back-contacted solar cell design with a limited number of holes in the wafer. These holes serve as vias for mechanical and electrical connection to an interconnection foil at the rear side based on expired patents [2,3]. A module interconnected in this way is named PUM (Pin Up Module). The cell has basically the same structure as a conventional cell. Metallisation is present on both front and rear side. The difference with standard cells lies in the vias and interconnection, see figure 1.

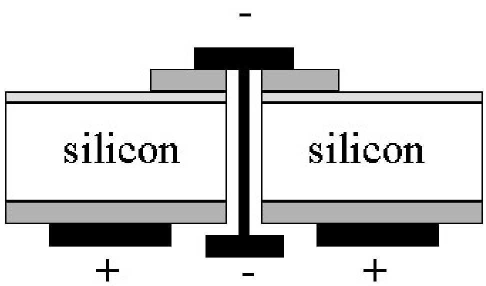

Figure 1: Cross section of a PUM cell. Light shading indicates emitter, dark shading indicates metallisation, strips are black.

Advantages of the PUM concept are:
1. The cell design allows for back-contacting and larger wafers can be used without interconnection problems and additional resistance losses in interconnection material.
2. Shadow losses due to front side metallisation are reduced because busbars for the interconnection are omitted, see figure 2.

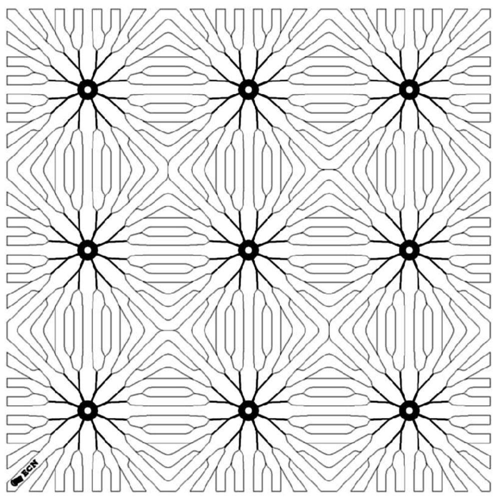

Figure 2: Metallisation pattern for a PUM cell

3. Resistance losses are reduced because current is collected at holes equally spaced over the wafer. For standard cells, current is collected at two busbars.
4. The packing density of cells in a module can be much higher (close to 100%) than for standard cells, because strips weaving between cells for series connection are omitted.
5. The only additional process step is production of a limited number of holes in the wafers. Cell processing is identical to that of standard cells. Any manufacturer can change to the PUM design immediately.
6. PUM is visually more appealing than conventional modules.

For large wafers of 400 cm^2, the improved design and interconnection of PUM leads to a large gain in efficiency of 1.4% absolute compared to standard cells interconnected with two strips.
Several methods have been introduced and tested for manufacturing of PUM. The purpose of this work is to quantitatively and qualitatively compare these methods and conclude which method is best suited for mass production of low cost Pin Up Modules.

2 PUM INTERCONNECTION METHODOLOGIES

In this paragraph, the possible ways to interconnect PUM cells will be discussed. First, two possible cell types will be presented. Second, several interconnection designs will be descibed. Third, interconnection technologies will be discussed, and fourth, the materials will be presented. Based on all these, the best possible ways to interconnect PUM cells will be selected for detailed study.

2.1 Cell designs for rear-contacting

The basic principle of the PUM cell is that the interconnection is established through holes, as is shown in figure 1. A more sophisticated concept is that the metal contact of the emitter is at the rear. This means that the emitter and the emitter contact should go through the hole to the rear side. This is the so-called front side metallisation wrap through cell, first introduced in [4]. This concept is shown in figure 3. The cell process is somewhat more complicated because a local emitter has to be formed on the rear side and the metal contact has to be formed in the hole. The latter can be done by screen printing a metal paste through the hole. This is an established process in the printed circuit board industry. An even more elaborate process is the Emitter Wrap Through design, for which all metal on the front side is omitted and more then 1000 holes per cell are needed.

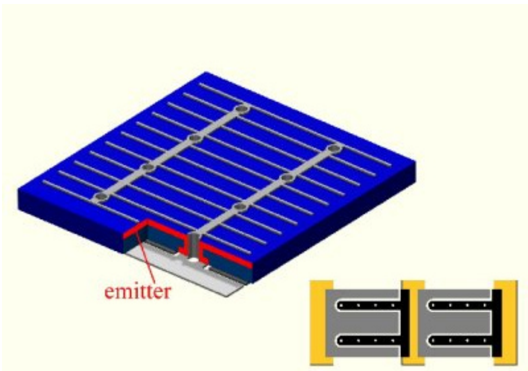

Figure 3: Front side metallisation wrap through cell. Emitter as well as metal contact to the emitter are lead through the holes in the cell.

2.2 Interconnection designs

In Figure 4, the basic principle of PUM interconnection is shown. Interconnection material is positioned at the rear of the cell, and the emitter contact and base contact are in some way connected to this material. There are several ways to establish this contact:

1. Pins are made on interconnection strips, which are positioned and connected on to the emitter and base contact. Each cell is in this way connected and cells are stringed in a similar fashion as standard cells. The advantage compared to standard cells is that thin and wide strips can be used. In Figure 5, this method is explained in more detail. The emitter contact strip and base contact strip are positioned on top of each other with isolation in between.
2. Pins are made on the interconnection material as in the previous way, but now these pins are positioned on a foil, see Figure 6. This method has the extra advantage that all interconnections are prepared before cells are positioned on the foil. Therefore, cells will be perfectly aligned by the pins on the foil and during lamination, and cells remain well aligned because they are fixed to the foil. Normally, cells can float on top of the molten EVA during lamination, which might lead to poor alignment.

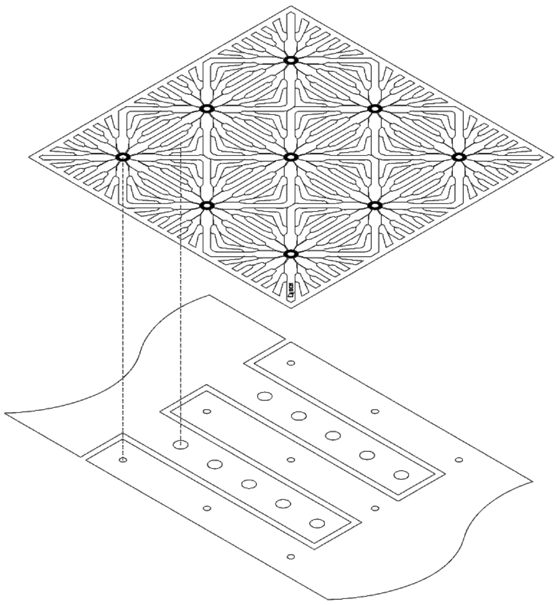

Figure 4: General principle for interconnecting a PUM cell

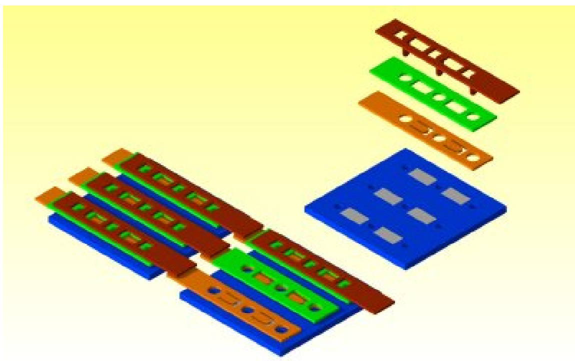

Figure 5: Stamped tab material to interconnect to emitter and base contact. Green material is to avoid shunting between base and emitter contact.

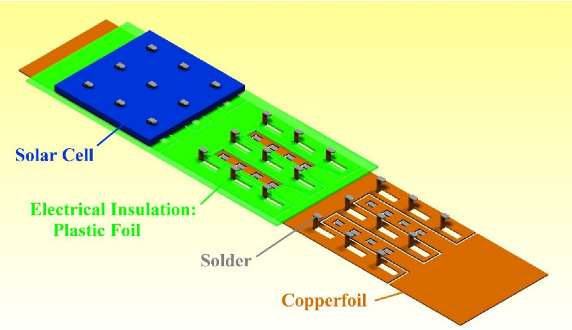

Figure 6: Stamped metal foil laminated with a plastic foil

3. The interconnection is made using a metal foil which is produced according to the design as presented in figure 4 and laminated with plastic. Instead of making the interconnection with stamped pins, now the interconnection is made by an additional metal that forms a connection between the metal contact on the cell and the metal foil. For example, this could be a conductive adhesive or solder.

2.3 Interconnection methods

Several ways to establish the mechanical and electrical contact between the interconnection material and the cell could be used. In this paper, we will only describe three ways:

1. Soldering: A tin based solder is molten by applying heat (temperatures between 250-400 ^{o}C). The molten solder wets the metal contact and the interconnection material. Upon cooling, the solder becomes solid, establishing a fixed contact between the cell and the interconnection material. In general, metal contacts on silicon solar cells are made by applying a silver paste onto the cell followed by sintering. The metal contacts produced in this way are very porous. Therefore, a rather thick layer of solder of about 10 microns needs to be used.
2. Glueing: A silver based conductive adhesive is applied between the metal contact on the cell and the interconnection material. The adhesive is cured in a furnace (anywhere between room temperature and 200 ^{o}C) and takes much longer than the soldering process. Glueing is not applied for interconnecting standard solar cells, because the initial mechanical contact is very weak until curing. So, handling uncured connected cells in a string is impossible. Glueing has the important advantage of much lower process temperatures compared to soldering. Important for establishing a good contact is the used material and surface treatments. At this moment, only conductive adhesives are available that lead to stable contact on silver. Currently, we are working on making a good contact on alumium foil.
3. Thermal spraying of liquid metal powder: Metal powder is heated for instance with a thermal arc and sprayed on the surfaces that need to be joined. The advantage is that a very good mechanical adhesion can be achieved on the porous metal contacts and that temperatures of cell and interconnecting material remain low. Of course, both materials need to be reached by the particles at the same time. Spray-on of liquid metal is not used in solar cell interconnection because a very well aimed beam is necessary on the front side of the cell to avoid metal particles on the front surface of the cell.

2.4 Interconnection materials

Standard interconnection material are tinned copper strips of around 150 micron with a solder finish of at least 10 micron. Other possibilities for interconnection materials are metal foils, either from copper or aluminium, of thickness around 25-50 micron. These foils can be laminated to plastic foils, for instance as used for the back side foil of the module, based on PVF, PET, and aluminium.

2.5 Selection of potential PUM interconnection schemes

Using the overview of cell types, interconection designs, interconnection methods, and materials, the following PUM concepts are selected for further research:

1. PUM cells connected to a full area punched tinned copper foil which is mounted on a polyester insulating foil. The cells are interconnected using standard soldering techniques.
2. Single PUM cell tabbing with tinned copper tabs with an electrically insulating layer on the cells, which is interconnected using standard soldering techniques.
3. PUM cells mounted on an etched aluminium/polyester foil and interconnected using thermal spraying, see figure 7.

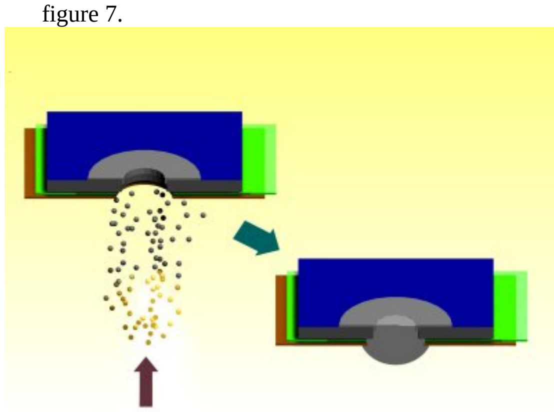

Figure 7: Thermal arc spraying of metal particles to form a mechanical and electrical connection of the metal foil and the PUM cell.

4. MWT cells mounted on an etched and locally silver plated aluminium/polyester/PVF foil (replacing the back sheet foil) and interconnected using conductive adhesives.
5. MWT cells connected with silver plated tabs using conductive adhesives.
6. MWT cells connected with tinned copper tabs using soldering.

3. EXPERIMENTAL RESULTS ON PUM LAMINATES

Several one-cell and four-cell laminates have been made according to the six methods described in 2.4. First, we will present the results of PUM cells soldered onto a punched metal foil compared to PUM cells that are thermally sprayed onto a metal foil. The results are compared to soldered standard cells. In Table 1 and Figure 8, fill factor decrease, relative to unsoldered cells, is presented, for standard cells, for PUM cells which are soldered and for PUM cells which are arc sprayed, each consisting of a batch of 5 laminates. Decrease in fill factor during interconnection and lamination of cells into modules is a measure of how well an interconnection methodology works.

These results show that a fill factor reduction occurs for all laminates compared to the fill factors of the individual cells. The reduction in fill factor is smallest for the soldered PUM cells, either with a punched foil (method 1) or with preformed tabs (method 2).

A large fill factor reduction occurs for the thermally sprayed laminates. A large change in diode currents occurs, whereas the series and shunt resistances remain constant. It seems that the impact of metal particles has an influence on the cell quality.

All MWT laminates show a relatively high fill factor loss. Also, a large spread in fill factors occur. A poor metallisation in the hole leads to a variation of about 2%. For each technique, the best fill factors are similar. More work is needed to improve the reproducibility of the glued interconnections.

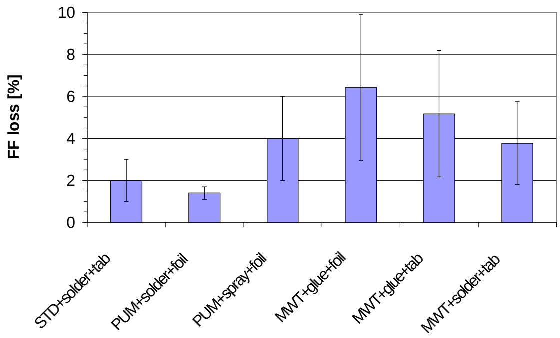

Figure 8: Relative fill factor decrease for a small sample of laminates compared to the cell results for standard cell laminates, soldered PUM cell laminates, thermally sprayed PUM cell laminates, glued MWT cells on foil, and with tabs, and soldered MWT cells with tabs.

Table I: Relative fill factor decrease for a batch of 5 laminates compared to the cell results for standard cell laminates, soldered PUM cell laminates, and arc sprayed PUM cell laminates glued MWT cells on foil, and with tabs, and soldered MWT cells on tabs.

Scheme	Cell type	Connection method	FF decrease [%]
-	STD	Solder	2.0 +/- 1.0
1,2	PUM	Solder	1.4 +/- 0.3
3	PUM	Arc	4.0 +/- 2.0
4	MWT	Glue	6.4 +/- 3.5
5	MWT	Glue	5.2 +/- 3.0
6	MWT	Solder	3.8 +/- 2.0

DISCUSSION

Almost all PUM concepts show similar fill factor losses due to interconnection and lamination. Only thermal spraying is not a good alternative due to the reduction of cell performance. To make a choice amongst the remaining concepts will therefore be based on the total costs, process stability, durability, development costs, and synergy with future developments in cell manufacturing.

Regarding the manufacturing process of interconnection, the highest process yield can be reached using “non-contact” interconnection techniques at low temperatures. Conductive adhesives are then the best suited process, and have the highest potential to be able to incorporate ultra-thin wafers in future manufacturing processes. Conductive adhesives are a slow curing process compared to soldering and can not reach the same process speed as with soldering. Therefore, a combination of lamination and curing is essential for conductive adhesives to be applied successfully. This can only be achieved for the MWT cells glued onto an interconnection foil, which also serves as the module back sheet.

CONCLUSIONS

Future trends in PV technology are to larger cells and thinner wafers. These trends force us to change to a new interconnection methodology, that poses no problem at currents of 10 A and introduce very little stress. Standard soldering technology has to be avoided. Then, the best interconnection methodology is when the back sheet material is combined with a conducting foil, and the interconnections are made with a “non-contact” method like applying conductive adhesives, cured in one cycle combined with lamination. This is only possible with a back-contacted cell concept. First results of back-contacted cells glued onto an interconnection foil are very promising, but further work is needed to improve process reproducibility.

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