A NOVEL MODULE ASSEMBLY LINE USING BACK CONTACT SOLAR CELLS

M. Späth[1], P.C. de Jong[1], I. J. Bennett[1], T. P. Visser[1], J. Bakker[2]
[1]ECN Module Technology, Westerduinweg 3, 1755 ZG Petten, Netherlands
[2]TTA / Eurotron, Van Beukelaarweg 45. 2971VL Bleskensgraaf , Netherlands

ABSTRACT

There is a great need for cost-effective high-throughput equipment to assemble thin and high-efficiency solar cells into modules. Presently, a module assembly line facilitating back-contact solar cells is build by TTA and ECN. This fully operational pilotline consisting of dedicated equipment to process back contact cell modules focuses on the production of 4 x 9 and up to 6 x 10 cells modules.
The emphasis is on the production of modules with ultra thin back contact cells of mc 156 x 156 mm^2 and only 130 µm in thickness. Comprising a throughput rate of 1 cell per second, which is 6-8 times faster than any existing technology, a module production capacity of 100 MWp is targeted for. Processing of the first set of modules shows good results in terms of process reliability and yield. The overall yield for the first series of 23 modules (4 x 9) was 100% while 8 of the remaining 23 modules generated a fill factor of 74%.

1. INTRODUCTION

The current price of PV systems cannot yet compete with consumer electricity prices. A major further reduction of turn-key system prices is essential and possible. At present, the costs of solar electricity are about € 0.50/kWh in North West Europe to € 0.35/kWh in Southern Europe. To reach competitiveness of solar electricity with consumer electricity ("grid parity") in Southern Europe by 2015, PV generation costs of 0.15 €/kWh are necessary. This corresponds to a turn-key system price of 2.5 €/Wp. This system price arises from typical manufacturing and installation costs of below 2.0 €/Wp. Not just very large-scale deployment of PV is needed to meet these ambitious targets. It is essential that manufacturing at very-large scale is developed for innovative low-cost technologies. The module assembly line for back contact solar cells forms a potential break-trough technology for competitiveness of solar electricity. It is expected that this novel module technology enables the route towards drastic cost reduction of solar modules from 2.8 €/Wp today to 2.0 €/Wp in 2010. Up to 0.5 €/Wp can be saved by reducing the wafer thickness to 130µm and assuming that feedstock is available at a competitive price level around 35 €/kg. More than 0.2 €/Wp cost savings are feasible by efficiency gains without significant changes to the cell processing technologies. With back-contact module assembly, most of the benefit arises from the module technology because the resistive losses can be much lower. Up to 5% relative (0.8% absolute) higher module efficiencies can be realized because of lower shading losses and lower losses in the current carrying conductors.

2. OBJECTIVES

The continuous drive for reducing cost of PV electricity has led to three main routes of cost savings relative to state-of-the-art module manufacturing with conventional H-pattern type cells: 1. Reducing the amount of materials; 2. High throughput manufacturing; and 3. Increasing the total-area efficiency of solar modules.

1. Reducing the amount of materials

More than 50% of the costs of a state-of-the-art crystalline silicon photovoltaic module are determined by material costs. It is found that the largest potential for cost reduction is by reducing the wafer/cell thickness. In the past years this trend was accelerated by the high Si-feedstock prices due to its limited availability. PV-manufacturers have responded to this by reducing cell thickness from 330 µm in 2002 to 200 µm in 2007, with a further reduction expected to 130-160 µm in 2010. Currently, the most important bottleneck arises during the module assembly process where individual cells are interconnected by soldering technology. Many of the yield losses occur during this cell interconnection step.

2. High throughput manufacturing

Reducing the cell thickness below 180µm has the consequence that state-of the-art module manufacturing technologies with H-pattern cells are no longer feasible. Massive yield losses will be the result of handling and interconnection process losses. This necessitates the need for new module processes and equipment. For many of the processing steps it holds that the throughput is determined by the amount of wafers per hour that can be processed. So, increasing the surface area of cells and modules automatically leads to an increase of production capacity while the additional material and manpower costs are limited. In the past years the surface area of solar cells has increased from 125 x 125 mm² to 156 x 156 mm², with experimental cells of 210 x 210 mm². Also, module configurations are growing in size. In 2002, a typical module area was 1m² which was composed of 4 x 9 cells. Nowadays, module areas are 1.5 to 1.6 m² and available in 5 x 10, 6 x 9 and 6 x 10 cell matrix configurations. The increasing size of the wafers, in combination with thinner wafers, leads to several processing difficulties. Processing these large and thin wafers to H-pattern solar cells and modules has several drawbacks which result in efficiency losses and/or yield losses:

- Larger cells suffer from increased series resistance as a result of longer metallization fingers on the front side, or will result in increased shading losses, when three bus-bars are applied.
- Larger cells will generate higher currents that will give higher series resistance losses in the interconnection material.
- Using traditional tabbing material might lead to breakage of the thin and fragile cells.
- Soldering tabs will account for highly stressed surface area because of differences in thermal expansion, and so reducing the production yield.
- Using a full aluminum rear-side metallization will result in cell bowing, which may lead to cell breakage during service life.

To overcome these drawbacks, innovative cell designs that have low-cost high-throughput potential are necessary, as well as module assembly equipment to interconnect these cells.

3. Increasing the total-area efficiency of solar modules

Due to the module assembly process, electrical and optical losses will be introduced, resulting in lower module efficiency then the acquired cell efficiency. State-of-the-art multi-crystalline H-pattern cells with 16.5% cell efficiency will generally lead to a total area module efficiency of only 14.0%. Therefore it is necessary to optimize the total area module efficiency.

Developments towards increasing the total-area efficiency of solar modules have mainly led to further investigating the physics of solar cells. However, it is equally important to reconsider the module concept. Developing modules efficiencies beyond 18% will require further integral development of alternative cell- and module technologies. This necessitates the need for new module processes and equipment.

The developing of new module technologies is to narrow the efficiency gap between the solar cell efficiency and module efficiency. Strategy is to drain the current from the cell as quickly as possible into a current carrying conductor which is part of the module process. This leads to a shift of relatively expensive metallization on the cell to relatively cheap metallization in the module. By proper design, resistive losses can be much smaller then with (smart) tabbing which results in module efficiencies that approach the efficiency of the cell. One example is the ECN busbarless MWT cell.

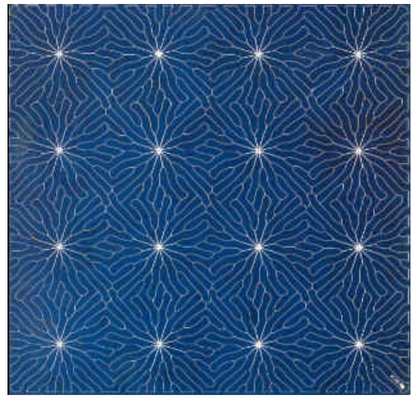

Figure 1. *Metallization Wrap Through solar cell, developed at ECN.*

3. MODULE ASSEMBLY LINE

It is essential that a module technology will be developed to enable to work with these extremely thin and fragile cells. A novel module assembly process, developed by ECN, has the potential to fulfill this requirement containing the following steps: 1) Conductive back-sheet foil comprising an electrical pattern for interconnection of solar cells. 2) Conductive paste deposition on the conductive tracks of the interconnection foil. 3) Placing of a pre-processed sheet of EVA. 4) Solar cell pick and placed unit to connect the cells with the conductive paste. 5) Lay up of an additional EVA sheet and a cover glass plate. Finally, the module lay-up will be laminated in a vacuum laminator while simultaneously forming the interconnections. In this context, a module assembly line is presently build by TTA and ECN to demonstrate manufacturing speed and handling of thin back contacted solar cells. This equipment is capable of assembling modules configured into matrices of 4 x 9 and 6 x 10 using 156 x 156 mm² cells. The module assembly line is designed to support existing cell types such as Interdigitated Back Contact (IBC), Heterojunction with Intrinsic Thin layer (HIT), Emitter Wrap Through (EWT), Metallization Wrap Around (MWA) and Metallization Wrap Through (MWT) solar cells.

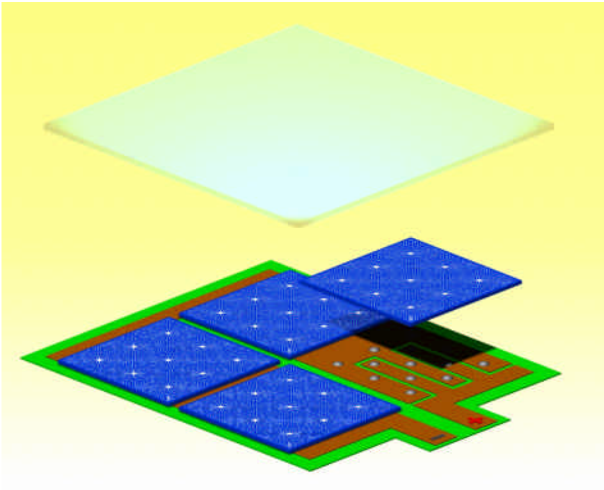

Figure 2. *Back-contact module assembly using MWT solar cells.*

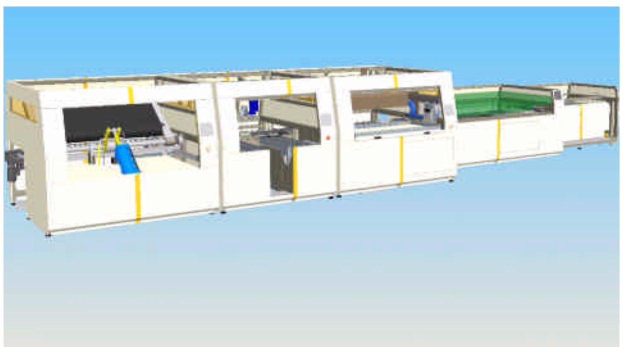

Figure 3. *Outline of the module assembly line using back contact solar cells and conductive back-sheet interconnection foils.*

Based on the module assembly process a full scale pilot-line, able to process back-contacted solar cells according to PV-industry standards, comprises:

1: Foil lay-up and transport system

The first station consists of the transport carrier system moving the back sheet foil through all substations. Supported by a vacuum table foil line out is the first step of the process.

Figure 4. *Substation for foil lay-up*

Station 2: Interconnection, lay-down of conductive adhesive

After the foil lay-up, the solar cells need to be interconnected. This interconnection between the conductive back-sheet foil and the back contact cells is established by means of deposition of conductive adhesive. It is of utmost importance that the interconnection yields low-stress to avoid cell breakage after the interconnection process. These stresses are the result of differences in thermal expansion which necessitates the use of interconnection materials that cure at a relatively low temperature and yet be tough during service life.

Figure 5. *Interconnection lay-down of conductive adhesive.*

Station 3: Encapsulant lay-down

When the conductive adhesive has been laid-down, the encapsulant will be placed. EVA that fits the design of the interconnection-foil is machined to generate holes for the formerly placed conductive adhesive dots.

Figure 6. *Substations for EVA encapsulant lay-down*

Station 4: Solar cell pick-and-place

The thin and fragile cells must be picked from a stack. Accurate positioning of the cells relative to the conductive back-sheet foil is realized with a dedicated handling and vision system. The vision achieves precise alignment between the actual position of the bonding area on the back sheet foil and the contact points of the cell.

Figure 7. *Substations for solar cell pick & place*

Station 5: EVA and glass lay-up is combined with station 3

At this station (see figure 6), the final lay-up of EVA cover sheet and top glass plate is realized. The EVA and glass plate is accurately positioned.

Station 6: Turning unit

The module needs to be flipped and placed into a vacuum laminator. A clamping system is developed to deal with the required force and to avoid shifting or breakage of solar cells during the flipping of the assembly. After turning the complete stack of module material the lamination process is activated. The module materials are now in the following order: glass superstrate, front-side EVA, cell matrix, back-side EVA, back-sheet foil.

Figure 8. *Turning unit final station before lamination.*

3. RESULTS

During the course of finalizing the module assembly line the capability of the installation was experimentally tested. In accordance with the assembly line objectives three topics were selected.

- Production experiments in order to reach the lay up speed of 1 cell per second. The outcome of the predicted speed is fully depending on the production speed at the assembly line substations.
- Processing of ultra thin solar cells of 130 μm on the assembly line without cell breakage
- Manufacturing of 24 modules with 4 x 9 MWT cells of 156 mm^2 comprising conductive back-sheet foil and conductive adhesive as interconnect.

3.1 Cell lay-up speed production experiments

In order to determine the production speed of the module assembly line several 4 x 9 modules comprising MWT cells and back sheet foil were fabricated. As a result, the most time critical part of the process, deposition of conductive adhesive paste, was simulated to prove the required production speed of 1 cell per second.

Deposition experiments have been conducted with 156 x 156mm^2 MWT cells that comprise 16 emitter and 15 base contacts each. The conductive adhesive dots must be deposited in high numbers and on large surfaces to form the interconnections between the MWT cell and the conductive back-sheet foil. A total of 1116 contact points are necessary for a module containing 36 solar cells (1m²). A large-size module with 6 x 12 cells (2m²) requires 2232 adhesive dots to be deposited. The deposition of the adhesive dots was tested for 4 x 9 and 6 x 10 cell matrix. As a result 1116 adhesive dots for 4 x 9 cells were deposited in a time sequence of 30 sec respectively 34 sec for a 6 x 10 cell matrix.

3.2 Handling of ultra thin solar cells (130 µm)

Several 36 cell modules were manufactured on the module assembly line comprising ECN MWT mc solar cells with a thickness of 130 µm. The emphasis for manufacturing modules with theses fragile cells was to prove the capability of the assembly line to demonstrate the cell handling and the low stress interconnection with conductive adhesive. These cells with a thickness of 130 µm as cut experienced no breakage during the process. A reason for this is the advantage of the assembly line pick and place. Moving of the solar cells is a one time action over a short distance without introducing external stresses. Temperature effects on the cell are non-existing as the interconnection is based on low temperature curing conductive adhesive. A flexible bond between contact pads of the back sheet foil and contact points of the solar cells is established. The curing of the conductive adhesive takes place during the lamination cycle.

3.2 Module reproducibility testing on the assembly line

The reproducibility of the pilot-line process was tested by processing 23 modules in one run. For this reason mc cells 156 x 156 mm^2 with a thickness of 220 µm were used. The distribution of FF for the 23 modules is shown in figure 9. An overall yield of 100% was reached without any cell breakage. In table I, the average values of the I-V parameters together with the deviations are presented.

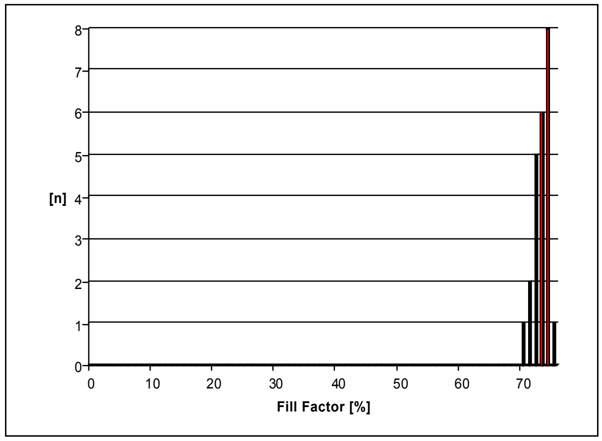

Figure 9. *Deviation of IV-parameters of manufactured module*

Tabel II Average I-V parameters for 23 modules (36 mc cells of 156 mm^2) and deviations from average

FF	**η_{encaps_cell} [%]**
72.9	14.8
Deviation FF [%]	**Deviation η_{encaps_cell} [%]**
1 module: <4 3 modules: 2.6 to 2.8 13 modules: 1.2 to 1.5 6 modules: 0	2 modules:3.3 to 3.4 5 modules: 2.7 4 modules: 2.0 8 modules: 1.3 2 modules: 0.67 2 modules: 0

The I-V measurements have been carried out with the aid of a class A (Berger) flash tester. As can be seen from the table, the deviations in the single I-V parameters FF and η_{encaps_cell}. are fairly low for the majority of the modules: all deviations are < 2.8 % for at least 22 modules (95%of total). The deviations add up in the efficiency values as is indicated by somewhat larger deviations in η_{encaps_cell}. The majority of the group of 23 modules (21 modules 91% of total) show a maximum deviation of 2.7% from the average η_{encaps_cell} value of 14.8%. From this it can be concluded that the reproducibility of the pilot-line is excellent.

IV parameters of the best performing module of this series are displayed in table II .

Table II. IV parameters of a 36 (156 x 156 mm²) cells module comprising electrical back sheet foil.

V_{OC}/V_{MP} [V]	I_{OC}/I_{MP} [A]	FF [%]	η_{encaps_cell} [%]
21.7 / 17.4	8.21 / 7.65	75.0	15.2

4. CONCLUSIONS

The relevance of a fully automated module assembly line for any back-contact solar cell is evident for a fast market introduction. A firm basis has been established to achieve the manufacturing of modules comprising back sheet foil, MWT cells and conductive adhesive. Functional modules have been manufactured on the module assembly line. The relevant lay up speed of 1 cell per second is limited by the deposition speed of the conductive adhesive. It was demonstrated that on a 4 x 9 and 6 x 10 module matrix configuration the deposition yield was reached within the time limit of 1 cell/sec.

First manufacturing of a 4 x 9 test module on the assembly line sub stations revealed excellent performance of the module efficiency and fill factor.

Processing of 23 modules has been successful in terms of yield and reproducibility. The yield was 100% while 91% (2l of the remaining 23) generated an encapsulated cell efficiency within 2.7% deviation from the average value.

It is expected that this novel module technology enables the route towards drastic cost reduction of solar modules from 2.8 €/Wp today to 2.0 €/Wp in 2010.

REFERENCES

[1] P.C. de Jong et al, Single- step laminated full size PV modules with back-contacted MC-cells and conductive adhesives, 19th European Photovoltaic Solar Energy conference, Paris, France, 2004, ECN-RX--04-067

[2] J.H. Bultman et al, 3rd WCPVSEC, Osaka, 2003, ECN-RX--03-019

[3] J.H. Bultman et al, Solar Energy Materials & Solar Cells, 65 (2001), pp. 339-345