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Sunovation II Development of a module production line for PUM

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Photovoltaic solar energy is a vital part of future sustainable energy supply and, slowly but surely, is becoming a mature source of energy. World solar photovoltaic (PV) market installations reached a record high of 2.8 gigawatts peak (GWp) in 2007. Photovoltaic production has been doubling every two years, increasing by an average of 48 percent each year since 2002, making it the world's fastest-growing energy technology. At the end of 2007, according, cumulative global production was 12.4 GWp.

The core of the Sunovation II project was to further develop back-contact solar cell and module technology and the design of a high-throughput module assembly line for such back contact solar cells. The main driver was cost reduction of module technology. At the moment, solar electricity is still expensive compared with electricity from the grid. In southern Europe, a break-even with consumer prices will come within a few years. For the Dutch situation, with the predicted fall in the cost of solar electricity and a conservative estimate of increasing consumer prices, break-even will be reached around 2015. The Sunovation II project was initiated by recognizing the potential for further cost reduction of solar modules. Cost reduction cannot be realized alone by very large-scale deployment of PV. It is essential that manufacturing at very-large scale is developed for innovative low-cost technologies.

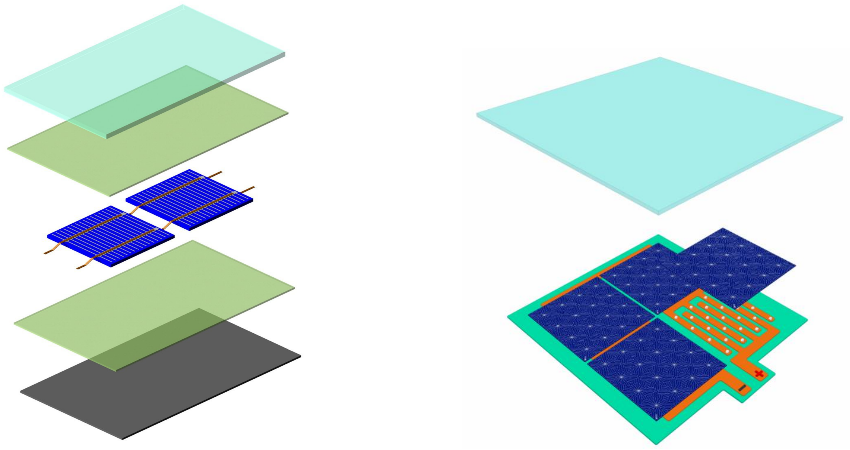
H-pattern and PUM solar cell.

The Sunovation II project was carried out in a collaboration between TNO, DOPT, Solland Solar, TTA and ECN. The project was coordinated by ECN. The PUM back-contact solar cell technology was initiated by ECN within the Sunovation I project in the period 1999-2003. The Sunovation II project was used to industrialize the PUM cell technology. The role of Solland Solar was to bring the PUM technology into production and to supply the consortium with cells. The role of DOPT was to focus onto the lamination requirements for high-throughput production. Unfortunately, DOPT went bankrupt in 2007. Their role was mainly taken over by ECN. From the technology side TNO supported the technology development by investigation of conductive adhesive materials. ECN was responsible for the module technology development. The proof-of-principle processes were developed by ECN while TTA designed and built the first prototype of the module assembly equipment to build back-contact solar modules in a fully automated fashion. Worth mentioning is that some subcontractors have contributed to the success of the project. QCells AG from Germany have supplied back-contact cells to ECN in the time that Solland did not yet have the capabilities to produce them. PGE and Boer & van Wijk have made several series of conductive back-sheet foils, which is an essential material for the PUM technology development.

The starting point of the Sunovation II project was to make a cost-performance comparison between the state-of-the-art H-pattern cell/module technology and the new PUM back-contact cell/module technology. In order to reduce the €/Wp costs of conventional modules, the industry has been moving forward by using larger and thinner wafers. In the past years this trend was accelerated by the high Si-feedstock prices due to its limited availability. Virtually all manufacturers have moved from 125mm to 156mm H-pattern cells in the past years while the cell thickness has been reduced from 330 µm in 2002 to 200 µm in 2007. Processing these large and fragile wafers into H-pattern cells and modules leads to several problems in the field:

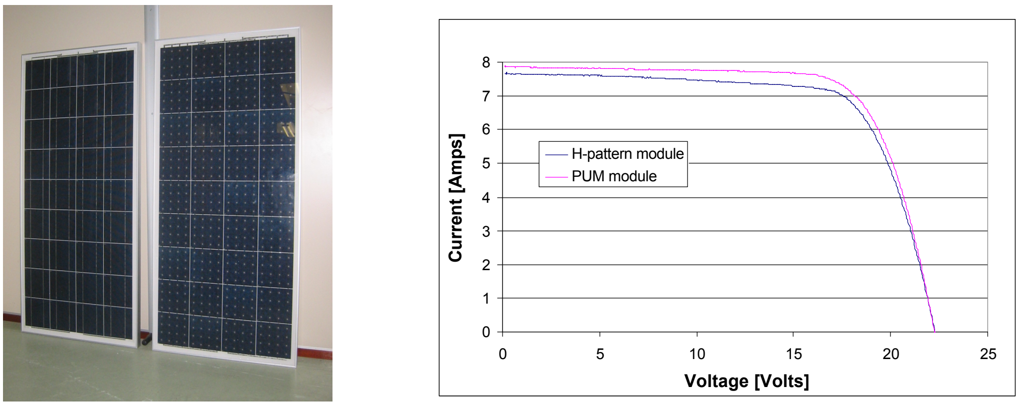
- Larger cells suffer from increased resistance losses as a result of longer metallization fingers on the front side, or will result in increased shading losses when going to 3 busbars.

- The full aluminium rear-side metallization of cells results in severe cell bowing which regularly leads to cell breakage during the module manufacturing process.
- Enlarging the cells and improving the cell's efficiency results in high currents. The maximum output current of solar cells have increased from 4.4A (125mm, 14%) in 2002 up to 7.8A (156mm, 16%) at present. The thickness of the interconnection material has to grow accordingly to avoid serious resistance losses.
- Soldering of tabs will result into a highly stressed surface area, which may lead to cell cracking and thus reduces the manufacturing yield.



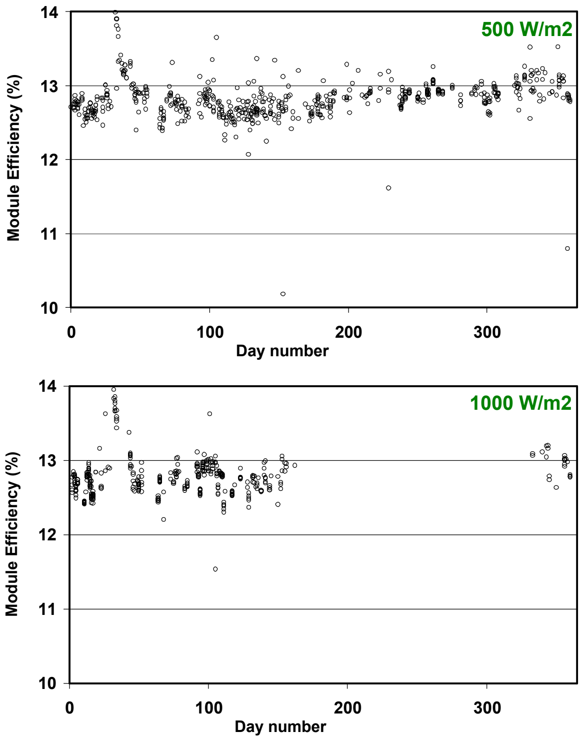
Module build-up of a conventional module with H-pattern cells and a back-contact module assembly using PUM cells.

The PUM module technology is a technology enabler to work with extremely thin and fragile cells. In addition, the output performance of PUM modules is 4-5% higher as compared to conventional modules. This was proven in 2006 on a set of hundred neighboring wafers. Fifty wafers were processed into H-pattern cells while the other fifty were processed into PUM cells. Subsequently, these cells were used to build a module of each type. All cells have been processed according to the ECN baseline process. The H-pattern module produces 122.8Wp while the PUM module produces 128.2Wp, a power gain of 4.4%. In this case, the H-pattern cells were interconnected with thick 175µm tabs. The PUM cells were interconnected with foil of similar resistivity which resulted in a power gain of the PUM module over the conventional design of 2.1%. The short-circuit current gain of the PUM module was 2.3%.



Photograph and IV curves of an H-pattern and a PUM module using identical cell processing. All cells were manufactured from neighboring wafers.

The choice of conductive adhesive as the interconnection medium was dictated by the need for a low-stress interconnection due to the ever decreasing thickness of solar cells. The processing temperature of conductive adhesives is ~150ºC compared to in excess of 250ºC for most solders. The residual stresses on cooling to room temperature after forming the interconnection are lower. The flexibility of the conductive adhesive also contributes to a reduction in stress levels. In this work, a number of adhesive were tested. The curing cycle for the adhesives match the curing cycle of EVA allowing a one shot lamination and interconnection process. One module made with conductive adhesive was mounted outside and monitored for a year showing little or no reduction in performance.



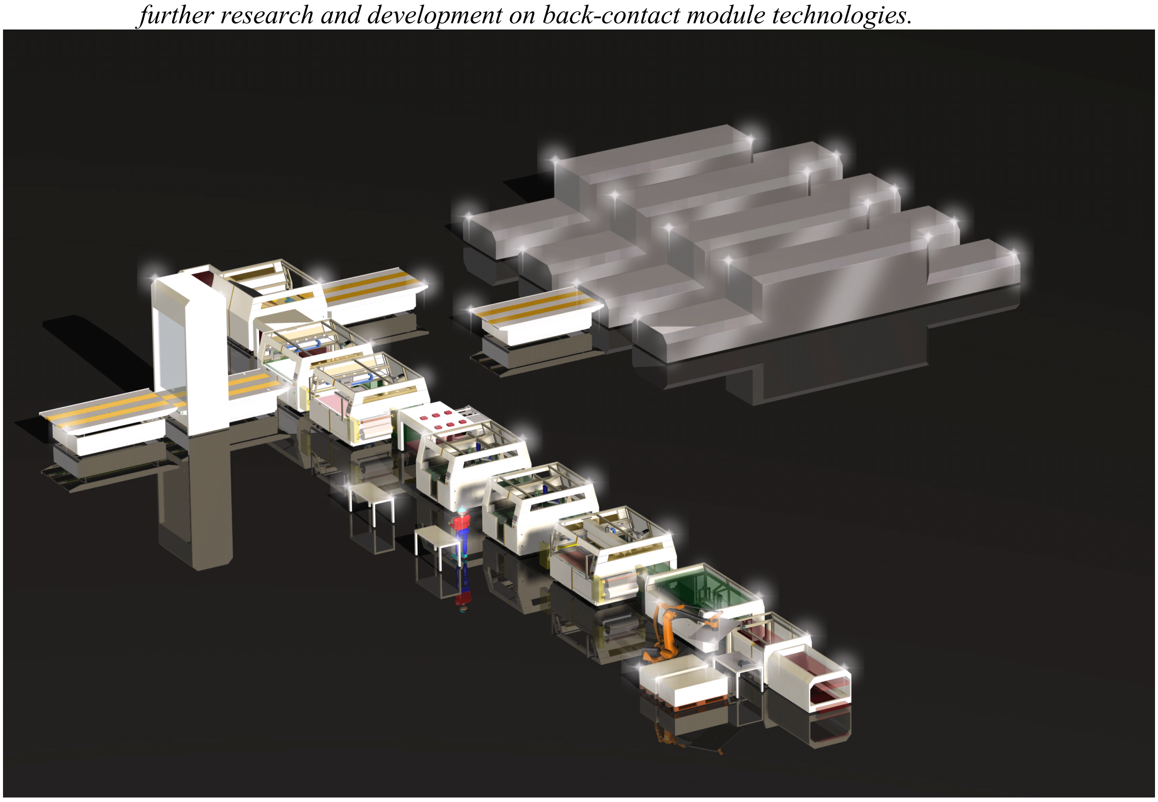
Module on ECN test rack and its measurement results for irradiance levels of 500 and 1000 Watts per square meter. The test period was one year and started in April 2007. Note that 1000 W/m² irradiance was not observed between October 2007 and March 2008.

The goals and objectives of the Sunovation II project were to develop an industrially applicable technology that allows the manufacture of modules using thin PUM cells in one step. A production line was designed to allow automated manufacture with high-throughput for interconnection and lamination at a rate of one 60 cell module per minute. The module was based on a patterned conductive foil with the interconnections between the cells and the foil made with a conductive adhesive. The advantages of this module concept are that it provides an enabling technology for the implementation of very thin solar cells (<160 μ). The cell is only handled once during production and the use of conductive adhesive reduces the stress imposed on the cell during fabrication. The module assembly process that enables the use of very thin back-contact solar cells contains 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 placement onto the conductive paste.
5. Lay-up of an additional EVA sheet and a cover glass plate.
6. Finally, the module assembly will be laminated in a vacuum laminator while simultaneously forming the interconnections.

In this context, a pilot module assembly line was built by TTA to demonstrate the feasibility of the concept. This equipment is capable of assembling modules configured into matrices of 4 x 9, 5 x 10 and 6 x 10 using 156 x 156 mm² cells.

Photograph of the module assembly pilot line. The line was built by TTA and is now at ECN to carry out further research and development on back-contact module technologies.



Design (courtesy of TTA) of a fully automated 100MWp module assembly line for back-contact solar cells.

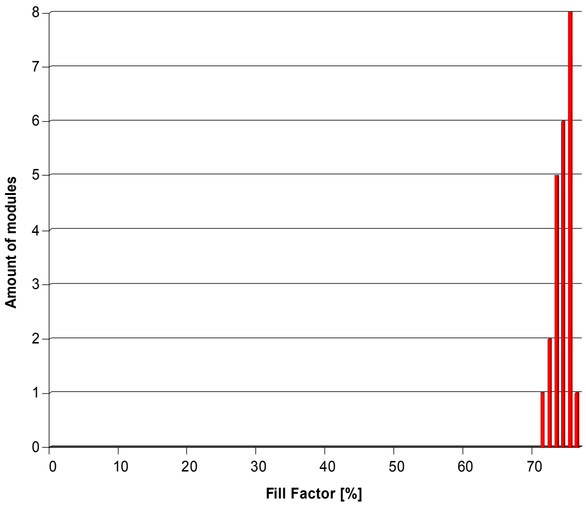
The testing of the module assembly line involved two main criteria.

First, it was shown that ultra-thin solar cells of 130 μm could be processed on the assembly line without cell breakage. Several 36-cell modules were manufactured on the module assembly line comprising ECN PUM cells based on 130μm as-cut wafers (110-115μm after cell processing). 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. The tests were very successful as none of the cells broke during the module manufacturing process. This proves the strength of the pick-and-place concept, i.e., the handling of the solar cells is only a single 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.

Second, the reproducibility of the pilot-line process was proven by building 23 modules on a single day. For this reason QCells-MWT cells with a thickness of 220µm were used. The distribution of the fill-factor, a direct measure for the module output power shows that 95% of all modules are within an output power range of ±1.4%. An overall yield of 100% was reached without any cell breakage. The IV parameters of the best performing module (133.5 Wp) of this series are displayed in the table below. The averaged fill factor of the cells was 76.9%.

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

IV parameters of a 133.5 Wp PUM module as part of the acceptance test.



Fill factor distribution of manufactured 4x9 PUM modules

A comparison of the results with the goals as defined in the Sunovation II project plan show that all the goals have been achieved or surpassed. The use of conductive adhesive as interconnection has been investigated and shown to be a viable low-stress alternative to soldering allowing module manufacture with very thin solar cells. A pilot production line is available allowing production of modules at a semi-industrial level. Further work is planned for to refine the process. In particular alternative adhesives, encapsulants and foil materials will be further investigated.