New Industrial solar Cell Encapsulation (NICE) technology for PV module fabrication at drastically reduced costs

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ABSTRACT: The direct production costs of state-of-the-art PV modules, produced with solar cells fabricated on wafers, represent between 30% and 40% of the total costs per Watt/peak of the entire PV production chain, including ingot production, wafer cutting, cell production and module assembly. The NICE technology aims at reducing these costs by more than 50%.
It combines an air- and humidity tight sealing technique, which is already known and proven from the insulating glass industry, with a solar cell interconnection that makes use of an under pressure between the front and back sheet which delimitate the module. The under pressure inside the module assures low resistivity contacts between cells and metal connectors. The entire NICE process takes place at room temperature avoiding all heat related risks of cell degradation. Compared to the state-of-the-art module technology the solder connection between cells and metal connectors is completely avoided, as well as the batch type lamination process, largely facilitating the automation of the NICE module fabrication process.
A number of test modules with 36, 12 and 6 125x125mm^2 silicon solar cells have been produced with the NICE technology and tested according to the IEC 61215 standard, resulting in no degradation of the module power.

Keywords: Module Manufacturing, Cost Reduction, Encapsulation

1 INTRODUCTION

The basic function of solar cell encapsulation in form of photovoltaic modules is the protection of the solar cells against degrading environmental influences, as well as to provide the necessary mechanical and structural support for the solar cells. In addition, the module should comprise elements for the electrical series connection of the solar cells and the electrical outside connectors. Finally, the module should allow for a maximum optical transparence to the incident solar radiation on the way to the surface of the solar cells. A schematic cross section of a state-of-the-art PV module is shown in Figure 1.

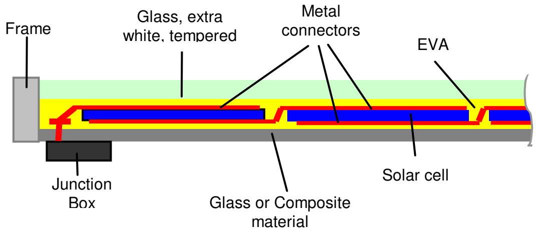

Figure 1: Schematic view of the cross section of a state of the art PV module (not to scale).

A detailed description of today's state-of-the-art PV module technology, can be found in literature [1]. The following section summarises the most important elements.

The electrical series connection of solar cells to be integrated in a PV module is achieved by soldering of metal connectors, for example solder coated flat copper wires, to the front contacts of one solar cell and the rear contacts of the adjacent solar cell. Apart from safety concerns, the soldering step, the related cell turning operations and the transfer of soldered strings of cells bear an elevated risk of cell breakage.

The protection of the module interior against humidity and air penetration is currently realized by a batch type lamination process. The matrix of series connected, soldered solar cells is placed in between EVA (ethylene vinyl acetate) sheets, which themselves are sandwiched between protective sheets, like tempered glass or a composite material, such as Tedlar. During the lamination process, the EVA is melted, a vacuum is applied to extract air bubbles and finally, the melted EVA is cured. The solar cells are thus sealed by the encapsulant and a physical and optical contact is established to the supporting protective sheets. The lamination process takes 10 to 30 minutes, depending on the type of EVA used, and the required processing temperature ranges up to 150°C. Due to its batch like nature, the lamination process is difficult to integrate in an in-line production scenario. Apart from the technical features, the lamination technology is relatively labor intensive, since it requires a number of manual transfers, assembling (e.g. placement and sealing of the junction box for external contacts) and cleaning operations (e.g. removal of debording EVA after the lamination process). Finally, long term degradation of the EVA encapsulation under environmental influences can lead to module performance losses, like for example analysed in detail in [2].

2 NICE MODULE TECHNOLOGY

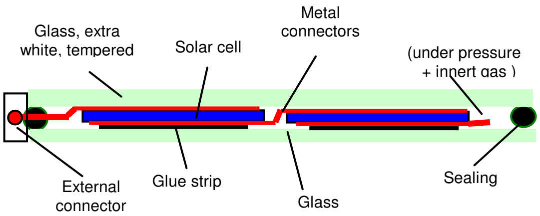

Figure 2: Schematic view of the cross section of a NICE module (not to scale, only 2 solar cells shown).

The key elements of the NICE module technology become apparent from Figure 2:

➢ Organic sealing material around perimeter of module sheets, assuring air/humidity tightness and physical contact between front and rear sheet.

- Under pressure in the module interior, to create electrical contact between cell contacts and metal connectors.
- Fixation of metal connectors and cells by glue or sealing material.
- Profiling of metal connector ribbons to allow for amortization of pressure on solar cells.
- New external connectors as integral part of module, replacing the junction box.

The **organic material**, used for the hermetic sealing of the modules, is a derivative from the family of poly-isobutylenes. It has been developed and specially adapted to serve as spacer for the fabrication of insulating double glasses for the building sector, replacing the traditionally used aluminium frame. The brand name of this material is TPS®, which stands for Thermo Plastic Spacer [3]. The multiple functions of the TPS® are: (i) providing distance between two glass sheets, (ii) perfect long term adhesion to glass, (iii) long term barrier to humidity and air penetration.

The technical requirements for the use of TPS® in the insulating glass industry are very similar to PV module requirements. TPS® as sealing and spacer material for insulating glasses is already field proven and qualified in the building sector. In addition, industrial equipment and processes for the application of TPS® have been developed and are also field proven. For these reasons, TPS® was selected as sealing material for the NICE technology. All TPS® related work for the NICE module technology was carried out by the German equipment manufacturer Lenhardt Maschinenbau GmbH which is part of the Swiss Bystronic Glass Group.

The application of TPS® in form of a 5-10 mm wide ribbon around the perimeter of one glass sheet is realized with a fully automatic equipment by Lenhardt. At the moment of deposition, while passing through a specially designed nozzle, the TPS® is locally heated to around 120°C. This is the only "hot spot" of the NICE process. All other process steps are carried out at room temperature.

The **sealing process** is terminated by pressing together the glass sheet having received the pre-deposited TPS® ribbon with a second glass sheet. The pressing to the desired final thickness takes place in a high precision press, also developed by Lenhardt. Both, the TPS® application unit and the press are part of fully automatic production line for double glasses which is capable of handling glass sizes up to 3.2 x 6.0 m^2.

After pressing, the TPS® requires no further treatment. The TPS® sealing keeps a certain elasticity that allows for compensation of shearing forces due to a potential mechanical impact or thermal expansion during field use of the sealed product. Although the TPS® sealing itself already mechanically reinforces the compound structure, it can be further strengthened by a secondary sealing, for example with a product based on poly-sulfides.

For the NICE process, a new special press is under development, which allows to float the interior of the module with neutral gas and to create an **under pressure** in the order of 200mbar, while pressing the two module sheets to the desired final thickness. During the experimental phase, the creation of the under pressure was realized by inserting an injection needle through the TPS® after pressing. The needle was used for both, the flooding of the module interior with neutral gas and the following creation of the under pressure in connection with a vacuum pump. Upon retreat of the needle, the small hole in the TPS® was simultaneously closed, keeping the under pressure inside the module.

The major role of the neutral gas (e.g. Argon) inside the module is to prevent the solar cells and electrical connectors from oxidation.

The under pressure inside a NICE module is a pre-requisite for establishing electrical contacts between the solar cells and metal connector ribbons, without the need to solder the connectors to the cells. The nature of the so realized multiple point contacts between solar cell busbars and the metal connectors results in a low contact resistance. The contacts of the solar cell strings to the module busbars, which electrically connect different cell strings, are also established by the under pressure, as are the contacts to the outside connectors.

The **metal connectors** and solar cells are fixed by adhesive strips which are pre-deposited on the rear sheet of the module and onto which the connectors and cells are placed. The glue should be solvent free. Pre-deposited TPS® strips were successfully used for the fixation of both, metal connectors and solar cells.

The connector material is a solder coated copper alloy, characterized by a higher mechanical rigidity or a more elastic behavior than standard copper, which shows a rather plastic deformation behavior on the impact of an external force. The total thickness of the Cu connectors is 150 to 200µm. In a variation of the NICE technology, the metal connectors which are in contact with the solar cells are profiled in a way to allow for a spring effect or a suspended contact to the solar cells, in order to lower the pressure impact on the cells and to compensate for local thickness variations of the cells. The generic process flow of the NICE technology is summarized in Figure 3.

Glue deposition on rear sheet
⇩
Positioning of metal connectors and cells on rear sheet
⇩
Positioning of external connector
⇩
Deposition of sealing material around perimeter of front sheet
⇩
Mounting of front and rear sheets (closing of sandwich)
⇩
Pressing of sandwich to desired thickness
Flooding of module interior with neutral gas
⇩
Creation of under pressure in module interior

Figure 3: Generic process flow of the NICE module process.

The newly proposed integrated external connector has the same thickness as the module sandwich, as shown in Figure 2a. It contains the protective diodes and a plug-in connector for the module interconnection. The connector is positioned and sealed during the module assembly. The metal ribbon, which establishes the electrical contact to the cell strings inside the module, is completely surrounded by the TPS® sealing.

3 RESULTS

3.1 Experimental conditions

During the development phase, 6 and 12 cells modules have been produced with the NICE process, using both, mono- and multi-crystalline silicon solar cells of 125x125mm^2 surface. First 36 cells modules could have been fabricated very recently. The front sheet used for these modules was standard photovoltaic, extra white, tempered glass of 3.2mm thickness. For the rear sheet the same type of glass was used; in addition, a 0.3mm thick stainless steel foil was tested as alternative, basically to reduce the weight of the modules. Concerning metal connectors, on the first modules non-profiled standard solder coated Cu ribbons were used with a thickness of 150µm and a width of 2mm. The newly proposed external integrated external connector was not yet available for the experiments. Therefore, the external electrical connection was realized by 5mm wide solder coated Cu ribbons, which were placed in a way that they were completely surrounded by the TPS® sealing. In a later experimental stage, profiled solder coated Cu ribbons were used for the cell interconnection. These ribbons had a thickness of 200µm and a width of 2mm. The applied pressure difference inside the modules compared to the outside pressure was varied between below 100mbar and 300mbar.

3.2 Module results

Figure 4: One of the first 36 cells modules realized with multi-c solar cells and textured extra white glass sheets.

The IV characteristics of different modules are shown in Table 1. It has to be pointed out that the performances of the cells used for the module experiments are not representative of certain cell types nor do they represent the typical performances of certain cell producers. The IV characteristics of the 36 cells module were measured at FHG-ISE, the 12 cells modules were tested with the equipment of one of the development partners, both according to standard test conditions: Irradiation of 1000W/m^2, AM1.5 spectrum and a module temperature of 25°C.

The following general observations can be made, comparing the IV characteristics of the cells before encapsulation with the module IV characteristics:

- The V_{oc} of the cells is conserved on the module
- The FF of the cells is conserved in the case of high (>75%) values on cell level. In case of low FFs on cell level, an increased FF after encapsulation was observed on several modules.
- The I_{sc} on module level is 3 – 5% lower compared to cell level, due to optical losses.

The I_{sc} losses are related to the non-ideal refractive index of the medium in between the glass front sheet and the solar cell surface, which in case of the NICE technology is air, or a neutral gas. This effect represents a small disadvantage of the NICE technology compared to EVA lamination.

Table 1: IV characteristics of NICE modules

Module type	V_{oc} [V]	I_{sc} [A]	FF [%]	P [W]
A	7.63	4.61	76.0	26.6
B	7.62	4.57	77.0	26.7
C	7.63	4.88	76.0	28.2
D	7.64	4.78	78.5	28.7
E	21.48	4.32	76.0	70.6

A: 12 cells multi-c, glass/glass, flat Cu ribbons
B: 12 cells multi-c, glass/metal, flat Cu ribbons
C: 12 cells multi-c, glass/glass, profiled Cu ribbons
D: 12 cells mono-c, glass/glass, flat Cu ribbons
E: 36 cells multi-c, glass/glass, profiled Cu ribbons

Cell cracks occurred in the beginning of the experimental phase, when the pressure difference between module interior and the ambient pressure was not yet optimized. The last generation of NICE modules with multi-c silicon cells that also used the profiled metal connectors with their amortization effect and an optimized pressure, did not result in any cell crack.

3.3 Degradation test results

A number of modules have been submitted to the following module qualification tests according to the IEC standard 61215:

a) Damp heat test: 1000 hours at 85°C and a relative humidity of 85%, tolerated maximum power degradation: 5%.

Figure 5 shows the FF and Power evolution of a 12 cells module that has been tested up to 3500 hours. As can be seen, the power degradation remains below 1% after this extensive testing time. Other modules were tested until 1000 hours without any signs of performance degradation, confirming the sealing quality of the TPS® and the quality of the contacts on the module.

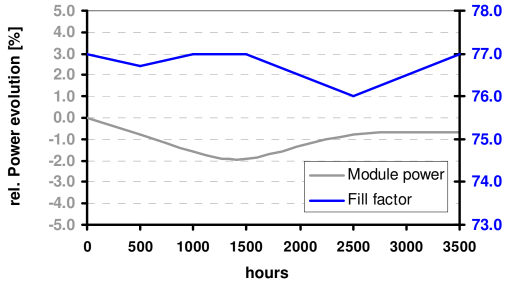

Figure 5: Damp heat test results after 3500 hours of a 12 cells multi-c glass/metal module with flat Cu ribbons.

b) Thermo-cycle tests: 200 cycles from -40°C to +85°C, tolerated maximum power degradation of 5%.

Figure 6 shows the absolute FF and the relative power evolution of 3 modules made from mono-c silicon solar cells during 200 thermo-cycles. Two of the modules are glass-glass modules, one is a glass-metal module. As can be seen, no serious degradation of the power or the fill factor can be observed, indicating again the quality of the sealing. A similar behavior has been found with a multi-c module after 220 thermo-cycles.

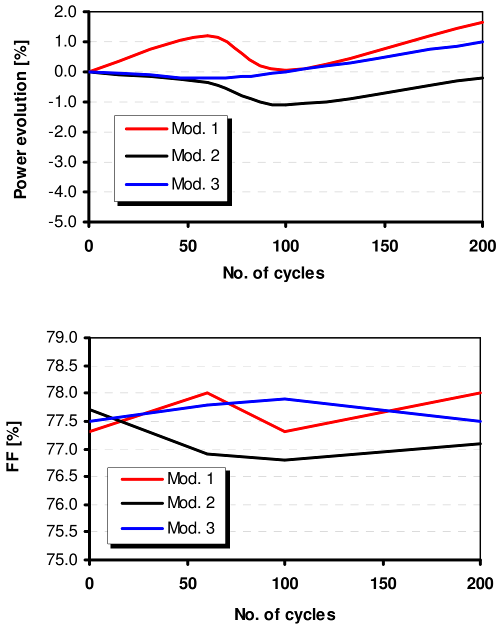

Figure 6: Results of thermo-cycle tests of 3 modules with 12 mono-c silicon solar cells, showing the power evolution above and the FF evolution below. Modules 1+2 are glass/glass modules, whereas module 3 is a glass/metal module.

Although a small number of metal connectors started to move away from the cell busbars during the thermo-cycles, no serious Fill-factor degradation occurred. It has to be noted that these modules have been made with non-profiled and less rigid solder coated Cu connectors of 150µm thickness. The more rigid solder coated and profiled Cu alloy connectors are more likely to remain in place as has been observed on the first modules realized with this type of metal connector.

3.4 Economic Evaluation

The presented cost evaluation has been carried out as part of the planning for a completely automated industrial pilot line, in close collaboration with Lenhardt and Vincent Industries, who is a specialist for automated production equipment.

Based on the following assumptions:

- 72 cells (150x150mm^2) modules, power: 230 W
- throughput: 2min/module, 34,5 MW/year
- 228 days year, 3 shifts
- production yield: 92% (~151.000 modules/year)

direct module production costs of 0.23€ per Watt have been calculated. These costs include all consumables used for the module fabrication and labor. Investment costs and cells have not been included.

4 CONCLUSIONS

The presented NICE module encapsulation technology overcomes limitations related to the state-of-the-art encapsulation technology, by avoiding the soldering of the solar cells and replacing the EVA lamination by a sophisticated sealing technology. Due to its simplicity the NICE technology allows to reduce the direct module production costs by 50%, while at the same time guaranteeing a highly reliable sealing quality, which has been demonstrated on a number of test modules that passed qualification tests. The next phase of the development work will be dedicated to real size modules and the realization of an industrial pilot line which already includes the full process automatisation. The aim of this pilot line will be the demonstration of the cost reduction potential of the NICE technology at industrial scale.

5 ACKNOWLEDGEMENTS

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Apollonsolar has recently received the European EUREKA label for the presented NICE project.

6 REFERENCES

[1] A. Luque and S. Hegedus (Editors): "Handbook of Photovoltaic Science and Engineering" John Wiley &Sons Ltd., 2003, Chapter 7.8, pp. 291 – 302.
[2] A.W. Czanderna and F.J. Pern, "Encapsulation of PV Modules using ethylene vinyl acetate as a pottant: A critical review", Solar Energy Materials and Solar Cells 43 (1996), pp 101-181.
[3] R. Karrer: "TPS®: One way to Warm-Edge Insulating Glass", Proceedings of Glass Processing Days, 18-21 June 2001, Tampere Finland, pp. 633-636.