IEC CERTIFICATION AND EXTENDED AGEING TEST OF NICE MODULES

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ABSTRACT: Apollon Solar's NICE (New Industrial Solar Cell Encapsulation) module technology is an innovative technology to encapsulate and electrically interconnect solar cells without neither soldering nor encapsulant. An organic edge sealing delimits the internal volume in which an underpressure is created, allowing to establish the electrical contact between solar cells and interconnectors by pressure. This technology represents a completely new approach for the solar cell encapsulation: besides industrial and cost advantages, a better long term module performance stability and an improved lifetime are expected.

The IEC certification of this technology represents a major step in its development, in order to prove the product robustness. This article present the results of the first certification process according to IEC of NICE modules manufactured with our prototype production line designed by Vincent Industrie and installed at INES. The certification is carried out by the TÜV Rheinland in Cologne, and shows a very high performance stability, with a maximal power degradation of 2 % (while IEC norms require a degradation lower than 5%).

In addition to the IEC tests, we also present results of several largely extended mechanical and ageing tests carried out at INES and TÜV Rheinland. We notably obtained remarkable results, with a power degradation after 1000 thermal cycling lower than 2%.

Keywords: Module Manufacturing, Reliability, Durability

1 INTRODUCTION

Apollon Solar's NICE module technology allows to overcome the limitations of the state-of-the-art module encapsulation technology based on EVA lamination and cells soldering. The NICE technology is inspired by a sealing technology, using a poly-isobutylene (PIB) material around the perimeter of the module, replacing the EVA lamination (figure 2), PIB which is already in use and validated in the insulating glass industry, replacing thus the EVA lamination (figure 2).

1.1 Interconnection without soldering

The PIB sealing assures very high and long term gas/humidity tightness, allowing the introduction of an underpressure inside the module thus pressing the enclosed components like cell busbars and metal connectors together and thereby enabling their electrical series connections as presented in the figure 1.

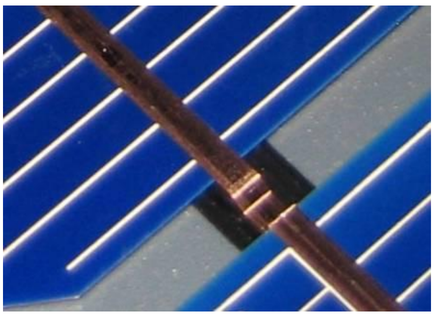

Figure 1: Cells interconnection without soldering

High module fill factors and low series resistances have been regularly obtained with this type of electrical series connection by pressure. A special focus has been given to the gas and humidity tightness of this PIB edge sealing: it has been investigated through experiments performed in cooperation with the Fraunhofer ISE in Freiburg [1].

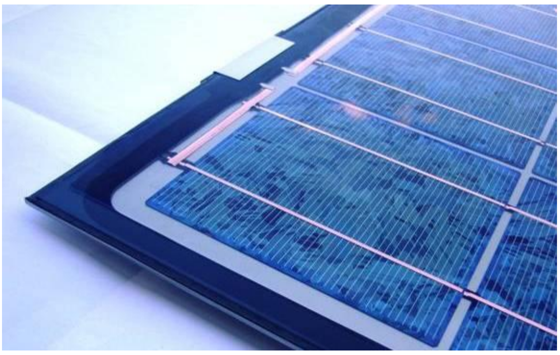

Figure 2: Detail of the sealing PIB material applied on the whole perimeter of the module.

One other important requirement for of the NICE modules is a rear sheet with perfect have to be a very good gas and humidity tightness rear sheet which can be a glass sheet or an electrically insulated metal foil (figure 3). A detailed description of the NICE technology, including first test results, can be found in previous publications [2-4].

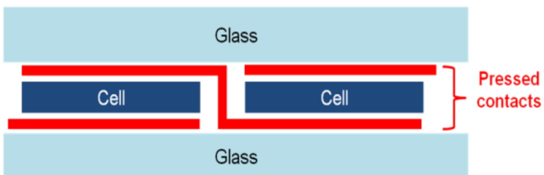

Figure 3: Double-glass NICE module construction

1.2 Fully automated and industrialized technology

The NICE process allows a simplified automated inline production of modules, as shown in our Key Process line at INES (France) since 2008. This prototype equipment demonstrated the feasibility of the process and production costs lower than 0,30€/Wc, for the module part, lower than 0,30€/Wc.

Thanks to these results, two NICE industrial lines with a capacity of 20 MW per year have been assembled built by Vincent Industrie and are currently under fine tuning and optimizing: the industrial launch with a cycle time shorter than 4 minutes is expected at the end of 2010.

The NICE is technology represents a completely new approach for the solar cell encapsulation: besides production industrial and cost advantages, a better long term module performance stability and an improved lifetime are expected. The IEC certification of this technology represents a major step in its development, in order to prove the product robustness, and the expectation of a 30 years lifetime.

In this paper, IEC's most critical tests are presented and discussed along with complementary tests performed at the French National Institute of Solar Energy (INES). We especially focused our experiments on the two harshest strongest tests for the NICE technology: thermal cycling and alternative mechanical load.

2 TEST-MODULES FABRICATION

2.1 Test-modules constitution

All test-modules presented in the following experiments are double glasses 36-cells NICE modules (125x125 mm² cells) of type NICE-80X, produced on the prototype line at INES (figure 4). We used pure copper (not tinned) metal interconnectors, multi-c-Si solar cells from Suntech Power, PIB from Kömmerling Chemische Fabrik and glasses from Lisec.

Figure 4: NICE Key Process prototype line at INES, Chambéry, France

2.2 Pressure optimization

The pressure control inside the module is one of the key elements of the NICE technology. Indeed, on the one hand the forces applied on solar cells should be as small as possiblehas to be minimized, in order to avoid cell breakage. To respect this condition, the internal gas underpressure has to be minimized (the absolute gas pressure has to be maximized).

On the other hand, the electrical contact quality is driven by (proportional to the) this underpressure, which also depends on the temperature: a minimal underpressure has to be guaranteed in order to maintain a sufficient force on the solar cells and metal interconnectors , especially at high temperature (> 85°C).

The optimization of this internal underpressure has been done thanks to electroluminescence imaging and thermal cycling tests. During these tests, the electrical continuity has been monitored in order to guarantee assure the permanence of the electrical contacts between cells and coupper interconnectors.

The following table presents our results for several internal pressures, in the range of acceptable pressure to avoid solar cells breakage. The different pressures are related presented in comparison to a reference pressure PN in the table I. Note that the values depend on components properties. All modules shown presented in these results presents no cells breakage which could affect the module's performance.

Table I: Electrical continuity depending on the internal pressure:

Internal Pressure (mbar)	Electrical Continuity
$P_N – 100$	**Yes**
P_N - 50	**Yes**
P_N	**Yes**
P_N + 25	**No**
P_N + 50	**No**

These tests allow to determine a maximum pressure P_N which guarantees the electrical continuity during thermal cycling test, notably at high temperatures. For the industrial lines currently under optimization, this parameter is carefully checked to guarantee the reliability of the NICE module even in higher temperature conditions than imposed by in the IEC tests.

3 IEC'S CERTIFICATION RESULTS

The NICE-80X Modules passed all relevant tests according to IEC-61215 and 61730, with outstanding results in terms of power degradation for all major tests. The tests were performed by the TÜV Rheinland in Cologne. The main results are presented in the tables below.

3.1 Major ageing test: thermal cycling, damp heat and mechanical load

Since the cells and copper contacts are not laminated into an encapsulant, the hardest test for the NICE technology is the thermal cycling test (-40°C to °85°C). It is important to notice here that the developments made on the prototype line allowed us to produce modules which can sustain these type of tests.

The electrical results are presented in table I below. the maximum power decrease obtained with these major tests is 2.01%, while the IEC norm allows demands a maximum degradation of 5%.

Table II: Ageing test: power variation (TÜV values)

Test	Power Variation (%)
Humidity Freeze (Sample 1)	-0.22
Humidity Freeze (Sample 2)	-0.31
Thermal Cycling 200 (Sample 1)	-2.01
Thermal Cycling 200 (Sample 2)	-1.20
Damp Heat (Sample 1)	-0.92
Damp Heat (Sample 2)	+2.26
Mechanical Load (2400 Pa)	+1.61

Positive variations (the maximum power increases in certain cases) can be explained by the measurement's uncertainty, but also by the amelioration of the electrical series connection between solar cell busbars and metal interconnectors contact. Indeed, the first thermomechanical variations induces micro-movements that allow the components to find their optimal place and seems to eliminate a part of the interstitial oxide between them and the cell's serigraphyscreen printed busbar. The electrical contact is thusen better established. after this phenomenon.

Thus, Wwe typically observed an improvement of the module power electrical performance between 1 and 2% after the first thermal cyclesing or after several hours of outdoor exposure.

3.2 Other normalized test

The IEC certification includes several tests which are, for most of them, related to security aspects. We do not present here the mechanical impact test here, because no power variation is required by the norms, but the modules succeeded in this test too. The table III below presents the power variation after all other required tests.

Table III: Power variation after normalized tests (TÜV):

Test	Power Variation (%)
Outdoor exposure	+1.23
Bypass Diode Thermal	+0.48
Hot-spot endurance	+0.64
UV preconditioning (Sample 1)	+1.42
UV preconditioning (Sample 2)	+1.83
Robustness of terminations	+0.48
Hail Impact	-1.60

As for the other tests that were already mentioned, the positive variations can be explained by the samesimilar reasons (measurement's uncertainty and electrical contact improvement establishment). The maximum power decrease is here 1.60%.

3.3 Report after complete certification process

Another requirement of the IEC-Norms regards the power variation after the complete all certification process: in this case too, the NICE modules largely fulfill this requiremente expectation, with a maximum power variation of -2.01 %, as shown in the table IV below (while the norm accepts demands a maximal variation of -8 %).

Table IV: Complete certification process: power variation (TÜV)

Module ID	Power Variation (%)
1	+0.16
2	+1.23
3	+1.37
4	+0.70
5	-2.01
6	-1.20
7	+0.71

Finally, as required by the and as IEC-norms require it, all modules succeeded in dielectric strength test and wet leakage test for a system voltage of 1000 V, before and after each test sequence. The resistance values measured by the TÜV during these tests are largely better than the requirements.

4. HIGHLY EXTENDED AGEING TESTS

In comparison to EVA-laminated modules, the damp heat test does not represent any specific difficulty for NICE modules, thanks to the excellent humidity barrier of PIB: its tightness had already been proved by the insulating glass industry, as well as by our own experiments [4].

Due to its conception without neither encapsulant nor soldering, the harshest strongest test for a NICE module is the thermal cycling test, according to the IEC 61215 norm. We performed a large number of thermal cycles on modules realized with the same components and the same process: our results are presented in the figure 5.

Impressive electrical results were obtained with modules showing less than 2% power loss after 1000 thermal cycles (still ongoing). As the initial pressure is correctly set in the modules, no contact disconnection occurred and cell breakages become even less important than in standard laminated modules.

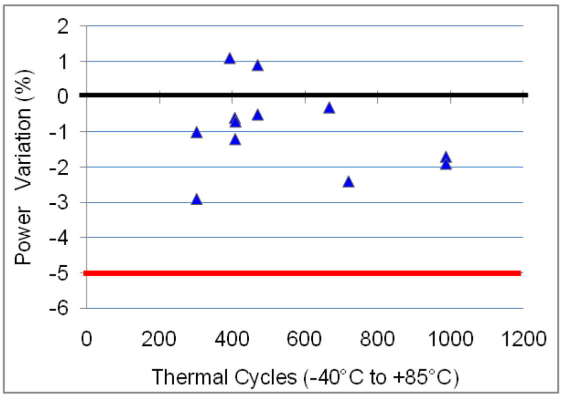

Figure 5: Extended Thermal Cycling: Power degradation beyond 200 cycles.

These tests prove the long term reliability of NICE modules: they resist much longer than an average EVA-laminated modules. According to these results, we can expect a very significant improvement of the photovoltaic module lifetime, estimated at 30 years.

5 DYNAMIC MECHANICAL LOAD

The test procedure according to "Resistance to wind load" DIN EN 12210 and DIN EN 12211, as well as IEC 61215:2005 "Crystalline silicon terrestrial photovoltaic (PV) modules" was determined for testing at TÜV Rheinland in Cologne.


Figure 6: Dynamic Mechanical Load (TÜV)

The test module was submitted to two times ice 50 alternating mechanical-load cycles, under a 2 000 Pa dynamic load (figure 6). To check for adverse effects before and after the dynamic mechanical load tests, electrical performance measurements were executed: the results are presented in the table V.

In addition, no visual damages have been observed on the modules: there wasn't any no migration, neither of solar cells nor of cuopper interconnectors occurred. These experiments prove the reliability of the component's fixation as well as the electrical contact by pressure.

Table V: Evolution of performances after alternative mechanical loads (TÜV Rheinland):

	Tensile Load	Pressure Load
Max. bending at Module centre (mm)	10	6
Pneumatic load (Pa)	2000	
Circuit interruption	No	
Power evolution after 50 Cycles (%)	0.40	
Power evolution after 100 Cycles (%)	-0.57	

6 OUTDOOR EXPOSURE

The main purpose of this study consists in comparing NICE modules to standard encapsulated and soldered modules. 24 units are monitored on the INES rooftop.

Figure 7: Laminated modules and NICE modules under outdoor exposure

The outdoor exposure of NICE modules (ongoing) showed consistent energy production (70 kWh during October) with no resistance degradation ($R_S = 1\ \Omega.cm^2$) after 7 months, demonstrating a satisfying behavior of the technology under real environmental conditions.

Other parameters like diode functionings and shunt resistance are evaluated, and several modules are connected on an IV test Bbench. These experiments are ongoing.

The measurements made by the TÜV during the certification process showed that the power degradation of the tested module was 1.23 % after 67 $kWh.m^{-2}$.

Last but not least, the Normal Operating Cell Temperature (NOCT) of the NICE modules determined by the TÜV Rheinland is 42.6°C, which is slightly lower than standard laminated modules. The double glass structure with its shallowfine intermediate nitrogen layer (containing the cells and the copper ribbons) allows for a cooling effect of the module.

7 CONCLUSION

The NICE technology proved its feasibility and reliability, largely exceeding the requirements of international standards.

IEC certification results according to 61215 and 61730 have shown low power losses and sometimes a power increase after the completion of all tests. Contrary to EVA-laminated modules, damp heat is not a difficult test for NICE modules due to the very efficient humidity barrier by the PIB barrier sealing. Standard Tthermal cycling tests and extended thermal cycling tests up to 1000 cycles have been validated with an appropriate underpressure inside the modules with no more than 3% power loss (cycles still ongoing).

The alternative mechanical loads test show no significant degradation of the module power (<1%). The outdoor exposure of NICE modules (ongoing) showed no critical degradation after 7 months, demonstrating a satisfying behavior of the technology under real environmental conditions. All other tests of the IEC specifications have been successfully validated.

These results obtained by an international recognized organism on the one hand (TÜV), and performed by a high level research organism (INES) are a new important proof of the reliability of the NICE technology. The next steps will include be the submission of NICE modules participation to the NREL test-to-failure protocol, and by the certification of industrial 60-cells NICE modules, made on the first industrial equipment, expected in 2011.

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