EVALUATION OF GAS AND HUMIDITY TIGHT SEALING OF APOLLON SOLAR'S NICE MODULES

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ABSTRACT: APOLLONSOLAR's New Industrial Cell Encapsulation (NICE) technology for the manufacturing of PV modules uses a ribbon of poly-isobutylene (PIB) around the perimeter of the module in order to seal the inside of the module from the outside atmosphere and provide environmental protection of the cells and interconnectors. The PIB sealing assures a very efficient and long term air/humidity tightness, allowing the establishment of an under pressure inside the module that is used to establish the electrical contact between solar cell busbars and interconnecting wires by pressure, thus avoiding the soldering of these contacts. High module fill factors and low series resistances have been regularly obtained with this type of electrical series connection by under pressure. In order to assure a module lifetime of at least 30 years it is therefore important to avoid degradation of the PIB sealing and associated losses of the under pressure inside the module. Although the gas and humidity tightness of NICE modules has been indirectly demonstrated by the positive degradation test results according to the IEC standard 61215, this work presents a method to directly measure gas leakage rates of the PIB sealing in contact with the materials typically found in NICE modules: Glass, metal sheet and metal sheet covered with an organic electrical insulation coating. With a newly designed experimental set up the long term gas and humidity tightness of different sealing materials was evaluated by monitoring the under pressure in the closed volume of the experimental set up, under different conditions: room temperature, temperature cycles between -40°C and +85°C, elevated temperatures of + 85°C at 85% relative humidity and over an extended time cycle. The obtained results are very encouraging in that no under pressure loss occurred for two out of three tested sealing materials.

Keywords: Encapsulation, Module Manufacturing, Reliability

1 INTRODUCTION

The main feature of APOLLON SOLAR's NICE (New Industrial Solar Cell Encapsulation) module technology is the absence of EVA lamination and suppressing of the soldering of metal interconnectors to the solar cell busbars. Instead of EVA lamination, the NICE technology applies an edge sealing technology, based on an organic material from the family of poly-isobutylene (PIB), which is known from the insulating glass industry. This sealing material provides the long term gas and humidity tightness required for a long module lifetime. The electrical series connexion between solar cell busbars and metal interconnectors on NICE modules is obtained by the use of an underpressure inside the module, that creates a pressure contact between the electrical components and thus allows the suppression of soldering.

1.1 Underpressure in NICE Technology

In previous publications [1, 2] the gas and humidity tightness of NICE modules was indirectly proven by submitting modules to standard degradation tests that resulted in no power degradation after the different tests according to the IEC standard 61215.

According to our experiments, the minimal underpressure guaranteeing the electrical contact is 100 mbar. In addition, and in order to avoid cell breakage during thermocycling, the initial underpressure at ambient temperature has to be limited to 300 mbar. Taking into account the increase of pressure when the temperature rises (100 mbar at 85°C), the NICE process could allow a pressure loss up to 100 mbar in 30 years, still guaranteeing the performances.

1.2 Tightness measurement

The tightness of a material or a sealing is usually measured through a helium leakage test. From the simple qualitative Helium-detector to the more complex mass spectrometer, a wide range of equipments can be used according to the need of accuracy.

In the case of the NICE technology, we can define a criterion of leakage acceptability for a module over a 30 years lifetime:

$$q = V.\left(\frac{dP}{dt}\right)_V$$

Where:
V: Constant Volume of the module (L)
dP: Pressure variation (mbar)
dt: duration of the measurement (s)

Considering typical data of a NICE module, our criterion is:

$$q = 0{,}78.\left(\frac{100}{30.365.24.3600}\right)_V = 8{,}2.10^{-8}\ atm.cm^3.s^{-1}$$

This order of accuracy can only be reached with a mass spectrometer, which is the equipment we have used in the campaign described below.

1.3 Leakage modes

There are classically two types of leakage. The first one is interfacial: it is caused by defects in adherence or geometric capillaries at the interface; this type of leakage appears very fast in leakage tests, from some seconds two a few minutes.

The second type of leakage is permeation: it is caused by the permeability of the material itself, the gases penetrate through the material due to diffusion processes; this type of leakage depends only on material properties, and appears slowly in leakage tests, from some minutes to several hours.

2 RESULTS WITH HELIUM

2.1 Set up

In order to measure the tightness of our modules, we realized experimental setups representing a real module, but able to be measured in a little climatic chamber and connected to measurement instrument.

A flat cylindrical stainless steel tube is used as a base, onto which the three different materials under investigation are attached by a PIB sealing, in the same way as it is applied during the fabrication of NICE modules. Two pictures of the set up we used are presented below: in this case a glass is used to close the volume of the set up and between the two faces the black PIB sealing ring and secondary sealing can clearly be seen.

Figure 1: Set up with glass and its connection pipe

The so created closed volume is connected to a Helium mass spectrometer and a vacuum pump. The entire set up is inserted into a Helium containing container, the pressure inside the sealed volume is held constant while a potential leak of the sealing is detected by the Helium mass spectrometer. These measurements were carried out by the CETIM institute in Nantes (France), at ambient temperature in a first step. A schematic view of the experimental set up is presented in Figure 2.

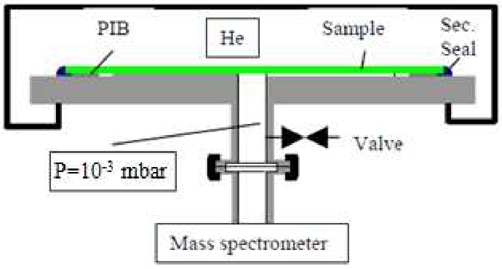

Figure 2: Schematic view of experimental setup

2.2 Test Conditions

Three test set ups were sealed with three different substrates, corresponding to the different back sheets we use in the NICE technology (metal, insulated metal and glass).

These first experiments were carried out at ambient temperature with a helium atmosphere, at a pressure difference of 1 bar between the inside volume and the outside atmosphere (inside: 10^{-3} mbar, outside: 1 bar).

In a second time, the set up were submitted to 50 thermocycles from(-40°C to +85°C.

2.3 Results at room temperature

These first results show a very good tightness to helium, comparable to a metal / metal sealing.

In a second step the measured leakage rates have been converted to the real scenario of a NICE module, which is flooded with Nitrogen as neutral gas. The Helium leakage rates were thus converted to Nitrogen leakage rates by using the generalised Knudsen equation, taking into account the molecular masses and the viscosities of both gases:

$$Q = \frac{\pi D^4}{256 \mu L}\left(P_{amont}^{\ 2} - P_{aval}^{\ 2}\right) + \frac{D^3}{6L}\sqrt{\frac{2\pi RT}{M}}\left(P_{amont} - P_{aval}\right)$$

L= Width of PIB sealing
D= Diameter of capillary
M= dynamic viscosity of Helium (Pa.s)
P_{amont}= external pressure (Pa)
P_{aval}= internal pressure (Pa)
T= Temperature (°K)
R= Coeff. of perfect gases equal to 8,31 J.mol^{-1}.K^{-1}

Table I: Leakage values by helium tests at room temperature:

	Glass	Steel	Isolation
Helium leakage (atm.cm^3.s^{-1})	1.10^{-9}	2.10^{-9}	7.10^{-9}
Equivalent nitrogen (atm.cm^3.s^{-1})	5.10^{-10}	1.10^{-9}	4.10^{-9}
Max pressure increase (mbar)	5.6	11.3	45

Table I summarizes the obtained results, namely the obtained Helium leakage rates for the three tested material/PIB combinations at an imposed vacuum of 1×10^{-3} mbar. The precision of the measurements was evaluated to be in the order of 25%. It has been found that the leakage rate was very stable at the indicated values for each material, and respects our leakage criterion.

At this stage, it is important to note that the use of the Knudsen equation is not valid for each material, and represents generally the most unfavorable case.

2.4 Results during thermocycling

In order to approach the real conditions of the module, we submitted our set up to thermocycles (-40°C to +85°C), and carried out the same measurement as in the previous experiments. All other conditions wer not modified (helium atmosphere, a pressure difference of 1 bar).

Figure 3 below presents the evolution of the partial pressures in one of the experimental set ups and the temperature changes as a function of time:

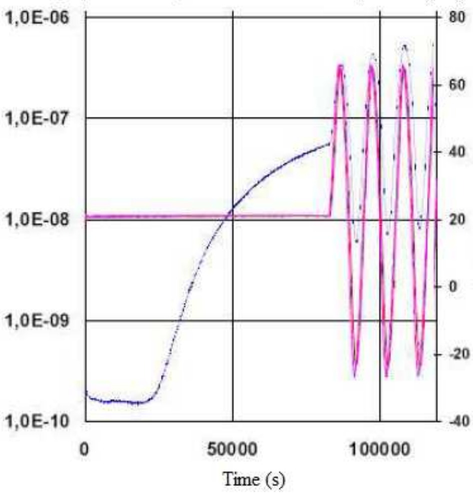

Figure 3: Evolution of leakage during thermocycling (blue = temperature; red = leakage)

The first conclusions we can draw from this result is the fact that no interfacial leakage appears. Indeed, the leakage curve (blue), indicates a slow establishment of the leakage: an interfacial leakage would have presented a brutal jump after a few minutes.

The second observation indicates that the most important leakage appears at high temperatures, which is a typical behavior for polymers.

Finally, no material ageing has been observed: the leakage levels did not evolve during the 50 cycles, independent of the substrate that has been used.

Table II below presents the numerical results obtained at high temperature for each substrate:

Table II: Maximum leakage values by helium tests during thermocycling

	Glass	Steel	Isolation
Helium leakage ($atm.cm^3.s^{-1}$)	6.10^{-7}	8.10^{-7}	5.10^{-7}
Equivalent nitrogen ($atm.cm^3.s^{-1}$)	3.10^{-7}	4.10^{-7}	$2.5.10^{-7}$

Following these results, PIB is not tight enough. But the result's transition from helium to nitrogen (and air) is only theoretical, and cannot be proven without other permeation test with air.

Moreover, the test conditions are far from the real conditions that a module is exposed to, concerning the pressure difference between the inside and the outside: while a real PIB sealing is exposed to a 300 mbar underpressure, the test set ups were exposed to a 1000 mbar difference. This is why we carried out further advanced experiments with the Fraunhofer ISE in Friburg (Germany).

3 RESULTS WITH AIR

3.1 Set up

Some modifications have been done on test set ups, in order to connect the additional equipment needed for these air leakage tests. Since no clear difference has been noticed between set ups equipped with different substrate (glass, metal, and isolated metal), we decided here to test three set ups with different type of PIB materials, from different manufacturers. Figure 4 below presents a modified experimental set up with its three connection pipes.

Figure 4: Modified set up for air leakage tests

3.2 Measurement configuration

The aim of this test is to approach the real conditions of the sealing in a NICE module. Therefore helium has been replaced by air at 85% relative humidity, the closed volume of the set up has been filled up with nitrogen (>96%) at a pressure of 800 mbar (inside pressure at 85°C in the module), and the whole set up placed in a climatic chamber at a temperature of 85°C in order to observe the highest possible leakage level.

The setup is subjected to humid air at 1bar and 85°C, and connected to a mass spectrometer through a capillary, since the mass spectrometer cannot make any measurement at a high pressure such as the one inside the set up (800 mbar): the capillary causes a pressure fall, allowing the mass spectrometer to make a correct measurement. Contrary to our first experiments, the used spectrometer here is a multigas equipment: it allows an observation of the partial pressure evolution for each gas under observation. The whole setup is presented in the Figure 5 below:

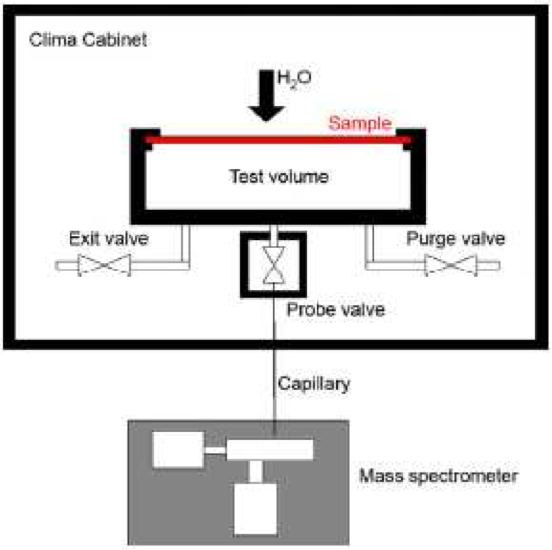

Figure 5: Modified experimental set up for air leakage tests

2.3 Results

The first tested sealing material (PIB 1) shows a very important leakage rate: we can observe on Figure 6 below that water vapor penetrates very quickly through the material, leading to a global pressure reaching the outside pressure of 1000 mbar, and a high rate of water vapor inside the set up. These results are obviously not satisfying for our technology.

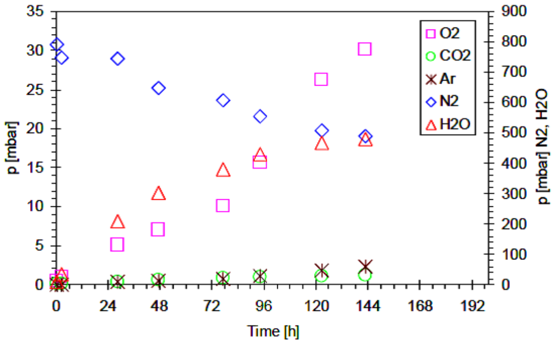

Figure 6: Gas concentration evolution: PIB 1

An explanation of these results can be related to the mechanical behaviour of PIB: depending on its composition and its adhesive properties, its adhesion to glass and metal can be insufficient. This was the case for this material: PIB migrated into the grooves, driven by the pressure difference and poor adhesion, probably generating defects in the tightness. Figure 7 presents the cases of a PIB that did not adhere and was driven to move inside the adjacent groove and a PIB that perfectly adhered to the two materials without moving due to the underpressure.

Figure 7: PIB that has migrated into the groove due to non sufficient adhesion (left) and PIB that adhered perfectly (right).

By PIB 2, no evolution of gas concentration has been observed: particularly, the rate of nitrogen N_2 remains constant over the 168 hours test period. This result allows us to have the first conclusions on the PIB tightness: even if the time period, during which these experiments have been done, is short, the accuracy of the measurement is high enough to deduce that our tightness criterion is respected for nitrogen.

Figure 8 below presents the evolution curves for gas relative pressure inside the set up (for N_2, H_2O, O_2, CO_2 and Ar):

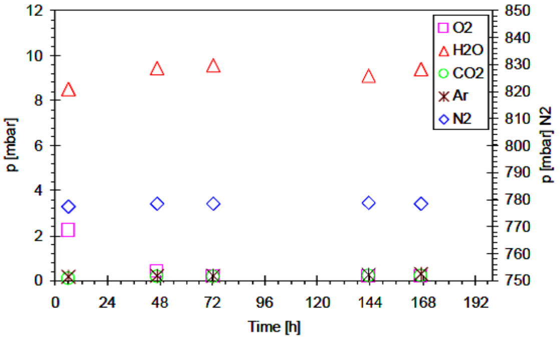

Figure 8: Gas concentration evolution: PIB 2

By PIB 3, we observed phenomena of sorption/desorption in the set up: the stabilization of nitrogen and water concentrations after 96 hours indicates that this evolution is typically due to this effect. Gas molecules have been absorbed at the glass' and metal's surface, and then released during the experiment: in order to definitely validate this point, a prolongation of the experiments is necessary.

Figure 9 below presents theses evolutions, and particularly the stabilization of gas concentration after 96 hours.

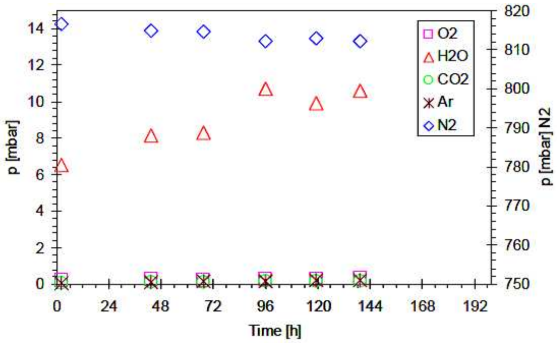

Figure 9: Gas concentration evolution: PIB 3
Desorption and stabilization after 96 hours

4 CONCLUSION

We have performed several experiments in order to determine the tightness of a PIB sealing, in the framework of the NICE module. To realize this objective, we designed a specific set up able to be connected to a mass spectrometer, and to be submitted to variable climatic conditions. Thus, we established a method to determine the tightness of PIB sealing, allowing to check any new combination of sealing materials and substrates to be verified.

The first results obtained with classical tightness investigation equipments showed that only permeation processes are to be taken into account in this case. But the theoretical transformation from helium numerical results to nitrogen (and then to air) presents limitation we had to overtake. Furthermore, classical equipments do not allow to submit the set up to similar conditions than a real module neither in terms of absolute pressure nor of relative pressure.

That was the reason of a second tests campaign, measuring with a high accuracy the evolution of partial pressure for each gas able to flow through the PIB sealing. The results put to evidence that this set up allows to characterize materials in different configurations: some materials have insufficient adherence properties and cause important tightness defects, while other materials resist very good to high temperature and humidity, guaranteeing a sufficient underpressure in NICE modules during a 30 years lifetime.

Nevertheless, we have to pursue these measurements with other type of substrate eligible to the NICE back sheet, and during a longer test period in order to avoid sorption/desorption effects.

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6 REFERENCES

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