Hindawi Publishing Corporation
International Journal of Photoenergy
Volume 2007, Article ID 27610, 5 pages
doi:10.1155/2007/27610

Research Article

Solar Module Fabrication

A. El Amrani, A. Mahrane, F. Y. Moussa, and Y. Boukennous

Silicon Technology Unit, 2 Boulevard Frantz Fanon, BP 140, Alger-7 merveilles, Algiers 16200, Algeria

Received 15 July 2006; Accepted 13 February 2007

Recommended by Nicolas Alonso-Vante

One of the most important steps in the photovoltaic industry is the encapsulation of the solar cells. It consists to connect the cells in order to provide useful power for any application and also protect them from environmental damages which cause corrosion, and mechanical shocks. In this paper, we present the encapsulation process we have developed at Silicon Technology Unit (UDTS) for monocrystalline silicon solar cells. We will focus particularly on the thermal treatment, the most critical step in the process, which decides on the quality and the reliability of the module. This thermal treatment is conducted in two steps: the lamination and the polymerization. Several tests of EVA reticulation have been necessary for setting technological parameters such as the level of vacuum, the pressure, the temperature, and the time. The quality of our process has been confirmed by the tests conducted on our modules at the European Laboratory of Joint Research Centre (JRC) of ISPRA (Italy). The electrical characterization of the modules has showed that after the encapsulation the current has been improved by a factor of 4% to 6% and the power gain by a factor of 4% to 7%. This is mainly due to the fact of using a treated glass, which reduces the reflection of the light at a level as low as 8%.

1. INTRODUCTION

In the photovoltaic fabrication line, the aim of the encapsulation step is to interconnect solar cells by soldering and packaging them into a weatherproof glass faced structure known as module. The cells are interconnected in series or parallel to give the appropriate current and voltage levels providing useful power. The packaging consists of a glass/polymer resin/back face protection which allows to solar cells circuit electrical isolation and protection from environmental damage in which they operate such as moisture, rain, snow, dust, and mechanical shock. This protection must insure to the modules a lifetime of twenty years.

The most important stage of the encapsulation is the thermal treatment of the polymer resin. The thermal treatment is performed in the laminator (Figure 1) in two steps, the lamination and the curing. The principle of the thermal treatment is to bond multiple layers of materials together with thermo sensitive polymer films.

The processing chamber has temperature, vacuum, and pneumatic pressure capabilities which are independently controlled to provide optimum processing conditions.

Practically, the electrically connected cells are sandwiched between two sheets of EVA and positioned on the glass sheet which will form the front surface of the module. The rear surface may be a glass (biglass process) or a multilayer sheet of Tedlar-Aluminium-Tedlar (monoglass process). The latter process has been chosen and developed because of its low cost and best performances.

2. MODULES COMPOSITION AND MATERIALS USED

The photovoltaic module consists of assembling a batch of 36 monocrystalline cells. They are interconnected and packed in a transparent resist, the EVA. The front and the back of the cells are covered, respectively, with a plate of glass and a waterproof multilayer sheet. Figure 2 illustrates the solar module composition. We will give, in the following, more details about the materials used.

2.1. The glass

It is a tempered and textured glass of 4 mm thickness with low iron content to allow transmission of short wavelengths in the solar spectrum. This optical glass characterization by means of the spectrophotometer (Varian Cary 500 UV-VIS-NIR) shows an optical transmission around 95% in the useful range of the solar spectrum 380 nm–1200 nm (Figure 3). Its external face is chemically treated with the fluosilicide acid (H_2SiF_6) to generate a porous layer of 1100 A depth. These

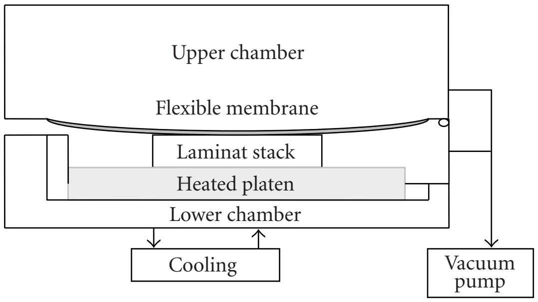


Figure 1: Schematic of the laminator.

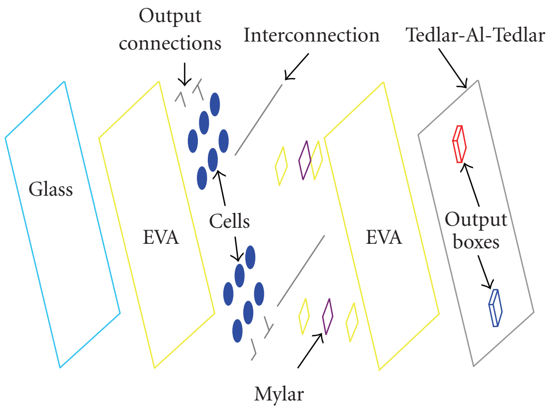


Figure 2: Exploded view showing the different layers which make up the module.

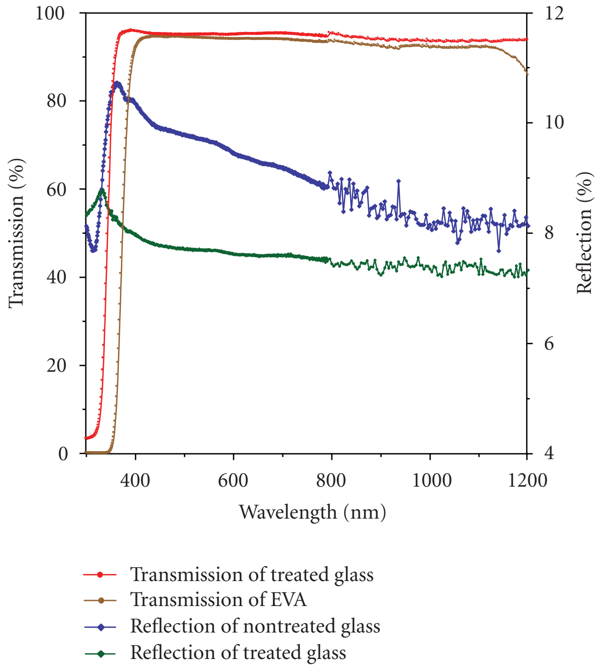


Figure 3: Optical transmission and reflection of the glass and the EVA used for the fabrication of the UDTS's modules.

Table 1: Composition of ELVAX 150.

Composition	Proportions (%)
Vinyl acetate	32–34
Curing agent	1.5
Photo-antioxidant	0.1
Thermo-antioxidant	0.20
UV absorber	0.25
Adhesive agent (Silane A174)	1

Table 2: EVA properties [1].

Properties	
Thickness	≈ 0.45 mm
Density	0.957 g/cm^3
Breakdown elongation	900–1100%
Elasticity modules	4.8 MPa
Electrical resistivity	10^{14} Ω cm
Melt index (190°C/2.16 kg)	43 g/10 min
Melting point	63°C
Water absorption	0.05%–0.13%
Refractive index	1.482

pores trap the incident light reducing the surface reflection to a value lower than 8% in the range of 380 nm–1200 nm as shown in Figure 3.

2.2. *The resin (ethylene vinyl acetate)*

It is a thermo-sensitive transparent resin of ethylene vinyl acetate (EVA) copolymer, ELVAX 150 type from Dupont de Nemour. It is 32–34 weight percent vinyl acetate compounded with additives such as a curing agent, a UV absorber, a photo-antioxidant (Tinuvin 770) and a thermo-antioxidant (Naugard P).

Tables 1 and 2 give, respectively, the composition and the properties of this material.

In the range of 400 nm–1100 nm it shows nearly the same optical transmission than the glass (Figure 3). The four properties which make the EVA encapsulation choice material are:

(i) its high electrical resistivity which makes it as a good electric insulator,
(ii) its low fusion and polymerization temperature,
(iii) its very low water absorption ratio,
(iv) its good optical transmission.

2.3. *The Mylar*

Mylar or polyethylène terephtalate film (PET) is a hard, strong, dimensionally stable material that absorbs very little water. It has good gas barrier properties and good chemical resistance. It is used to electrically isolate the output connections from the back of the cells. It is a 56 μm thick and transparent film with a high dielectric constant (Table 3).

Table 3: Properties of polyethylene terephthalate.

Properties	Value
Dielectric strength @25 μm thick	300 kV mm^{-1}
Permeability to water @25°C	100×10^{-13} $cm^3 \cdot cm\ cm^{-2}\ s^{-1}\ Pa^{-1}$
Thermal conductivity @23°C	0.13–0.15 W m^{-1} K^{-1}
Surface resistivity	10^{13} (Ohm/sq)
Melting point	260°C

2.4. *The multisheet Tedlar-Aluminium-Tedlar*

The back of the module is a multilayer film of Tedlar-Aluminium-Tedlar. The Aluminium sheet is used to protect the module against humidity and mechanical shocks [2, 3]. It is sandwiched between two sheets of Tedlar of 180 mm thickness. In order to reflect the maximum light towards the cells, we have used a white Tedlar.

3. PROCESS DEVELOPED AT UDTS

The lamination cycle is an empirically determined sequence of events. The main objective is to determine the shortest sequence which produces a good lamination without negative effects to any of the laminate components. The most critical part of the lamination cycle is the part prior to plastic melt of the sheet encapsulant. The amount of time the assembly is under vacuum, the time at which pressure is applied, the temperature when pressure is applied, and the duration and quantity of pressure all affect the quality of the lamination.

As the polymerization reaction is irreversible, the thermal treatment step is crucial in the solar cells encapsulation process. It is a decisive step for the quality of the module and for its lifetime. If a default (break, short circuit, string moving) happens during the polymerization, the module will be rejected.

The lamination cycle is performed in Spire SPI SUN 240. It starts with the introduction of the laminate stack (cells and the encapsulant materials) in the lower chamber where the temperature is kept constant at 100°C. The upper chamber is under vacuum (0.1 mm Hg).

The lamination operation is conducted in two phases (Figures 4 and 5).

(i) In the first, the air inside the lower chamber is removed during 5 minutes. The pressure is then set at 0.1 mm Hg and maintained at this value during both the lamination and the polymerization cycles.

(ii) In the second phase, the upper chamber is filled with air to provide pressure on the module. During this step, the combination of the lower chamber air-pumping and the pressure applied by the membrane allows to drive out the residual air and moisture present in the laminate.

And meanwhile, the module is heated and the EVA melts and surrounds the electrical circuit forming seals to the glass front and back sheet of the module. Note that additional EVA material is added at the module perimeter to ensure complete sealing of the module edges.

The curing is done at 156°C and lasts 15 mm. The EVA resin polymerization occurs during this step. The EVA crosslinks forming a chemical bond which hermitically seals the module components. At the end of this step we get a compact structure, the photovoltaic laminat.

After cooling at 100°C, the lower chamber is at the atmospheric pressure and the upper chamber is at 0.1 mm Hg. This is “the long cycle” of the encapsulation process which is conducted completely in the laminator (Figure 5).

In the industry, the short or fast cycle is used for higher throughput. Its average duration is about 22 minutes if we do not take intoaccount the time of load and unload of the module. The short cycle finishes with the lamination step (6 minutes). After setting the laminator in unload conditions, the laminat is withdrawn from and placed in the curing oven for the required reticulation process.

4. PROCESS FABRICATION EVALUATION

In order to evaluate the fabrication process developed at UDTS, we have fabricated 9 modules using four inches square monocrystalline silicon solar cells. Each module consist of 36 electrically series-connected cells. These current well-matched solar cells are arranged in three strings of 12 cells.

At first, we have conducted reticulation tests of the EVA to be sure that the thermal treatment parameters lead to a sufficient EVA curing. Lot of samples has been analyzed by the EVA gel content test method. The gel percentages calculated were lying in the 83%–85% range involving a good treatment. These results were confirmed by the aging tests conducted on the same modules at the European Laboratory ESTI of JRC ISPRA, Italy [4].

In addition, electrical characterization of the modules has been done with two different simulators, the SPIRE SPI-SUN 240 simulator at the UDTS and the LAPSS of the ESTI (JRC-ISPRA). The typical electrical characteristics measured by each of them are given in Table 4.

5. DISCUSSION

The average efficiency of the nine nonencapsulated modules is 10.5% whereas efficiency of the constituent cells is 12.3%. This module efficiencies decrease is due to three factors: series resistance, mismatch between the electrical characteristics of the components cells, and to the total area of the module.

(1) The series resistance increases substantially on cells interconnection soldering regions raising the dissipated generated current.

(2) In addition, whilst the open-circuit voltage of the module becomes the sum of the voltages from each

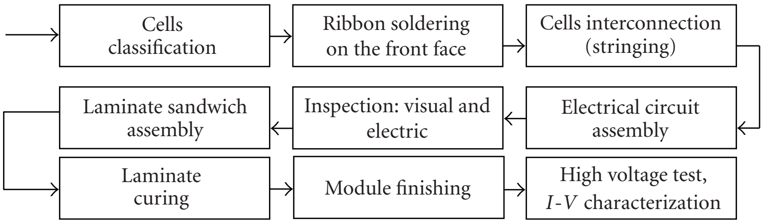


Figure 4: Flow chart of the solar module fabrication process.

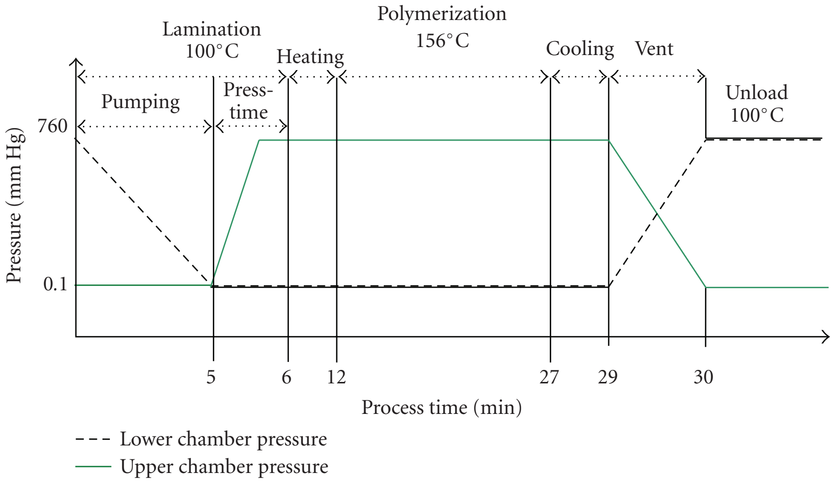


Figure 5: Thermal treatment profile (long cycle) in the laminator.

cell, the module short-circuit current is equivalent to the lowest cell short-circuit current.

(3) In order to avoid the short circuit it is necessary to have the cells physically separated. The sum of the cell areas represents 89% of the total module area. As the efficiency of a cell is related to the total area of the cell, in the same way the module efficiency is related to the total area of the module therefore the module efficiency is lower than the cell efficiency. Typically, a photovoltaic module will have a packing density in the range 80%–90% and this involves an efficiency reduction of 2% [3].

When encapsulated, the average modules efficiencies increased by 1% absolute.

This enhancement is mainly due to the lower level of the light reflection at the interface cells-glass back face. The incoming light is trapped and optically amplified by bouncing in the porous microstructures of the glass before to be 95% transmitted to the cells surface. Efficiency improvement is also due to two other effects. The first is the well optical matching of the glass/EVA/TiO_2 ARC structure and the second is the white color of the Tedlar which reflects the maximum of the light towards the back of the cells. All of these three effects increase the current. Indeed, a relative increase of 9% has been observed on the short-circuit current.

Table 4: Comparison of SPI SUN and ESTI encapsulated module electrical characteristics.

Electrical characteristics	SPI-SUN (UDTS)	LAPSS (ESTI)
Isc (A)	3.38	3.25
Voc (V)	20.9	21.9
FF (%)	69.76	71.1
Efficiency (%)	12.10	11.9
Serie resistance (Ω)	1.7	2
Isc (Spectral response) (A)	—	3.24

For evaluating the encapsulation effect, the two parameters (α, β) have been calculated [2].

$$\alpha = \mathrm{Pm(E)/Pm(NE)}(\%), \tag{1}$$

where

Pm(E), the maximum power after encapsulation;
Pm(NE), the maximum power before encapsulation.

And

$$\beta = \mathrm{Isc(E)}/\mathrm{Isc(NE)}(\%), \qquad (2)$$

where

Isc(E), the short-circuit current after encapsulation;
Isc(NE), the short-circuit current before encapsulation.

The I(V) characteristics of the modules before and after encapsulation have given, respectively, the following results:

α = 1.04 and 1.07 power gain increase comprised between 4% and 7%.
β = 1.04 and 1.06 current gain increase comprised between 4% and 6%.

6. CONCLUSION

We have presented in this paper the encapsulation process of monocrystalline solar cells developed at UDTS. This process whose reliability was confirmed by the tests conducted at JRC ISPRA have revealed an improvement of the electrical characteristics of the modules after the encapsulation. This improvement is mainly due to glass optical properties. It is to be noticed that the technological parameters given in this paper are related to the type of the EVA used and the characteristics of the laminator used. The EVA is widely used for the encapsulation of solar cells. Nevertheless, nowadays the EVA can be replaced by the PVB which has two advantages: its stability to UV radiations and it's great adhesion to the glass [5].

REFERENCES

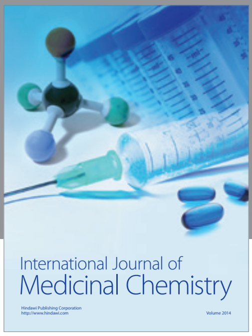
[1] Data sheet Dupont de Nemours DuPont$^{\text{TM}}$Elvax$^{\circledR}$ Grade Selection Guide for Adhesives, Sealants and Wax Blends pp3, 2005.

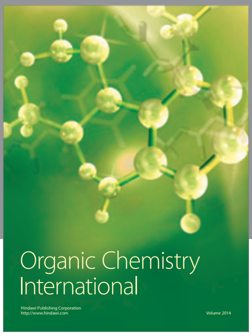
[2] I. J. Muirhead and B. K. Hawkins, "An assessment of photovoltaic power in the Telstra network," *Fuel and Energy Abstracts*, vol. 37, no. 4, p. 278, 1996.

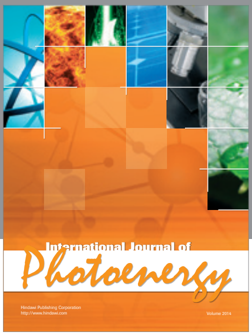
[3] N. M. Pearsall and R. Hill, "Photovoltaic modules, systems and applications," in *Clean Electricity from Photovoltaics*, M. D. Archer and R. Hill, Eds., vol. 1 of *Series on Photoconversion of Solar Energy*, pp. 1–42, World Scientific, London, UK, 2001.

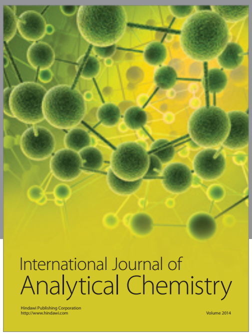
[4] Y. Mesbahi and A. El amrani, "Test d'homologation des modules UDTS," Internal report, UDTS, Dubuque, Iowa, USA, 1998.

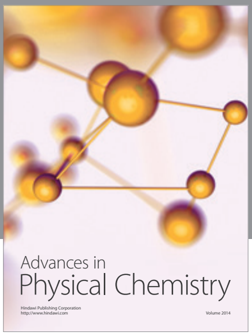
[5] H. Schmidhuber and K. Krannich, "Why using EVA for module encapsulation if there is a much better choice?" in *Proceedings of the 17th European Photovoltaic Solar Energy Conference and Exhibition*, vol. 1, pp. 662–663, Munich, Germany, October 2001.

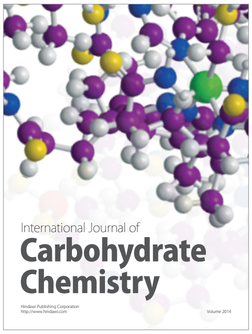

International Journal of
Medicinal Chemistry

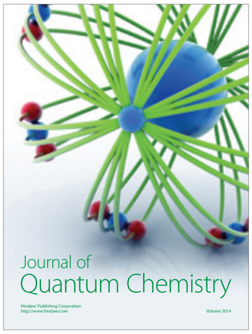

Organic Chemistry
International


International Journal of
Photoenergy

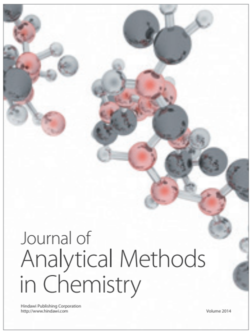

International Journal of
Analytical Chemistry


Advances in
Physical Chemistry

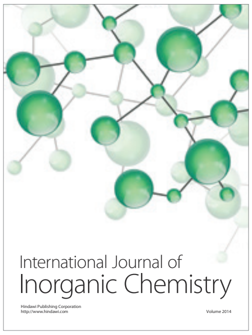

International Journal of
Carbohydrate Chemistry


Journal of
Quantum Chemistry

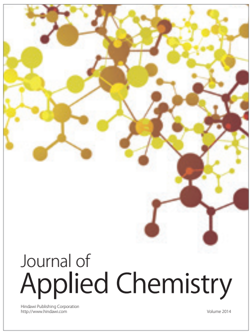

The Scientific
World Journal

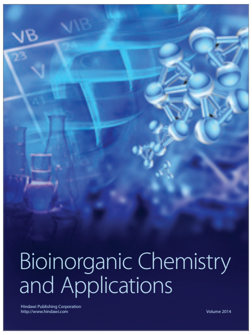

Journal of
Analytical Methods
in Chemistry


Journal of
Spectroscopy

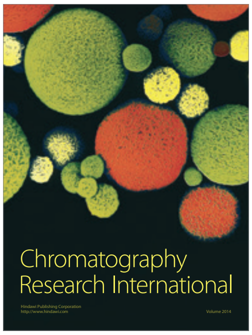

International Journal of
Inorganic Chemistry

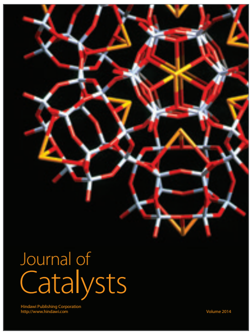

International Journal of
Electrochemistry

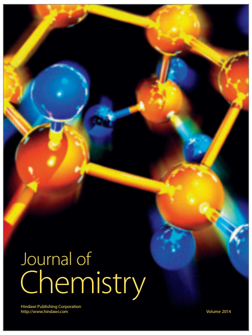

Journal of
Applied Chemistry


Bioinorganic Chemistry
and Applications


Journal of
Theoretical Chemistry


Chromatography
Research International


Journal of
Catalysts


Journal of
Chemistry


International Journal of
Spectroscopy