LAMINATING PV MODULES WITH EVA USING SOLAR OVENS

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ABSTRACT

More than three decades ago, The Jet Propulsion Labs in California developed methods of manufacturing PV modules using Ethylene Vinyl Acetate (EVA) as the encapsulant. This encapsulation method has become the industry standard used for virtually all the certified PV modules sold and installed worldwide However, this system needs special, complex laminating machines precluding its use as a cottage industry for people in the developing world. This paper reports on a simplified encapsulation system that uses weights in solar ovens to encapsulate PV modules with the new fast-cure EVA formulations. This new encapsulation system is now successfully being used in a village in Nicaragua to replace a previous encapsulation method that used an expensive two part silicone encapsulant that could be cured at room temperature, The drop in the price of finished commercial modules has required a reduction in the cost of the encapsulation material, which had gotten to be about equal to the cost of the cheaper PV cells. This work, the details of which are given in this paper has been successful ensuring that cottage PV module manufacturing is still a viable option for developing countries.

1. INTRODUCTION

Over one half of the people living in the rural areas of developing countries have no access to utility grids. Photovoltaic (PV) electricity is often the most ideal solution to the problem of furnishing these people with electricity but the PV systems are generally far too expensive for the average rural peasant to afford, and an entire infrastructure needed to be created for the installation and maintenance of these systems. Over the past decade, we have developed techniques that allow the peasants to build and install their own PV systems[1].

Back in the late 1970s, the newly formed US Department of Energy (DoE) gave the Jet Propulsion Laboratory (JPL) in Pasadena California the mandate to develop an inexpensive, stable and reliable method of encapsulation for the crystalline silicon PV cells used as the most common material for manufacturing PV modules. They were very successful with a method using heat cured ethylene vinyl acetate (EVA), which became the standard method of encapsulating these cells for the entire PV industry which produces high quality modules that could be sold with 20 to 25 year guarantees[2]. However, the process normally calls for an expensive, energy intensive vacuum laminating machine and large production rates to justify the capital costs making the method unacceptable for a cottage industry of producing PV modules in developing countries, since it requires a large capital investment, complex machinery and large amounts of utility electricity to run the equipment.

Three years ago, Richard Komp and Mauro Perez a Nicaraguan peasant and landmine survivor working in a remote village workshop, started experimenting with a roll of EVA encapsulant to see if it was possible to use the material without the usual laminating machine. We succeeded in encapsulating small sample pieces of broken PV cells between two pieces of glass; by putting the sandwich in a clear polyethylene bag, pumping all the air out of the bag with a small hand pump hooked up backwards to suck instead of pumping air, then tying off the bag to keep the vacuum and then putting the little bagged "module" on a brick in a solar oven and laying another brick on top to give the required laminating pressure. The work was not continued until recently, when the continual rise in the price of the Dow Chemical Sylgard 184 silicone we have been using as our encapsulant in the cottage PV module manufacturing process[3] forced us to look for alternatives.

In the summer of 2010, coauthor Christopher Orr, an intern from the Falls Brook Centre in New Brunswick Canada came down to Nicaragua to work with the Grupo Fenix and was looking for a project to participate in with Susan Kinne and the Solar Women of Totogalpa. We decided to revive the experimental work of EVA encapsulation. Using the sample rolls of EVA donated to the Grupo Fenix by the University of New South Wales in Australia, we started laminating small pieces of broken PV cells in a sandwich comprising a glass front, two sheets of the EVA with the piece of PV cell between them and a polyvinyl chloride back sheet, all inside a polyethylene plastic bag. We discovered that the vacuum was not necessary, simply using sufficient weight would force the air out of the sandwich. We then graduated to larger laminates with four PV cells soldered together in series to make an actual solar battery charger, and started to take notes of the work and the times and temperatures involved in the process.

2. THE MODULE ASSEMBLY PROCESS

2.1 Details of the Basic EVA Module Assembly Process

This method was developed in Nicaragua by Dr. Richard Komp, Susan Kinne and Christopher Orr, for use in the field, to allow for secure sealing of cells and PV modules while away from standard power sources and without expensive laminating machines.

The first step is soldering PV cells into series strings using thin ribbons of tin plated, annealed copper. The Evergreen Solar string ribbon grown cells we used in these experiments normally came with 1.5 mm wide by 0.25 mm thick ribbons already attached to their front (n-type) surface, but in some cases we soldered our own 2 mm wide by 0.15 mm thick ribbon. Since these PV cells are only 0.12 mm thick, care is needed in this and all subsequent steps. Most of the experiments used short strings of four 65 mm by 32 mm cells, to produce a 1 Watt 2 volt solar battery charger for 1.2 volt NiMH or 1.5 volt alkaline dry cells; but as we developed the laminating techniques, we assembled longer strings of larger PV cells for more powerful modules.

After the string of PV cells was tested using the outdoor sun, the lamination process was started. A piece of ordinary window glass 9 cm x 18 cm by 3mm thick was cut and cleaned. Two pieces of 0.4mm thick Specialized Technology Resources (STR) Photocap 33554-P/UF fast-curing EVA were cut slightly smaller than the glass size and the first sheet was laid directly on the glass. Then the string of PV cells is laid face down on the EVA and the second piece of EVA was laid on top. A piece of 0.25mm thick white or clear soft polyvinyl chloride film was cut slightly larger than the glass and laid on the top. A second piece of glass the same size as the first is placed on the top to act as a pressure equalizer and the whole sandwich was slid into a plastic bag and masking tape was wrapped around the entire package to keep anything from moving during the lamination.

2.2 The Solar Oven Curing Process

For the small PV modules, a solar oven was used as the heating chamber. A red clay tile or a brick was used as the bottom platen and red clay bricks were used at the weights on top of the PV module sandwich. Normally only one brick was used for the small solar battery charger modules.

Fig 1 Richard Komp with the solar oven used for laminating the PV modules, showing the clay tile platen used under the module sandwich. This platen has electric heating elements buried in the middle.

Sometimes the platen and the bricks were preheated in the oven before the module sandwich was put between them, but normally the whole assembly was put in at room temperature and the oven set up to start heating. These solar ovens have been developed by the Grupo Fenix based on a design promoted by William Lankford in Nicaragua over more than ten years and are now being made by the Solar Women of Totogalpa under the tutelage of coauthor Susan Kinne. They are well sealed and heat up quickly once the oven is turned to face directly into the sun and the cover reflector is adjusted to bring the reflected light squarely into the double glazed top opening. A small mirror on the front of the reflector aids in this aiming process. The front door opening in the oven we used was fitted with a custom made silicone rubber gasket to give a tight seal with a tiny opening to bring out the type K thermocouple wire we used to measure the oven platen temperature. A separate oven thermometer was also used to measure the air temperature in the oven, but normally, these agreed with each other within a degree C.

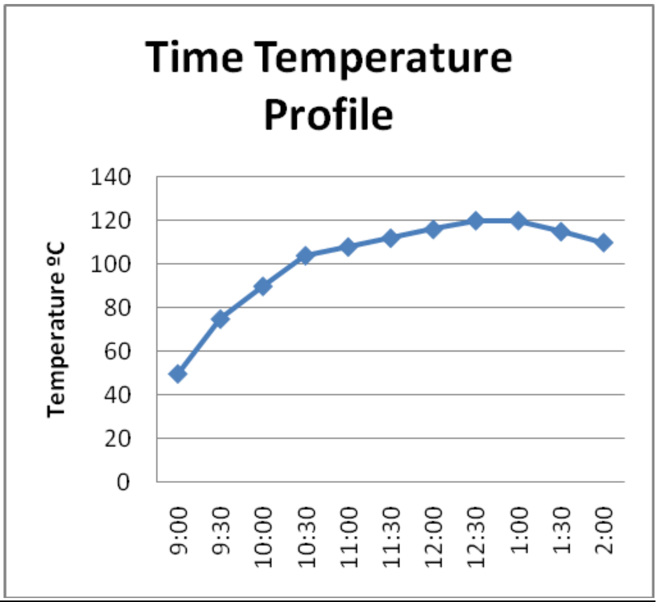

Fig 2 The time-temperature profile for a typical encapsulation: Number 9 on 28 October 2010.

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At first we assumed that we had to reach a temperature of at least 120º C but later on Chris Orr discovered that the Photocap 33554-P EVA would reach more than 80% cross linking at a temperature of only 110º C. There is some evidence that sufficiently complete cross linking may take place at temperatures as low as 105º C but we have not determined this yet and always waited until the oven got to at least 110º C before removing the sandwich. Sometimes clouds would obscure the sun and the oven never reached the EVA curing temperature. We would simply leave the PV module sandwich in the oven and continue the lamination the next day, with no apparent detriment to the quality of the final PV module.

3. <u>RESULTS</u>

3.1 <u>Small Solar Battery Chargers</u>

During this set of experiments in 2010, we produced a total of 15 finished PV modules encapsulated with the EVA materials. Three of these were small test laminations to determine the proper encapsulation procedures, two were small experimental two cell modules laminated between two pieces of glass instead of the PVC backing sheet and one was a small sample to test a new large solar oven made from a solar food drier used to make the final module. However, six of the tests produced solar battery chargers. While five of these are of the type using four small PV cells, one used full size 80mm by 150mm Evergreen Solar cells and produced 3.5 amps at 2 volts (7 Watts) to quickly recharge large NiMH D cells.

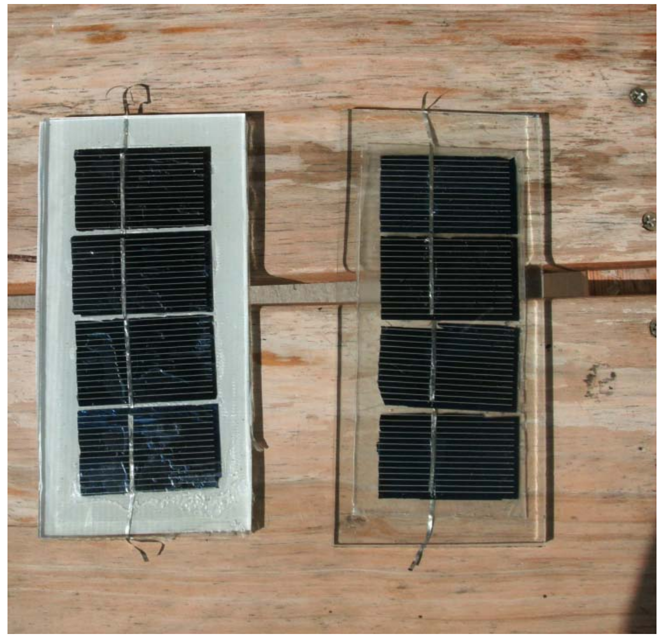

Fig 3 Two small solar battery chargers. The charger on the left with a white PVC back was encapsulated using the two part silicone encapsulant the Solar Women of Totogalpa normally use, while the charger on the right was one of the first modules made with EVA cured in a solar oven. We used a clear PVC plastic backing sheet but didn't make the EVA sheets as big as required.

After successfully making the five PV cell solar battery chargers, we made a 12 cell solar cell phone charger that works perfectly with most brands of cell phones (once you find the proper plug for a particular cell phone).

3.2 <u>The Large Laminating Machine</u>

The next step was to convert an older solar food drier into a solar laminating machine capable of handling modules more than 120 cm long and 50 cm wide. This would make it possible to produce 65 watt PV modules using 36 full size Evergreen Solar cells. Chris Orr carefully rebuilt this solar drier, adding double glazing, a wide, well fitting door and a large reflector lid to increase the solar input power. The new device easily reaches temperatures over 120º C. Because the heat gain of a solar oven is directly proportional to the size of the glazing and reflector areas and the heat loss is mostly related to the heat loss through the tiny air gaps in the construction, the large solar ovens are more efficient than the smaller ones and will reach a higher temperature under the same sunlight conditions. Chris Orr used two heavy 120 cm x 50 cm x 3 mm thick steel plates to act as the lamination platen and weight and after testing the machine, successfully made a 40 cm x 80 cm 32 Watt PV module using 36 half cells cut from cracked or broken Evergreen Solar cells. This module produces 1.78 amps at 18 volts at its maximum power point to produce 32 Watts.

Fig 4. Rich Komp Testing the 32 Watt PV module made in the larger solar laminating oven with the small laminating oven in the background.

This 32 watt module has some areas where trapped air has created spaces in the front of the lamination but the PV cells are completely sealed and protected. It may be that simply applying more pressure than the weight of a single steel sheet will solve this problem and it may not be necessary to incorporate a vacuum bag and pump into the design. The bricks needed to produce this weight can be preheated in a solar oven to speed up the laminating cycle.

4. FUTURE WORK

The next step in the development of the solar laminating system is to start to produce 65 watt PV modules using full size Evergreen solar cells. These 106 cm x 50 cm modules with three rows of 12 cells each, will fit in the new bigger solar cooker and with a large quantity of bricks, the proper laminating pressure should be obtainable. Because the cost of the EVA laminating sheets is about $1/10^{th}$ the price of the two-part silicone they are currently using, the cost of these PV modules should be low enough that the Grupo Fenix will be able to compete with the Chinese modules now being imported to Nicaragua and still make a good profit[4].

One of the problems that has occurred many times is clouds obscuring the sun in the middle of a laminating session, dropping the temperature before the cross linking has completed. Richard Komp has started work on a solar thermal-electric hybrid oven. He constructed a 20 cm x 20 cm ceramic platen that incorporates ceramic power resistors in a series parallel arrangement to produce 150 watts of electric heat from a 12 volt input.

Fig 5 The 32 Watt EVA encapsulated PV module charging a 12 volt storage batterybeing used to power the experimental solar electric platen heating the solar oven used to laminate the PV modules. The module still needs its aluminum frame.

This solar electric hybrid will have a thermostat incorporated in the side of the case to maintain a set minimum temperature when the sun is obscured. We intend to use thermostats from old toaster ovens for these experiments. These platens can also be incorporated into the solar food cooking ovens made by the Solar Women of Totogalpa and with a PV module, can be used in places without electric utility power.

5. CONCLUSIONS

We have shown that it is possible to use EVA to laminate photovoltaic modules without the need of a large, expensive laminating machine. Neither a vacuum system nor electric power is needed in order to get complete cross linking of the EVA encapsulant and produce high quality PV modules in a cottage industry setting that will last more than 25 years. This work will continue the work that we have been undertaking in many parts of the developing world to not only bring affordable electric power to these rural areas, but to do so in a way that supports the economy of the area and creates local jobs[5].

6. REFERENCES

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