

CAPILLARITY SOLAR CELL ENCAPSULATION: A NEW VACUUM-FREE, COST-EFFECTIVE ENCAPSULATION TECHNIQUE COMPATIBLE WITH VERY THIN STRING RIBBONS

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ABSTRACT: This work describes a new encapsulation process: strings of cells are first positioned face-up on a porous layer (namely, in this study, a large sheet of white paper). Then liquid RTV silicone is poured on top of them. The excess liquid silicon impregnates the paper, creeps by capillarity under the cells creating a watertight seal around the cells and the tabbing material. A standard glass is then laid on top of the encapsulated strings, weighted, and left for complete curing for several hours at room temperature. After curing, the panel is flipped over and protected with a back plastic sheet. Despite the rural conditions of manufacturing, the resulting 36-String-Ribbons panels are very professional looking, and display a short-circuit current of 4 A, for an open-circuit voltage of 21 V, while they deliver an approximate 60 W at maximum output power. The success of this study proves the principle of capillarity encapsulation. The technique can probably be optimized in several ways, but the interesting and original concept can seed ideas for Northern hemisphere module technology developments.

Keywords: Encapsulation, Ribbons, Developing countries

1 INTRODUCTION AND CONTEXT

The encapsulation of solar cells into a solar module ensures good mechanical properties and protection against moisture that would rapidly lead to contact corrosion, and electrical characteristic degradation. In state-of-the-art solar modules, the module assembly (including materials) accounts for 30% of the cost of the solar panel [1]. It also represents more than 10% of the energy needed to build a solar panel, among which more than half is dedicated to the lamination step [1,2].

Standard encapsulation of industrial silicon solar cells (lamination of EVA between a front hardened glass and a back Tedlar sheet) is reliable and warrants a panel lifetime over 25 years [2]. But it is energy consuming and necessitates the use of a laminator. In places where energy is scarce and a laminator is a far too costly investment, alternative ways of encapsulation have to be worked out.

In Madriz, a northern rural region of Nicaragua, the CIPPER (Centro de Investigación, Promoción, y Producción con Energía Renovable) was created by a local non-governmental organization [3], as a rural scientific center that provides the infrastructure and assistance for the production of renewable energy technologies appropriate for the local reality. The exchange between local “scientists” and outside researchers lead to the development of a vacuum-free, cost-effective, developing-country-material-available encapsulation technique based on two-component Room-Temperature Vulcanizing (RTV) silicone described elsewhere [4,5]. This technique carries a lot of assets (e.g. vacuum-free, robustness, repairing made possible... see [5] for details) and the optimization of the process is still going on [5]. Usually, as a starting material, the rural center uses broken or lower class mono-crystalline Si cells from Northern hemisphere countries solar cells industries.

Recently however, the center has been able to purchase high quality very thin (120-150 μm) String Ribbons from Evergreen Solar, with only cosmetic defects. The cells were too fragile to be assembled with the casting technique previously reported, and we had to

work out a completely new solution using capillarity to fully encapsulate the cells. This new process was a great success, and can for sure seed ideas for developing future generation very-thin-cell encapsulation processes. In this paper, we report on this new vacuum-free capillarity encapsulation technique.

2 ENCAPSULATION PROCESS DESCRIPTION

In the encapsulation method previously developed and used at CIPPER, the cell strings were positioned by hand face down in a RTV liquid silicon bath, in an aluminum-framed window glass (cast encapsulation) [4,5]. This manipulation badly altered the manufacturing yield when tried with the very thin cells, such as silicon ribbons from Evergreen Solar.



Figure 1: Dispensing of liquid silicone on top of the cells.

With the new encapsulation technique, several cell strings are positioned face up on a porous material (in this case, a sheet of standard paper, but other materials might prove even more suitable). The tabs at the ends of each string are forced down through slits in the sheet of paper. Two-component RTV liquid silicone (Dow Sylguard 184) is then poured on the front surface of the cells. The excess liquid silicon floods on and impregnates the porous underlying layer, creeps by capillarity

underneath the cells and ensures complete moisture sealing of the cells and the tabbing material. Figure 1 shows the dispensing of liquid silicone on top of the cell strings. Note that for some of the figures the modules are made of thin monocrystalline cells, but not necessarily of Evergreen String Ribbons. Figure 2 presents schematically the impregnation of the underlying material with the liquid silicon, by capillarity.

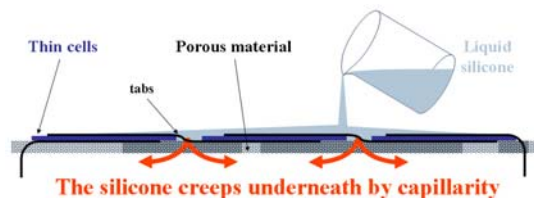


Figure 2: Schematic description of the encapsulation process. The excess silicone will flow over, impregnate the underneath porous layer and finally encapsulate the cell completely, by capillarity.

The strings are kept for drying in a closed room. The strings are indeed reinforced by the fiber underneath, and manipulation is already possible at this stage without breakage, even with thin cells.

An additional thin film of fresh liquid silicone is poured on the array, which is rested for a few minutes to let possible air bubbles escape, and before the silicone cures a window glass is laid on top of it. This timing avoids air gaps between the glass and the encapsulant, which would increase the module reflectivity and possibly degrade its lifetime. Figure 3 shows the positioning of the glass on top of the cells.



Figure 3: A standard window glass is positioned on top of the cells.

The panel is let for curing during approximately 10 hours at room temperature. Figure 4 shows a picture of a panel made of Evergreen String Ribbons at this stage. Note that during curing, some weight is applied on the solar panel.



Figure 4: Capillarity encapsulated Evergreen String Ribbons during curing of the encapsulant.

After curing is complete, the panel is flipped over and the strings are soldered together behind the paper. The glass is aluminum-framed to provide mechanical strength to the module and a plastic sheet is applied on the back of the module to protect silicone and improve watertightness.

The finished module is again tested in the sun (see Figure 5).

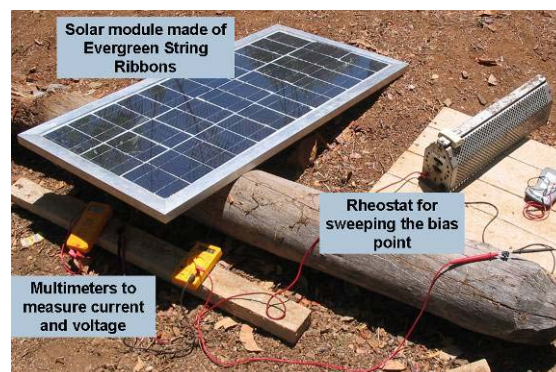


Figure 5: Testing of modules in the sun

3 ASSETS OF THE TECHNIQUE

This process was developed in the framework of a rural experimental center, and under the restrictive constraints of material and energy availability of a rural part of a developing country (very few imported products, no access to a laminator, limited energy consumption of the process only coming from the soldering irons...). Nonetheless, the assets of this technique are so numerous that it might partly feed the development of Northern hemisphere industry processes. First, the process hardly requires any energy. The module assembly cost (investment and energy costs), as well as the energy payback time, are thus reduced.

In addition, the panel can be pulled apart for repair and a small amount of fresh liquid silicone can fill in the hole(s) after repair. State-of-the-art industrial vacuum-lamination-assembled modules (using EVA and tempered glass) do not yet allow repairing and are just discarded and replaced when broken [6].

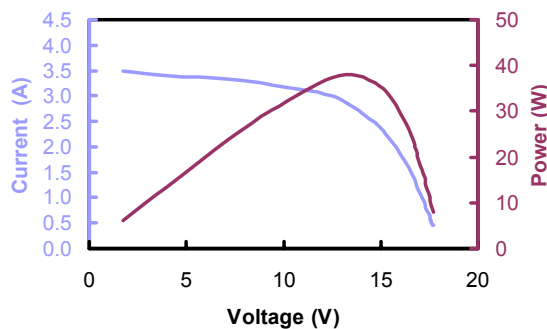
Furthermore, unlike other encapsulation materials (see for instance [7,8]), Dow liquid silicone has proven to be a very UV-stable encapsulant. It is not an inexpensive material, but the use of capillarity reduces the amount of liquid encapsulant needed for complete sealing, compare for instance to full cast lamination. We estimate that,

with 1 L of RTV silicone, it is possible to produce two 60 Watt modules by capillarity encapsulation, as compared to a little more than one module for cast encapsulation as described in [5].

Finally, the use of capillarity to encapsulate the cells enables the assembly of a solar module with only limited string manipulation. The risk of cell breakage is thus reduced, making this technique suitable for thin and fragile cells. In this study, as a proof of concept, we have used silicon String Ribbons manufactured by Evergreen Solar. The thickness of the ribbons does not exceed 150 μm .

4 EXPERIMENTAL VALIDATION OF THE PROCESS AND DISCUSSION

In order to validate the proposed encapsulation technique, we have built some solar panels with very thin silicon String Ribbons following the described process. Figures 4 and 5 show examples of the very professional-looking solar panel encapsulated by capillarity at CIPPER. The short-circuit current measured in Fig. 5 is 3.5 A, the open-circuit voltage is 18.6 V, and the maximum output power is close to 40 W (measured in natural sun, with no cooling systems, at 37°C of outside air temperature). Fig. 6 displays the IV curve measured with the setup shown on Fig.5.



With an encapsulated cell area of 0.43 m^2 , the characteristics might look disappointing. It must be noted though that the cells are second choice cells, that they are not very precisely selected to ensure perfect current matching, and that the test was performed without cooling system, with an outside air temperature of 37°C!

This work is very relevant for two main reasons. First, the process has been developed within the restrictive constraints of a remote and rural area of a developing country: by construction, the process optimizes the use of energy, and reduces the cost at each step of the module assembly.

In addition, the process was developed for very thin cells. It is thus suitable for the cells of the next generations which are going thinner and thinner. The proof of principle that we propose in this article was actually achieved with String Ribbons from Evergreen Solar.

5 LOOKING FOR NEW COLLABORATIONS

CIPPER is a very innovative scientific center working on solutions using renewable energy technologies for the development of rural communities. It is willing to play a role in the photovoltaic research

community. We are currently looking for institutional or industrial partners to develop jointly photovoltaic processes. This collaboration could for instance take the shape of field testing of new liquid encapsulation materials, which can be useful for the process developed at CIPPER, as well as for alternative encapsulation processes developed in other parts of the world, such as cast encapsulation, or roll lamination.

6 CONCLUSION

We have developed a new cell encapsulation process for thin cells within the restrictive conditions of a third-world-country rural region workshop. Several strings are positioned next to each other on a porous layer (here a sheet of paper). Liquid encapsulant is poured on top of the cells, and the excess creeps under the cells by capillarity in the porous underlying layer. The resulting panels are very satisfying proving the principle of this new technique that might feed Northern hemisphere country encapsulation process developments.

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