Presented at the 21st European Photovoltaic Solar Energy Conference
Dresden Germany, September 2006

SOLAR MODULES OF BACK-CONTACT CELLS CONNECTED WITH LAMINATION-CURING CONDUCTIVE ADHESIVE

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ABSTRACT: Back-contact solar cells are already coming into production, and since they display several advantages over conventional cells, their volume of production is very likely to expand strongly in the near future. Nonetheless, innovative tabbing and stringing solutions have to be worked out before the module assembly of back-contact cells can be automated. One of the solutions proposed is the Pick-&-Place technique where automated arms would place the cells and all the tabbing material directly on the front glass of the panel, which would stay at the same place during the whole module assembly process. This concept is particularly well suited when all the contacts of the cells are on the same side, and when conductive adhesives are used, one of the best alternatives to release the stress in cell tabbing. We present here a detailed study on the combination of back-contact cells and conductive adhesives for module assembling. We first select among several conductive adhesives the one that is best suited, and, then we manufacture 2 full-size modules with back-contact cells and conductive adhesive. Finally we discuss the results, identify the possible problems and discuss the outcome of reliability tests.
Keywords: Module manufacturing, back-contact cells, conductive adhesives

1 INTRODUCTION

Back-contact solar cells display several advantages over conventional cells [1]. Since less metal is needed on the cell side facing the sun, the shading losses are lower. In addition, since the metal busbars and contact pads are transferred to the back of the cell, they can be expanded over the complete cell area, thus lowering the series resistance. Last but not least, the absence of soldered connections on the front of the cells enables a higher module packing density, and an improved homogeneity in the visual aspect. This last feature, together with the good performances of crystalline silicon cells, compared to other technologies that might share the uniform aspect, provides an excellent argument in favor of back-contact solar cells for building integrated photovoltaic systems.

Nonetheless, as the two types of contacts are placed at the rear of the cell, the contacting pattern proves not as obvious as for standard busbar-contacted cells, and tabbing from one cell to another strongly depends on the contacting pattern. Therefore innovative stringing solutions (efficient, reliable and flexible to a change in contacting pattern) become necessary for industrial module production. Besides, back-contact cells follow the general trend in solar cell manufacturing and see their thickness reducing as the scarcity of solar quality bulk material is becoming more and more critical. Again, innovation is needed to release the stress in thin solder-tabbed cells and new tabbing solutions have to be worked out.

A European consortium contracted under the Crystal Clear European Integrated Project is currently addressing the issue of encapsulating at low cost back-contact cells, and is proposing two innovative solutions. One solution uses a specific conductive backsheet: the backsheet includes the interconnection circuitry patterned according to the design of the contacts on the rear side of the cells [2,3,4]. In the single-step lamination version, the cells are glued with conductive adhesives to the backsheet, and the curing of the adhesive takes places during lamination. The cost reduction potential is estimated between 10 and 20 % [2,5], and is limited by the replacement of tabs by the interconnection backsheet [2].

The other solution proposed to take benefit of the specific features of back-contact cells without loosing the cost effectiveness of tabs, is a fully-automated Pick-&-Place module assembling method. In this concept, the front cover glass (covered by a first sheet of encapsulant, e.g. EVA) stays at the same place while robot arms are laying out the cells face down on top of it, at their final position. Conductive adhesive is then dispensed on the contact pads of all the cells, and the tabbing material is picked and placed at its correct location. These steps can be very easily automated. The module assembling is finished when a second layer of encapsulant and the backsheet are positioned on the cell lay out.

This concept is particularly well suited for back-contact cell modules since all the connections can be made from one side of the cells. It is particularly convenient in combination with the use of conductive adhesives, because conductive adhesives can be easily dispensed (using dispensing syringes), because the tabbing material does not need adhesion before lamination (all the material stays at the same place during the assembling of the module), and because it is possible to develop a conductive adhesive, that has a curing cycle (temperature and pressure) compatible with the curing cycle of EVA [2]. In addition to simplifying the assembling process, the use of conductive adhesive might provide as well a low-stress interconnection [6].

We report here on the demonstration of the proof of principle of the Pick-&-Place method, in combination with lamination-curing conductive adhesives. We first test several conductive adhesives on strings made of standard cells. Then we use the best-behaving adhesive to implement manually the Pick-&-Place technique for assembling modules of back-contact cells with different contacting patterns. The modules are then tested in a climatic chamber and the outcome is discussed.

2 CONDUCTIVE ADHESIVE

2.1 Selection of the adhesive

With the aim of selecting a suitable conductive adhesive, we have built up 4 strings of 9 conventional cells. One string is soldered, and the three others are assembled using different types of conductive adhesives (A,B,C). The adhesive type A is a low-temperature snap-curable adhesive, whereas the adhesives type B and C are cured during lamination. All four strings showed similar characteristics with fill factors ranging from 74.6 % to 75.2 %, showing the good electrical behavior of the adhesives, including the lamination cured adhesives. The strings were then sent for thermal-cycle testing in a climatic chamber. Figure 1 presents the electrical behavior of the strings after 250 cycles (between –40 and 85°C). Out of three strings built with conductive adhesives, only one (here type B) keeps 95 % of its output power.

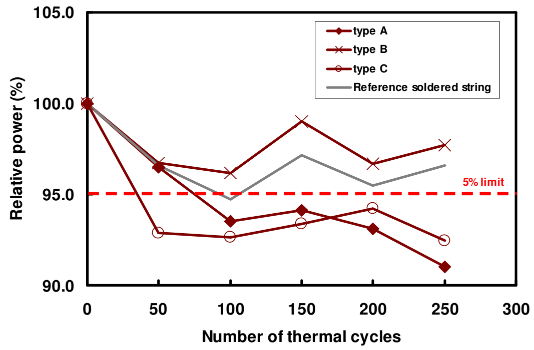

Fig. 1: Power of the strings made of standard cells and interconnected with conductive adhesives after 50, 100, 150, 200, 250 thermal cycles, relative to the power delivered by the strings just after lamination.

It should be noted that the conductive adhesive that behaves best performs even better than standard soldering. In addition, as it is a lamination-curing adhesive, we will be able to benefit from the lamination cycle to cure the adhesive.

2.2 Manufacturing of solar modules with back-contact cells and conductive adhesives

Within the Pick-&-Place concept, the cells are first placed rear side up by automates directly on the front cover stack (front hardened glass and a layer of EVA). As both positive and negative contacts are on the rear side of the cell, it is easy to have automates dispensing on the contact pads a stress-free conductive adhesive. The selected adhesive cures during the lamination cycle, so that no stress or thermal power has to be applied on the cells at this stage. Then the interconnection circuitry is placed to match the specific rear side contacting scheme. A sheet of encapsulant and a back foil is applied on top of the cell layout, and the module stack is sent into a laminator. This lamination step also serves as a curing step for the conductive adhesive.

To deliver a proof of concept, we manually implemented this module assembly approach.

Two modules of each 36 back-contact cells from different suppliers (namely Photovoltech, Belgium, and ECN, Netherlands) were manufactured using the conductive adhesive selected during the first part of this study. The cells were connected in series, following the specific contacting pattern of each cell supplier using conventional Sn-plated Cu tabs to build up the interconnection circuitry.

Table 1 provides the characteristics of the modules after lamination.

The fill factors of the modules are similar to the fill factors of the individual cells of the same type measured after conventional tabbing by soldering, confirming again the very good behavior of the conductive adhesive. From the obtained open circuit voltage of the module it becomes clear that no shunts were introduced in spite of the tight tolerances and close proximity of different polarity metal areas on the rear surface and the limited position control of manual dispensing. The heavy manual labor stemming from this proof of principle could easily be alleviated by programming a Pick-&-Place prototype to place the cells and tabbing material and to dispense the adhesive.

Table I: Electrical characteristics of the 36-cell fully rear-contacted modules built-up using the Pick-&-Place approach and conductive adhesive

Cell dimensions	V_{oc}	J_{sc}	FF	P_{max}
15x15 cm^2 multi-c Si	21.7 V (603 mV/cell)	7.3 A (32.4 $mA.cm^{-2}$)	68.8 %	108.9 W (13.4 %)
12.5x12.5 cm^2 multi-c Si	21.6 V (600 mV/cell)	7.3 A (32.4 $mA.cm^{-2}$)	73.1 %	81.3 W (14.5 %)

2.3 Thermo-cycling reliability tests

The modules were then placed in a climatic chamber. Thermal cycles were performed and the 4 strings of each panel were tested independently after 17, 50 and 100 cycles. The results are displayed on figure 2.

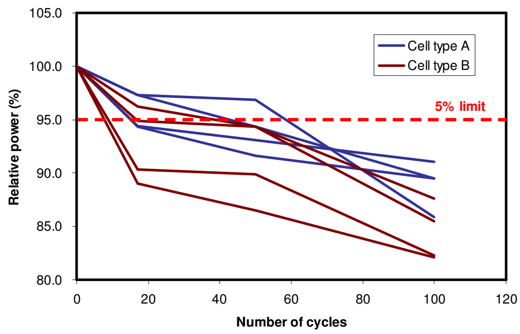

Fig. 2: Power of the 4 strings of each of the 2 full-size panels made of back-contact cells with conductive adhesives after 17, 50, 100 thermal cycles, relative to the power delivered by the strings just after lamination.

After 100 cycles all the strings already show a decrease in performance exceeding acceptable values. The decrease mainly occurs through the fill factor which drops 10% (relative) on average for the strings made with cell type A, and nearly 15% (relative) on average for the strings made with the cells of type B. This disappointing result is in contradiction with the successful thermal cycling tests performed with the same paste, in the same conditions, on H-pattern cells.

There was a need to clarify these contradicting results, and we therefore built a laminate of four strings containing back-contact cells (type A), and H-pattern cells from the same company manufactured with similar conditions. Among the two strings of each type of cell, one is soldered and the second one is glued with the same conductive adhesive (type B) that successfully passed the thermal-cycling tests. After lamination the strings are measured in standard conditions and their fill factors are shown on Table II.

The difference in FF between the H-pattern strings and the back-contact strings is due to the lower FF displayed by the back-contact cells and was observed already on solder-tabbed cells. Within a same type of cells, the FF is nearly the same whatever the interconnection material, in agreement with what was observed when the conductive adhesive was selected.

Table II: Fill factor of the four strings laminated in order to study the combination conductive adhesive + back-contact cell behavior during lamination

Cell type	Back-contact		H-pattern	
Interconnection material	solder	glue	solder	glue
FF (%)	73.0	72.6	76.9	76.7

Again the laminate was submitted to thermal cycling tests and the strings were measured after 48, 100, 150 cycles. figure 3 displays the relative power of the strings after thermal cycling.

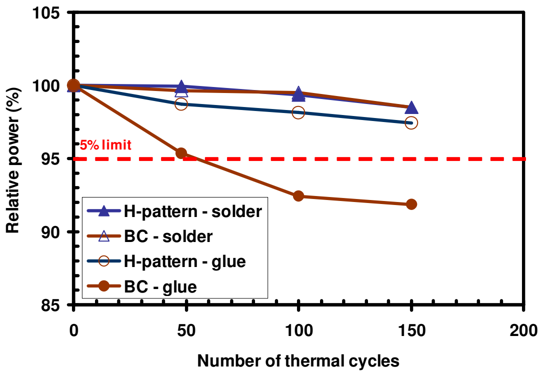

Fig. 3: Power of the strings made of standard cells or back-contact cells, interconnected with conductive adhesive or soldered, after 48, 100, 150 thermal cycles, relative to the power delivered by the strings just after lamination.

This result confirms that this type of conductive adhesive is suitable for industrial use in standard modules. It also shows that the back-contact cells used for this study perfectly suit the reliability need for commercialization. Unfortunately, if both features (back-contact cells and conductive adhesive) successfully pass the reliability test, the combination of both does not withstand 150 thermal cycles. This surprising result is nonetheless consistent with behaviors previously observed in this study.

We can see two reasons explaining the test failure. The first can be that the conductive glue keeps on spreading after lamination and eventually reaches the other polarity, shunting some of the cells of the string. The failure can also come from the fact that there is absolutely no stress-relieving possibility in the ribbons for back-contacted cells. In the standard H-pattern cells configuration, the ribbon goes from the bottom of one cell to the top of the next cell, creating a “S”-shape in the ribbon that can withstand some deformation. The high stress induced every time finally alters the contact quality after some thermal cycles.

If the first reason appears to be the cause of failure, depositing (e.g. screen-printing) an isolating element on top of the cell should improve the reliability. If the second reason is the correct one, then introducing a stress-relieving hook in the tab or using a softer tab can help prevent failure.

The decrease mainly happens on the fill factor and more precisely on the voltage of the maximum power point. This observation tends to point out that the failure comes more from an increase in series resistance, than from a decrease in shunt resistance between the contacts of different polarities. The second hypothesis is thus more probable. Nevertheless, both solutions need to be tried before a conclusion can be drawn.

3 CONCLUSION

We have successfully proved the concept of pick-and-place module assembling with back-contact cells and conductive adhesive. A suitable lamination-cured conductive adhesive was selected among several on the basis of reliability tests carried out on standard cell strings. Then two modules have been assembled with back-contact cells from two different manufacturers, and with two different back-contact pad patterns. Both modules display a fill factor similar to the fill factors that can be measured from a tabbed cell. The open-circuit voltage also fulfills expectations. Unfortunately, the manufactured modules do not pass the reliability thermal cycle tests. It is shown that only the combination of back-contact cells with conductive adhesive fails the test. It is foreseen that the problem either comes from the spreading of the conductive adhesives during the thermal cycles, or from the absence of stress-relieving features in the tabbing material. We propose then to increase the isolation between the two contacts of each cells, or to create a stress-relieving shape in the ribbon.

4 ACKNOWLEDGMENTS

This work was partly funded by the European Commission under contract SES6-CT-2003-502583. The authors are thankful to Paul De Jong (ECN) and Jozef Szlufcik (Photovoltech) for providing the back contact cell samples, Yvan Van Gorp (Emerson and Cuming) for providing samples of the conductive adhesives, Anne Magali Messant (Photowatt), Norbert Lenck (Schott Solar) and Harmut Schmidt (Solarworld) for the thermal cycling tests.

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