EVALUATION OF STRESS ON CELLS DURING DIFFERENT INTERCONNECTION PROCESSES

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ABSTRACT: During the last years, new stringing techniques with low stress have been developed, such as the use of conductive adhesives [1], low temperature solders [2] or laser soldering. The aim of this work is to evaluate the stress introduced in the cells during the soldering process, making a comparison between different techniques and solder materials that exist nowadays in the market. The interconnection technologies under investigation have been: low-temperature snap-cure conductive adhesives, induction and infrared soldering and laser spot soldering. For the soldering approaches different alloys and materials were evaluated, such as low temperature solders, low CTE alloys and copper ribbons of very low yield strength. Electroluminescence imaging and mechanical tests have been used to quantify the stress experienced by the cells. In addition, the possible propagation of microcracks during thermal cycling has been investigated.
Keywords: interconnection, stress, electroluminescence

1 INTRODUCTION

The interconnection process is a critical step in the fabrication of crystalline silicon PV modules, in particular in the last few years, when the thickness of the wafers has been drastically reduced and the cell area has been increased. The stress applied on cells during the stringing process can cause microcrack formation and therefore increase the breakage rates in industrial production lines.

Three processes and three solder materials have been evaluated in terms of stress: conductive adhesives, induction and laser spot soldering, low temperature alloys, low CTE materials and low yield strength copper ribbons.

- Conductive adhesives: a silver-filled acrylic polymer is cured at temperatures ranging from 80 to 150ºC. A lot of research has been done during the last years in this field.

- Induction soldering: a high-frequency voltage is applied through a copper conductor, creating an alternating magnetic field. Foucault currents flow through the materials and, due to the Joule effect, heating takes place. There is no need of mechanical contact to the heating system.

- Laser spot soldering: it is also a non-contact method. The advantages are that spot area and energy intensity can be precisely controlled.

- Low-temperature solders: two tin-bismuth alloys have been used: SnBi 42/58 and SnBi 60/40, with melting points of 138ºC and 138-170ºC, respectively.

- Low CTE ribbon: it is based on a combination of copper and a low thermal expansion coefficient alloy. The resulting CTE is 8,4 µm/(m ºC) instead of the typical 17,3 µm/(m ºC) of copper 100%.

- Copper ribbon of very low yield strength: this ribbon presents a yield strength reduction of 25% with respect to the standard copper ribbon used for these experiments.

To evaluate the stress on the cells, bow and stability measurements were selected as mechanical tests, and a electroluminescence camera was used to detect the existence and propagation of microcracks.

Electroluminescence imaging is a non-destructive method that is widely used in cell and module characterization. In normal operating conditions, the solar cells emit light due to radiative recombination. This emission can be detected by a silicon CCD camera in dark conditions, filtering the visible light. Microcracks are observed as discontinuities in the electroluminescence signal, making this technique a powerful tool to detect cracked cells in modules with exposure times of 1-3 seconds.

2 MECHANICAL TESTS

2.1 Bow measurements

Monocrystalline cells of 156x156 mm were soldered only on the rear side, to obtain the maximum possible bow and avoid the compensation of forces between the two sides of the cell. Cells of two silicon thicknesses were used: 150 and 200 microns. 10 samples per point were evaluated, measuring the bow in the central point of the cell. Samples of laser as well as induction soldering were not available for this test.

Bow measurements were carried out immediately after soldering to avoid relaxation and make it maximum. Results are shown in Fig. 1.

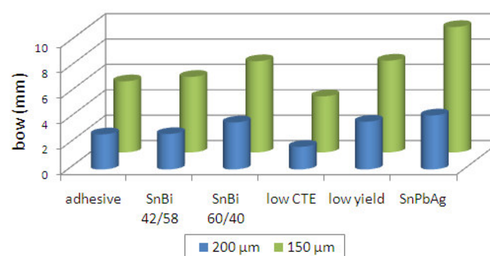


Figure 1. Bow data with different processes and materials.

The tendencies are the same for both thicknesses, but as expected, for 200 micron cells the differences are not very significant. The best results are obtained combining the low CTE ribbon with IR-soldering, or using conductive adhesive. In both cases the bow is minimum,

below 2 milimeters for 200 microns and approximately 4 mm for 150 microns. The cell bow using the tin-bismuth alloy with lower melting point is also in this range for 200 microns cells, whereas for 150 microns cells, the bow is slightly higher.

The other tin-bismuth solder and the low yield ribbon are in the same order of magnitude. It is remarkable that the same bow reduction is obtained from decreasing the melting point of the solder alloy (SnBi 60/40) by 20ºC or decreasing the yield strength of the copper ribbon by 30 N/mm^2 (low yield).

Table I presents the percentage of bow reduction with respect to standard IR-soldering using SnPbAg as solder alloy.

Table I. Percentage of bow reduction with respect to SnPbAg IR-soldering.

	150 µm	200 µm
Adhesive	43%	35%
SnBi 42/58	40%	34%
SnBi 60/40	27%	13%
Low CTE	55%	58%
Low YS	27%	12%

2.2 Mechanical stability

In this test a force is applied on two of the four extremes of the cell, causing cell torsion until it breaks. The maximum force applied to cause breakage is recorded, which represents an estimation of the tension in the cell (Fig.2).

Figure 2. Device used to measure break torsion forces.

Cells of 156x156mm were divided in two batches as in the test before: cells of 150 and 200 microns of silicon thickness. In this test they are soldered on both sides. Breakage force was also measured for unsoldered cells to have reference data as a comparison. Ten cells were measured in each case.

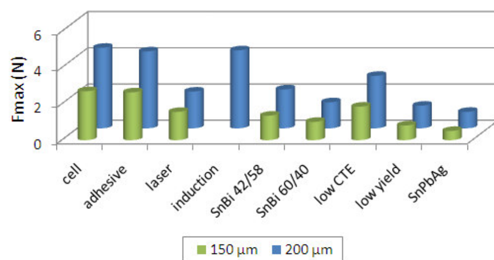


Figure 3. Maximum breakage force for 150 and 200 micron cells.

The results correlate well with the bow data (Fig. 3). Induction and adhesive processes have demonstrated to be a stress-free alternative, since the breakage force is almost the same for interconnected and unsoldered cells. After these technologies low CTE ribbons prove to be the next best option. Laser soldering and low temperature alloys also showed a stress reduction with respect to SnPbAg IR-soldering, but to a smaller degree.

Table II resumes the percentage of the maximum breakage force that a soldered cell resists with respect to the force resisted by a unsoldered cell.

Table II. Percentage of breakage force with respect to not soldered cells.

	150 µm	200 µm
Cell	100%	100%
Adhesive	98%	96%
Laser	58%	46%
Induction	-	97%
SnBi 42/58	50%	48%
SnBi 60/40	37%	32%
Low CTE	69%	65%
Low YS	30%	28%
SnPbAg	19%	20%

3 ELECTROLUMINESCENCE IMAGING

3.1 Cells before interconnection

Monocrystalline cells of 156x156mm and 150 microns of silicon thickness from the same batches were inspected before interconnection using an electroluminescence camera.

Three measuring probes per busbar were used to apply the current on the front side of the cells, whereas the posterior contact was obtained with a metallic chuck. Cells are forward-biased with a current slightly lower than their Isc. No microcracks were found in any cell, and then these previously inspected cells were used to compare the different interconnection techniques and materials.

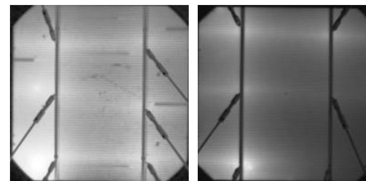


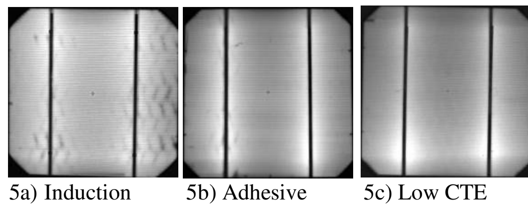
Figure 4. Electroluminescence images of cells before interconnection. The black lines represent the measuring probes.

3.2 Interconnected cells

Ten 150µm-cells were soldered with each technology used in the previous tests: the processes based on conductive adhesives, laser and induction soldering, and with respect to materials, ribbons of low CTE, low yield strength and low temperature alloys were used, as well as IR soldering with SnPbAg as reference.

As it has been observed in the mechanical tests, conductive adhesives, induction soldering and low CTE ribbons cause slight damage on the cells during the interconnection process. This is corroborated by the images obtained by electroluminescence, which show no

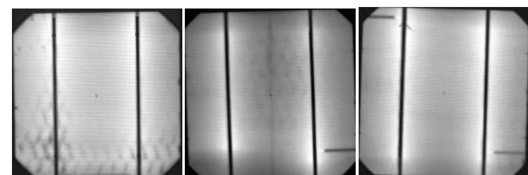
cracks on the cells interconnected by using these three technologies (Fig. 5).



5a) Induction 5b) Adhesive 5c) Low CTE

Figure 5. Cells interconnected by induction soldering, adhesive and low CTE ribbons.

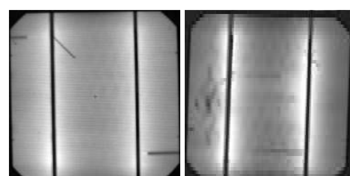
Laser soldering and low temperature alloys showed similar results in the mechanical tests. Using electroluminescence, microcracks were not observed in laser soldered-cells. In the case of low temperature alloys, some cells presented small microcracks at the end of the busbars due to soldering, as can be seen in Fig. 6c.



6a) Laser 6b) SnBi 42/58 6c) SnBi 60/40

Figure 6. Cells interconnected by laser soldering and tin-bismuth alloys.

Finally, electroluminescence images of soldered cells using low yield strength ribbons showed small microcracks along the busbars, and in the case of standard SnPbAg ribbons, most of the samples had more than one microcrack per cell (Fig. 7).



7a) Low YS 7b) SnPbAg

Figure 7. Cells interconnected by IR soldering and SnPbAg, with low yield strength and standard copper.

4 MICROCRACK GROWTH

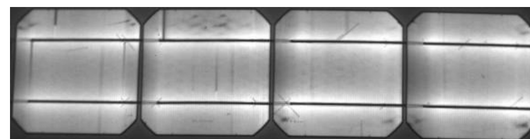
When there are microcracks in the cells, the possibility of their propagation exists due to the expansions and compressions that the components of the modules suffer when they are subjected to thermal gradients during their outdoor life. With the objective of investigating the microcrack growth, several strings were fabricated with microcracks induced by aggressive soldering. Microcrack growth was studied using electroluminescence.

4.1 Electroluminescence imaging

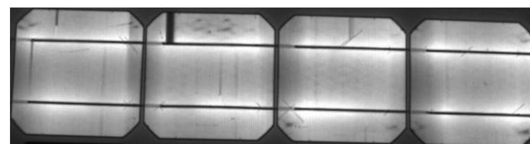
Three strings of four cells were used to fabricate a mini-module of 673x514 mm. Several microcracks were intentionally caused on the cells to investigate the growth of the microcrack length during thermal cycling.

These microcracks were obtained using very aggresive soldering profiles, with high temperatures and excessive soldering times, and there were not visible by naked eye. The module construction was 3mm-glass/EVA/white TPT and the strings were not connected between them, in order to measure them individually.

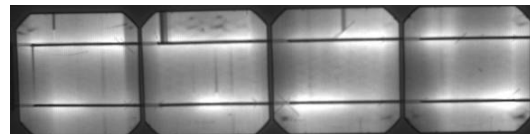
The module was initially inspected by electroluminescence, and then introduced in the climatic chamber. It was subjected to fast thermal cycling between -40ºC and 85ºC, with a temperature ramp of 10ºC/min. Samples were inspected at the middle and at the end of the test to verify if there were any changes in microcracks length. The images obtained are presented in Fig. 8, 9 and 10. Strings 1 and 2 have microcracks on all the cells, as well as several disconnected fingers. String 3 has some disconnected areas due to large microcracks near the corners.



8a) Initial image of string 1.

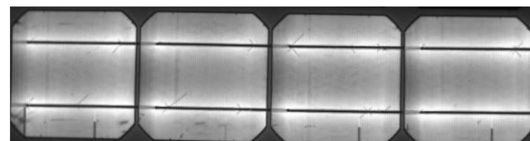


8b) String 1 after 200 cycles.

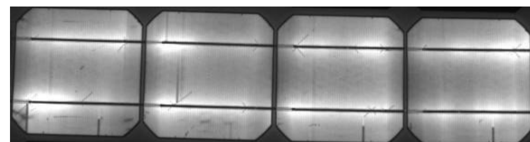


8c) String 1 after 400 cycles.

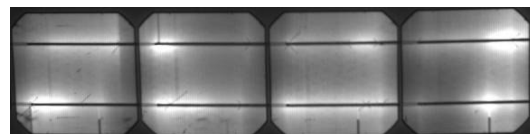
Figure 8. Evolution of string 1 during fast thermal cycling.



9a) Initial image of string 2.

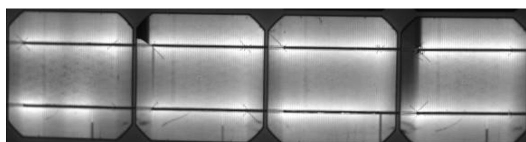


9b) String 2 after 200 cycles.

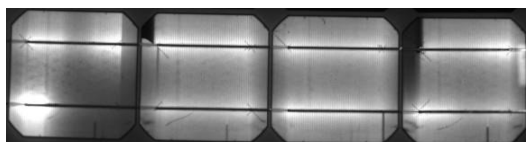


9c) String 2 after 400 cycles.

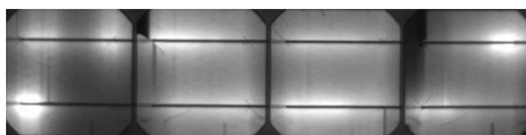
Figure 9. Evolution of string 2 during fast thermal cycling.



10a) Initial image of string 3.



10b) String 3 after 200 cycles.



10c) String 3 after 400 cycles.

Figure 10. Evolution of string 3 during fast thermal cycling.

As the images highlight, the microcracks remain stable during the whole test. No microcrack is observed that increased its length after 400 fast cycles. Microcracks near the corners can propagate and cause the disconnection of a partial area of the cell. However, at the end of the test, the only disconnected areas were the same that at the beginning (Fig.10).

5 CONCLUSIONS

Several interconnection processes and different materials have been evaluated in terms of stress induced in the cells: conductive adhesives, laser and induction soldering, ribbons of low CTE and low yield strength, and low-temperature solders. The reduction of stress with respect to standard IR SnPbAg soldering has been calculated. In addition, microcrack growth during thermal cycling and its influence on module performance have been investigated.

Conductive adhesives, induction soldering and low CTE ribbons have demonstrated to be the least damaging technologies. The disadvantages of using gluing interconnection are related to cost and process changes. The undesirable property of low CTE ribbons is their low conductivity, which would cause power losses if the ribbon cross section is not increased [4]. On the other hand, the advantage of induction soldering is that it is similar to the current process and that only some modifications in the existent equipments would be needed.

Laser soldering and low temperature alloys have shown similar stress reduction. Commercial laser soldering equipments are already available on the market. Low temperature solders produce a considerable stress reduction without any mechanical changes in the process, which makes them an attractive option, as well as the use of low yield strength copper ribbons. The long-term fatigue life of these has to be demonstrated.

In conclusion, a moderate stress reduction can be obtained from solely changing the solder alloy, whereas a stress-free interconnection can be obtained changing the process to adhesive or induction soldering.

The electroluminescence imaging of strings with microcracks during fast thermal cycling showed that their length did not increase; however, the electrical measurement revealed that the module performance is strongly affected by the presence of microcracks on the cells.

6 ACKNOWLEDGEMENTS

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