MECHANICAL STABILITY OF SOLAR CELLS WITHIN SOLAR PANELS

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ABSTRACT: The PV market is still expanding causing the situation in PV industry becoming more and more complex. Different cell types emerge on the market provided by a growing number of cell suppliers. Due to silicon shortage in the past solar cells were getting significantly thinner within the past few years. All these parameters have a potential impact on the mechanical stability of a solar panel. This paper focuses on the dependency of the mechanical stability of solar cells within a solar panel on different factors as cell thickness, cell interconnection technology and cell supplier. Test procedures concerning the mechanical stability of solar panels were carried out according to industry standards and beyond. For detailed evaluation of the panels suitable analysis methods as IV curves and electroluminescence images were utilized. Beside other observations discussed in this paper it has been found that the mechanical stability of solar cells within a solar panel is significantly reduced with decreasing cell thickness. Referring to this result the rapid thickness reduction on wafer level going on in PV industry needs to be investigated closely. Solar cell processes and the module manufacturing need to be adapted.

Keywords: Stability, Degradation, PV Module

1 INTRODUCTION

In the past years the PV industry worked hard on decreasing costs for solar cells and panels. Wafer costs account for a big part of the costs for the end product. Hence reducing the costs for the wafer is a good strategy for reducing the final costs. A common approach is the increase of the overall yield by reducing the wafer thickness. However thickness reduction without consequent adapting of all process steps in subsequent processing leads to a lower breakage force on cell level and thereby to increasing breakage rates and decreasing mechanical stability of the solar panel.

Why is cell stability in a panel an important issue? Depending on the grade of cell breakage the output power can be reduced. If parts of the cell are electrically isolated the active cell area is reduced and the resulting current mismatch might cause the cell operating in reverse bias and bearing an increased hot spot risk due to higher current densities. Accordingly, mechanical stability of solar cells within the panel influences both potential power degradation and reliability of a PV panel.

In this paper we present an investigation of the influence of the wafer thickness on the cell stress and the resulting mechanical stability within a solar panel. The studied wafer thicknesses are ranging from 160µm to 270µm. Asides from wafer quality and thickness also the handling in general and the cell processing affects the stability of a solar cell. We show two examples where cell process optimization results in an improved stability of the cells within the panel.

Furthermore the panel manufacturing has an influence on the mechanical stability of the product. Process parameters and kind of interconnection technology impact the interaction of cell and ribbon. Different thermal expansion coefficient (CTE) of cell and ribbon lead to stress in the cell during soldering. To reduce this stress is the main objective of a panel manufacturer.

A bunch of other factors influence the mechanical stability as well for example glass thickness, panel geometry and frame. Here we focus on the influence of ribbon geometry and alternative interconnection methods on the mechanical stability of the solar panel.

How is the mechanical stability tested?
The common PV standard IEC 61215 [1] includes only a static mechanical load test with 2400Pa respective 5400Pa in the extended test version. This pressure is applied to simulate snow loads.

Since these standard is not covering all mechanical loads a panel is facing in reality [2] Solon has introduced a test procedure for the evaluation of the mechanical stability including also a dynamic load tests (shaker test) simulating for example transportation and other dynamic loads. This test meets the transportation standard in DIN EN60068 [3]. Evaluation of degradation due to cell breakage is done by STC flash testing and electroluminescence (EL) images. Prior and after every test step a panel is measured. In a first step a panel is tested with the shaker and afterwards this stressed panel is placed in the climatic chamber and tested according to IEC 61215. Power degradation as well as breakage rate is determined. To evaluate the solar cell stability without the influence of the panel production the cells are tested with a so called twist tester as described in the following section.

2 EXPERIMENTAL

2.1 Twist test for investigating on cell level

To evaluate mechanical stability of solar cells without the influence of the interconnection and lamination processes an offline twist tester is used. Details of this test are described in [4]; a picture of replication is shown in fig. 1. The solar cell is supported in two edges along the diagonal. An increasing force is applied on the two other edges until the cell breaks. Maximum bending and breakage force are measured.

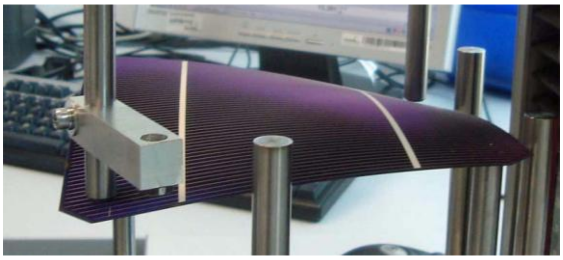

Figure 1: Twist tester setup.

2.2 Dynamic load test for panels

To simulate mechanical stress that panels may experience during their lifetime a so called shaker is an appropriate setup. The excitation of the specimen is in a broad frequency range where frequencies occur randomly. The shaker utilized at Solon, see fig. 2, from LDS is capable of simulating transportation in the broad frequency band from 5 to 500Hz. The resonance frequency of a panel is in the range of 10-15Hz which is part of the excitation spectrum. Testing is carried out according to the transportation standard part of DIN EN60068.

Figure 2: Shaker setup.

Other established mechanical load tests that are named in common PV standards IEC 61215 usually work with static loads (2400Pa/5400Pa). Static or single frequency loads do not cover naturally occurring multi frequency loads from wind or transportation. Material fatigue can be tested in an appropriate time if a load is applied with a higher frequency, as done with the shaker.

2.3 Evaluation of the mechanical damage

In this study all panels are evaluated with an electroluminescence (EL) image taken with a high resolution CCD camera. To weight power loss due to mechanical stress the power of the panels is measured before and after each test with a common flasher.

Concerning power degradation the grade of cell breakage can be investigated with the EL method: Two extremes can be distinguished: (a) micro cracks that do not change the performance of a cell and (b) further propagated and expanded cracks that lead to isolation of parts of a single cell. This isolation creates loss of power due to lower cell short circuit current or an increase in series resistance. During mechanical or thermal stress a crack of type (a) can propagate to type (b) as shown in fig. 3.

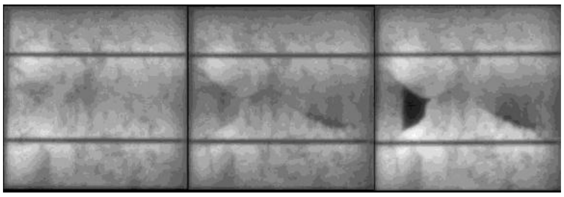

Figure 3: EL image of a cell initial (left) after shaker (middle) and after TC400 (right). Clearly visible is the origin and evolution of cracks because of mechanical and further growth due to thermal stress.

The breakage rate of a panel is determined by simply counting the number of cells showing cracks or breakage and dividing this by the number of cells in the panel. This rate neglects classification of breakage but the degree of damage is indicated by the power degradation.

3 EXPERIMENTAL RESULTS

3.1 Wafer thickness dependence

Cells made from acidic (160, 180, 200 and 220µm) and alkaline textured (270µm) wafers by one of Solon's suppliers were used to build framed 60 cell panels. Every group of panels (4-8 panels per group) was tested with the shaker. For each group of panels and every cell position in the panel the average breakage rate is shown in fig. 4. Cells located closer to the aluminum frame show less damage. Clearly visible is the large damage for 160 and 180µm after the shaker test.

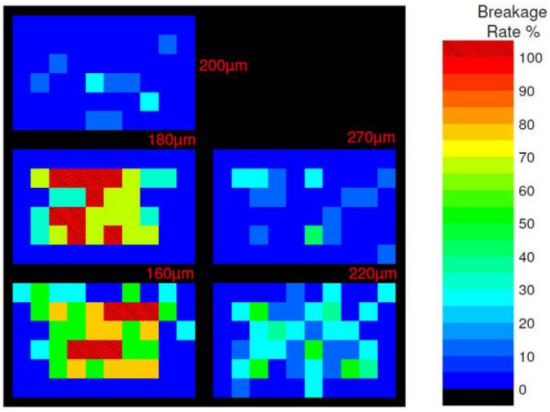

Figure 4: Average spatially resolved breakage rate for 60 cells panels made from cells with varying thicknesses after shaker test.

Aside from counting broken cells the power of the panels was re-measured after the test. Results of breakage rate and power degradation are shown in Fig. 5.

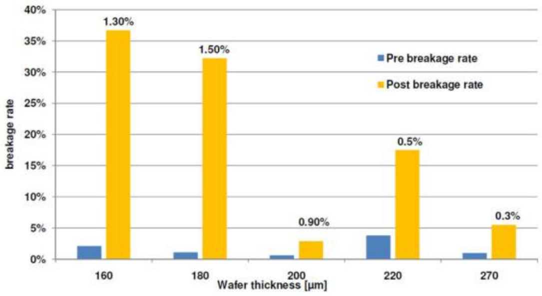

Figure 5: Average breakage rate depending on wafer thickness before and after shaker test. Values for power degradation are also noted.

Both the number of broken cells and the power loss clearly increase with decreasing wafer thickness. The power loss in the field can be higher, because only mechanical stress was applied in this experiment. Deviations may be explained on cell side by large tolerances in wafer thickness (usually specified are variations up to 20%) and quality but also the cell process has a large influence on the mechanical strength as will be shown below. The impact of wafer thickness and manufacturing process effects the cell stability as investigated in [4]. Especially the texturization as well as printing and firing of the Al paste play an important role. Soldering and lamination process have a large influence on the stability of the cell in the panel compound.
As shown here thinner cells are more likely to break although they are more flexible in the twist test. But as will be shown in the next sections there is room for improvement on cell and panel level.

3.3 Influence of cell process on stability

The shaker test became an essential part of the cell release process. For example first tests with one of our mono suppliers using 200µm wafers showed a breakage rate of up to 60% (fig. 6). This rate is not acceptable concerning long term reliability in the field.

This experiment shows that not alone thickness affects the mechanical stability of a cell but the whole cell process has a large impact.
With these results the cell supplier analyzed their cell process concerning mechanical stress and optimized the process. New cells were delivered and tested again. The breakage rate dropped to below 10%. See figures 6 and 7 before and after process optimization.

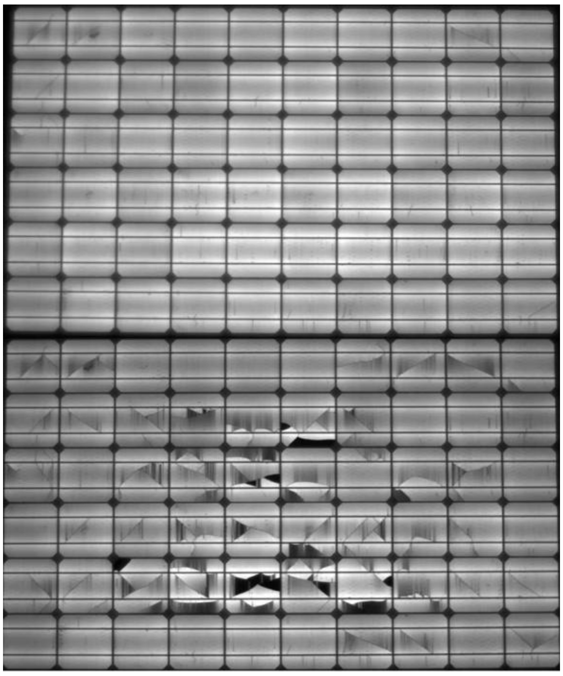

Figure 6: Panel EL image before (top) and after (bottom) mechanical load test before optimization of the mono crystalline cells.

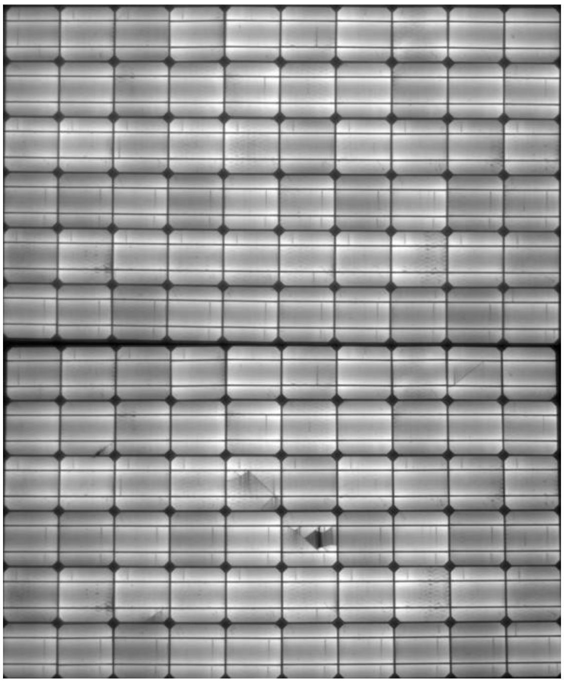

Figure 7: Panel EL image before (top) and after (bottom) mechanical load test of the optimized mono cells.

Optimized and not optimized cells from this supplier were compared with the twist test. A significant increase in breakage force of about 7% was found. The internal stress or pre damage of the cell must have been reduced. This indication supports the results of the mechanical load test on panel level. Another important result of this investigation: simply using thick wafers or cells for panels is no good assurance for good reliability.

As shown in the section about the thickness dependence, thin cells are more likely to break but there is the potential to reduce overall costs. Nowadays panel manufacturer are facing solar cell thickness as low as 160µm. Initial tests at Solon with these cells showed low stability and a breakage rate of almost 40% and a power degradation of 1.9% after mechanical load and TC200, see fig. 9.

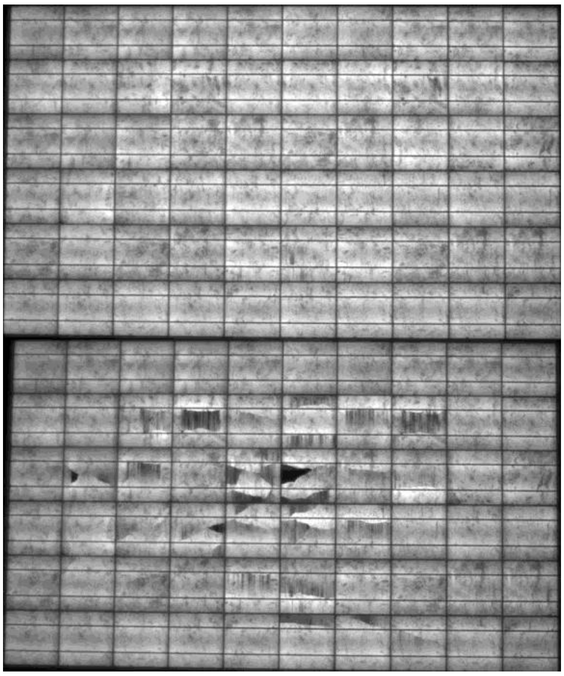

Figure 8: EL image of panel with 160µm cells (II run) before test sequence (top) and after shaker and TC400 (bottom).

After several test runs and significant adaption within the cell process later batches of 160µm test cells showed promising results. Further process optimizations lead to stable power during the shaker test and low degradation in thermal cycling (TC) with 200 cycles (<1%). The breakage rate stayed in a reasonable range during the test sequence. A comparison of figures 8 and 10 visualizes the improvement. During these two tests there was a switchover from two busbar to three busbar, but the improvement seems to come rather from other cell process optimizations than from the additional busbar. As shown in the case of a two busbar mono crystalline cell manufacturer the process optimization is the key to mechanically stable cells.

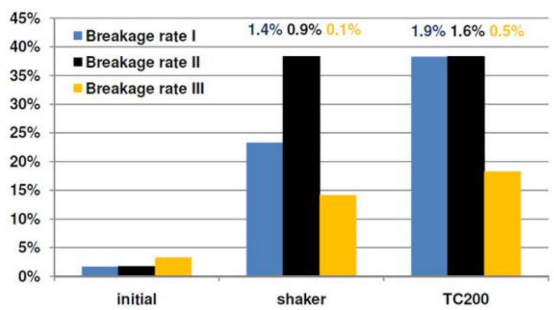

Figure 9: Shaker test and thermal cycling test of panels with 160µm cells. Cells were mechanically optimized from round I to II and again before III.

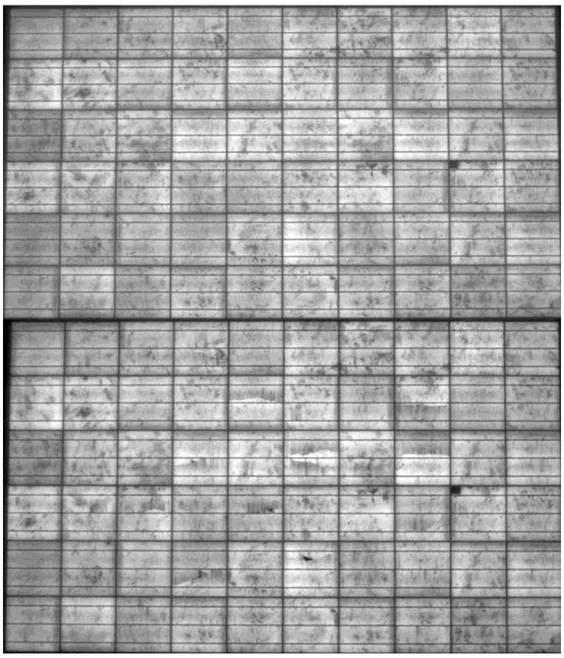

Figure 10: EL image of panel with 160µm cells (III run) before test sequence (top) and after shaker and TC200 (bottom).

From the results shown above it becomes clear that severe cracks like shown in fig. 8 where cell parts are isolated by larger cracks can lead to higher power degradation in the range of 1% during mechanical load tests. Cracks of this type are likely to degrade more in TC200 in present case the power degradation increased from 0.9% to 1.6%. This degradation and the high breakage rate are not acceptable since degradation may be higher in the field for severely cracked cells.

Light cell breakage on the other hand is of second order for power degradation. In the last example a small number of light cracks lead to insignificant degradation in power after the shaker test and the following environmental chamber test. The degradation in the field may be higher but the additional TC tests estimates the power degradation to be in a reasonable range.

3.4 Cell supplier comparison.

At Solon different suppliers of cells from mono and multi crystalline wafers were compared concerning their stability within a standard panel. A large variation was found for both materials. Breakage rates ranging from almost 0% to 60% were found after the dynamical load test. Surprisingly no significant difference between cells made from mono or multi wafers as well as cell thickness was found in this investigation. Since the mechanical load test is part of Solon's release process suppliers delivering fragile cells are informed and are able to optimize their process and the release can be continued if mechanical stability is improved. The following graph, figure 11, shows the results of this comparison.

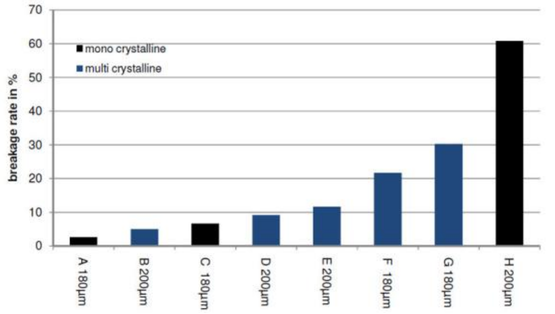

Figure 11: Mono and multi crystalline cell supplier comparison in breakage rate after shaker test.

The power degradation in the supplier comparison was always below 2% after shaker test and the maximum degradation found after the following TC200 was 2.5% compared to the initial power.

3.5 Ribbon thickness variation and alternative interconnection technique

During the soldering process stress is introduced in the cell because high temperature is needed to form a stable electric contact between busbar and ribbon. Solar cell and ribbon have different CTEs and thereby during the cool down of the string the cell gets stressed.
One way to reduce this stress is to solder at lower temperatures while good adhesion must be guaranteed another way is to use a more flexible ribbon. Thinner ribbons reduce the stress introduced in the cell as well. Concerning power degradation and influence on the mechanical stability different ribbon thicknesses and alternative interconnection techniques were compared. Besides conventional soldering mechanical clamping and gluing with electrical conductive adhesive (ECA) was investigated. The results of power measurement and breakage rate are shown in fig. 12.

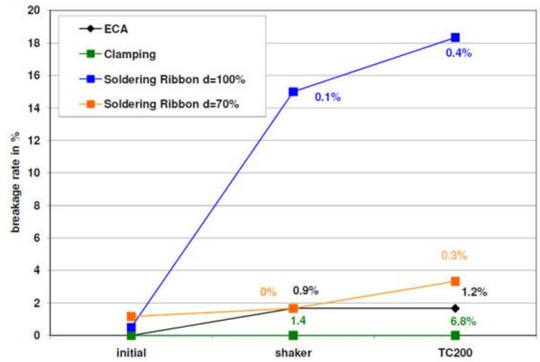

Figure 12: Breakage rate of two panels soldered with different ribbon thicknesses (blue and orange) and two panels made with non soldering techniques - mechanical clamping (green) and ECA (black). Above the data points is noted the relative power degradation.

In the case of mechanical clamping all cells survive the mechanical load test without any breakage. Compared to this glued and soldered cells show higher breakage rates of ~2% for ECA and the thinner ribbon and 15% for the thicker ribbon after shaker test. After the following TC200 breakage rate rose a bit for the soldered panels. Looking at the power degradation the impression is contrary. Soldering shows only negligible power degradation while ECA has a little higher as noted in fig. 12. The clamped panel degrades by extreme 6.8% because the electric contact is not stable during thermal expansion and contraction. Table I summarizes the results of this investigation.

Table I: Comparison of interconnection techniques

Ribbon Interconnection	Clamped	Soldered	Glued
Long term stability	-	+	+
Mechanical stability	+	0	+

This experiments shows that soldering does induce stress to the cell which increases if thicker ribbons are used. In terms of long term reliability soldering is more stable than clamping as interconnection technique. The use of ECA could be an interesting compromise between higher power degradation compared to soldering but with less mechanical stress. Ribbon thickness can be adapted to reduce the stress introduced in cells during soldering. In the end this is a question of minimizing the overall costs keeping in mind the higher encapsulation losses for thinner ribbons.

4 CONCLUSION

Wafer thickness reduction leads to higher sensitivity of the solar cell to mechanical loads. For further decreasing of wafer thickness all following process steps within the value chain have to be carefully adapted in the cell production as well as the panel production. As shown for cells made from 160µm wafers it is possible to build stable panels provided the internal stress is reduced on cell and panel level. Therefore all processes within the value chain need to be optimized concerning mechanical stability. On panel production side it was shown that the stress introduced by the soldering process can be significantly reduced by the usage of optimized ribbon or alternative interconnection techniques like ECA.

All these process optimizations for solar cells are the key for panel reliability and a lifetime of 25+ years.

5 REFERENCES

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