OPTICAL µ-CRACK DETECTION IN COMBINATION WITH STABILITY TESTING FOR IN-LINE-INSPECTION OF WAFERS AND CELLS

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ABSTRACT: High-throughput production lines for silicon solar cells are installed with an overall capacity of app. 200MW/a worldwide last year [1]. Throughput rates of up to 2.500cells/hr per installed production line are reached already. These production lines have to be capable of handling thin wafers, with wafer thickness in industrial production already reaching a thickness of 230µm and below. At the same time silicon feedstock and wafer material with decreasing quality is penetrating the global market, due to shortcut in low-cost and solar-grade silicon. Additionally final average efficiency in the range of 15,0 up to 16,0 % on mc-Si material (wafer size: 156 x 156mm^2) can be achieved by some of the existing production lines. All these boundary conditions lead to a significant importance of in-line characterization. Inline quality control mechanisms are and have to be developed either for silicon wafer material and cells. This work was focused on a more comprehensive inspection of wafer material, regarding µ-cracks. It could be shown that µ-crack detection has to be carried out at different steps of a production line due to processes, which advantaging crack formation. The work gives the basis for an inspection tool to be used as in-line characterization of wafer material and finished solar cells.
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Keywords: Qualification and Testing – 1, c-Si - 2, Stability - 3

1 INTRODUCTION

Reduction of wafer thickness directly leads to lower stability and higher risk of breakage. This has been shown in several previous studies [1,2]. Important for the breakage risk is the minimum force to be applied before breakage occurs. The main factor to increase this minimum force is the existence of cracks or µ-cracks. Detection of cracks is therefore a effective method to sort out “weak” wafers.

Solar cell production lines have to fulfil three simple rules, in order to be competitive: (1) high throughput, (2) high yield and (3) high efficiency. The first two objectives are directly linked to the breakage rate in a production line.

Achieving a high throughput and yield is only possible by characterisation of stability and detection of cracks. The latter opens the chance to define the source of crack formation. Several techniques have been evaluated in order to achieve the needs of industry: e.g. detection by thermography (either with excitation by light or be ultrasonic checking), sound detection in combination with ultrasonic excitation, optical detection with cameras. Only some techniques are used so far in industry: manual inspection (optical and sound detection by twisting the wafer), camera systems (standard backlight setup) and twist testing.

The following experiments show two characterisation techniques with the industrial capability to detect cracks and sort wafers and cells by mechanical stability. An advanced optical method “light-through” detection in combination with a fast twist testing.

2 EXPERIMENTAL SETUPS

The detection of µ-cracks and cracks and the influence on the stability of silicon wafers was the goal of our experiments. Figures 1&2 show the used technique for detection of cracks. The wafer will be placed above a very intense flash-light app. 1.000 suns at wafer surface with a broad light spectrum.

Several different techniques using light of different wavelengths were proposed already. None of these techniques could show the potential of µ-crack detection down to a range of < 10µm together with a processing time < 2 sec.

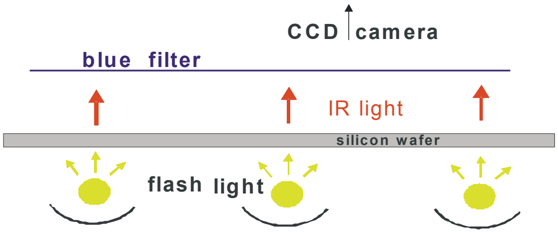

Figure 1: Schematic drawing of measurement setup.

New high-resolution CCD cameras can be used to improve the minimal crack width to be detected. At the same time light sensitivity has to be high in order to detect very small light intensities. The goal is only detection of cracks without determination of crack width.

Figure 1 shows the setup of such inspection system. The camera detects the IR-light coming through the silicon wafer. For selectively detecting open cracks > 1µm a blue filter can be used to suppress IR light and only detect white light coming through a crack (Fig. 1).

The high flash intensity leads to a high detection sensitivity and allows registration of even µ- cracks with multiple reflections within the crack edges (Fig. 2). The crack therefore doesn’t need to be perpendicular to the wafer surface. This method is as well not limited to the middle area. With a special design of the wafer mounting, all wafer area even edges can be checked. First prototype setups are finished to test this method with a large number of wafers and cells in industrial conditions.

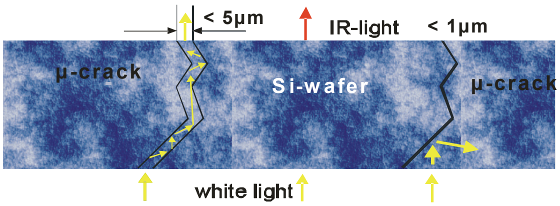

Figure 2: Schematic drawing of detection µ-crack methods. “Open crack” detection by light penetrating through the wafer crack (left hand side). “Closed crack” detection by visual inspection of transmitted IR-light and total reflection at µ-crack flanks (right hand side).

As an additional method the well-known twist-testing method has been used for determination of wafer stability. Setup has been described in previous publications already [3, 4].

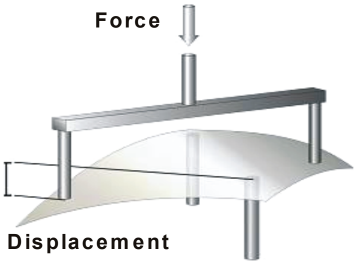

Figure 3: Schematic drawing of stability-testing set-up.

Fig 3 shows the method of testing with two points supporting points from below and two bending points from above. Stress distribution is relatively even over the whole wafer surface [5].

Figure 4: Commercially available STAB-TEST system used for stability characterization by twist testing.

A picture of the commercially available twist testing setup is shown in Fig. 4. It allows testing by twist bending and parallel bending. A comparison of different twisting procedures showed only little differences. The classical twist testing [6] has advantages because of homogeneous stress distribution and non-directionality of stress. Almost all types of damages or cracks (center, edge or corner oriented) can be detected.

3 STABILITY TESTING

Testing wafer stability by twist testing is a straight forward way to achieve data of the actual mechanical status of a wafer. Many previous experiments showed a clear relationship between cracks and stability of a wafer (see as [3] an overview). This can be concluded not only from as-cut wafer material, but as well for etched, textured, diffused wafers and finished solar cells.

Out of a stability test two results can be identified: max. force and max. bending before breakage occurs. The result for a typical distribution of these values is shown in Fig. 5.

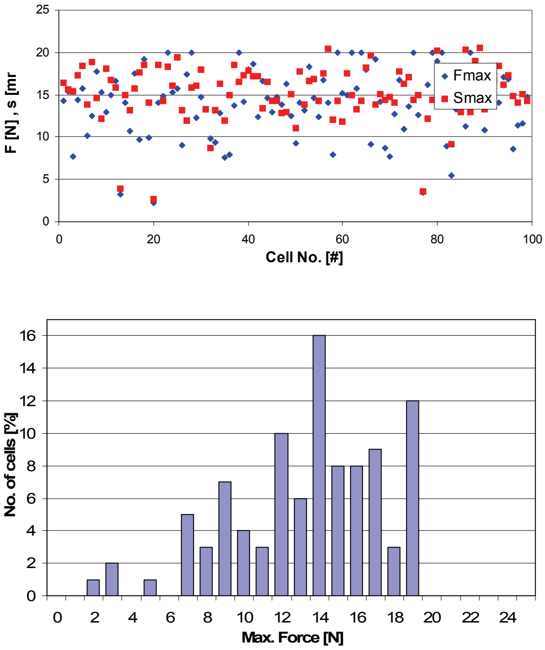

Figure 5: a) Max. force and max. bow of 100 solar cells of a standard bin after shipping. b) Distribution of max. force of same measurement.

100 cells were tested under equivalent conditions with the STAB-TEST system. A large number of cells ≥ 95% show a distribution well known for silicon wafers or crystalline solar cells. But a small number of cells show much less stability < 4 N. This discrepancy is a clear evidence of the existence of cracks or µ-cracks. Only wafers with such defects show a decrease of stability.

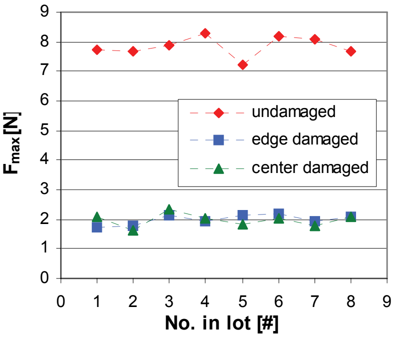

Figure 6: Effect of mechanical stress to as-cut wafer material. Wafer damaged at edges and in the centre.

In order to clarify these effect, 24 wafers were used and divided into 3 identical groups. First group was left unchanged, second group was damaged in the center and a third group was damaged at the edge of the wafer. Fig. 6 shows the results of the afterwards carried out stability test.

The average stability (max. force) of the as-cut wafer material was 9.6N with a standard deviation of < 1.0N. All wafers were chemically textured before damaging treatment. For generation of cracks a light stick was used with same falling height to define app. the same damage. Change in stability was significant for all types of cracks.

This result is an indication, that reduction of stability is directly linked to µ-cracks even if detection of such cracks is not always successful so far. This was the goal of further experiments.

In Fig. 7 results of a "weak" bin are shown. The measured cells showed a very high rate of breakage during processing and were sorted out manually. The characterization of these cells is shown by 4 different methods: 1.) µ-crack camera system (as presented in Fig. X), 2.) accurate visual and manual inspection, 3.) manual detection of noise while twisting, 4.) stability and bow-testing

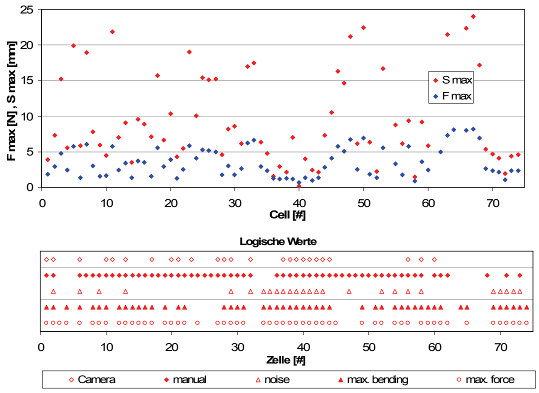

Figure 7: Correlation of max. stability and max. bending with different techniques to determine cracks.

Out of the correlation between max. force and bending on one hand and the detection rates of the different techniques on the other hand it can be concluded, that only some of the techniques have the capability of use as inline methods. Even if very weak cells seems to be easier to detect with all methods. Some techniques showed non reproducible systematic as noise detection. Sometimes even if a noise could be clearly detected no influence in max. force was measured and vice versa.

3 STABILITY DURING PROCESSING

As already previously shown [4] wafer and cell stability changes quite significant during processing. Except of surface etching it is mainly caused by thermal processing and growth of crack length. This effect could be shown by different pre-damaged wafers, which were tempered at app. 900°C for about 45min. After this procedures different groups were tested with the twist testing mechanism. The results are shown in Fig. 8. Group No. 1 and 2 are as-cut wafers from different ingots, showing almost identical characteristics.

Group no. 3 were not treated additionally except the thermal processing. The change in stability is obvious, but due to handling problems during processing, these effects will not be discussed in more details.

The other groups show pre-damaged wafers no. 4 and 6 (without thermal and wet-etching process) and no 5 and 6 (with thermal processing and wet-etching process). Taking not into account the very weak wafers after processing (marked with arrows), a clear broadening of the stability distribution could be observed. This effect is slightly stronger for µ-cracks in the center of the wafer. An additional known effect is the increased stability due to the etched surface.

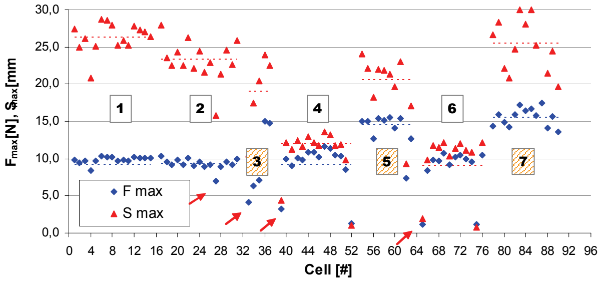

Figure 8: Change of max. stability and max. bending after thermal processing for damaged and undamaged wafer material.

The total number of wafers was to small for a definition of the rate of µ-crack effect. It can only be assumed, that two effects are affecting the stability: 1.) new cracks will be produced due to the processing 2.) existing µ-cracks start to grow during heating and cooling.

4 µ-CRACK DETECTION

The above described technique was used to detect and characterize previous created µ-cracks. As fig. 9 shows, can these cracks detected either by light penetrating through the crack or by detecting the shadow effect of the crack.

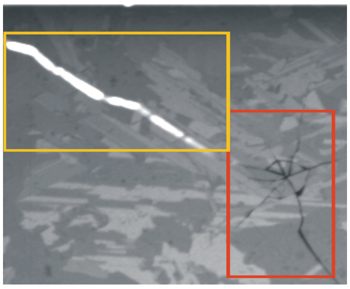

Figure 9: µ-crack in as-cut mc-Si wafer material detected by µ-crack vision system.

Fig. 9 shows the effect of damaging the wafer. Around the point of contact several unopened µ-cracks could be detected (dark rectangle). On the upper left hand side the crack has been opened (by thermal processing). The open crack is app. 5 – 10µm thick compared to a thickness < 1 for the "closed" µ-crack.

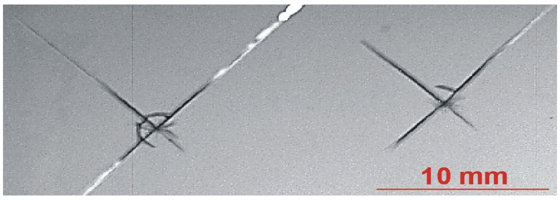

Figure 10: μ-crack in Cz mono-Si, after artificial damaging. Detected with μ-crack system.

The same effect can be shown for μ-cracks in mc-Si wafers. Fig. 11 shows to different cracks with artificial μ-cracks produced by a falling stick. On the left a very small μ-crack close to the edge could be found.

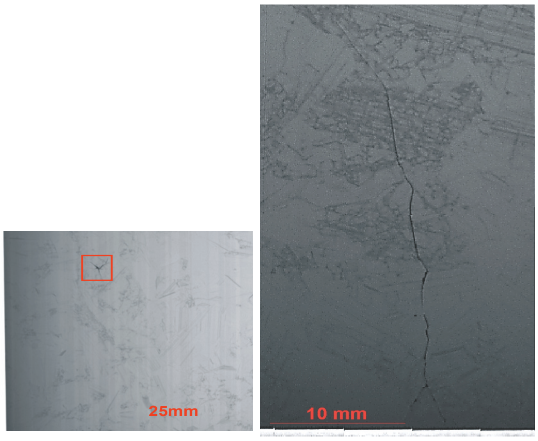

Figure 11: μ-cracks in multi-Si, after iso-textured etching and artificial damaging. Detected with μ-crack system.

On the right a μ-crack with more than 50mm was detected after thermal processing.

These experiments show a very high detection rate for all types of cracks on mono- and textured mc-Si. On as-cut material there are still problems due to the high contrast of the grain boundaries. Additional experiments will be carried out in order to further improve the rate of detection.

5 TECHNOLOGY TRANSFER

The shown techniques will be integrated into a modern solar cell production line (Fig. 12). As a result of the shown experiments, both STAB-TEST and the μ-crack vision system can be used as inline tools.

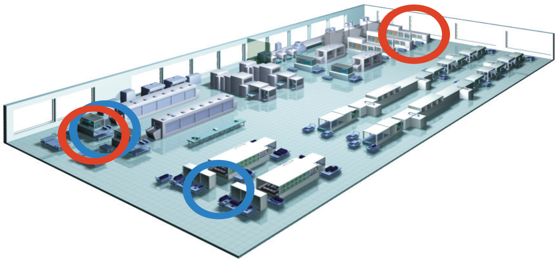

Figure 12: Schematic drawing of a solar cell production line incl. STAB-TEST inline and μ-crack vision system.

The stability testing unit will be used as an inline tool for incoming inspection of wafer stability and cell stability testing before sorting. The μ-crack vision system can be used for crack detection and characterization of cracks as incoming inspection (as-cut) or after texturisation and thermal processing. The results for finished cells were much less significant due to the aluminum layer.

6 CONCLUSION

With the presented experiments, the following conclusions can be drawn:

- the developed μ-crack vision system allows detection of all types of μ-cracks (without Al-paste coverage) silicon wafers
- Detection of „crackling sound“ is not reliably connected with a low stability of cells
- Testing of stability is one reliable way to detect μ-cracks in wafers and cells
- Sorting out wafers by min. stability lead to a decrease of breakage in the production line
- Sorting out of cells by min. stability lead to a decrease of breakage during tabbing of cells
- Detection of μ-cracks with crack dimensions < 1μm makes retracing of originator of crack possible
- Proposal for integration: optical μ-crack system for wafers and additional or separate stability characterisation at end of line

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