μ-CRACK DETECTION AND OTHER OPTICAL CHARACTERISATION TECHNIQUES FOR IN-LINE INSPECTION OF WAFERS AND CELLS

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ABSTRACT: In-line characterisation of wafer material and cells becomes more and more important especially with increasing grade of automation in photovoltaic production lines. Latest solar cell production lines in Europe show a very high level of in-line characterisation tools, including optical inspection systems. The use of optical characterisation leads to a significant increase of yield due to faster reaction times and better process control.

A crucial item for successful inspections of wafers and cells is adapted illumination and colour filtering. Automated 100% optical inspection of the cell production is mainly used at the following stages: 1.) Inspection of the silicon wafers, 2.) characterisation of the anti-reflection coating (e.g. ARC thickness and homogeneity), 3.) inspection of front and rear side metallization (screen printing or plating processes) 4.) optical classification of finished cell (front- and rear side inspection). All optical inspections can be carried out on mono- or multi-silicon material after every production step. This work was focused on a more comprehensive inspection of wafer material, regarding μ-cracks, saw marks and multi-crystallinity. The work gives the basis for an inspection tool to be used as in-line characterisation of wafer material.

Keywords: Characterisation - 1, Crystalline - 2, manufacturing and processing - 3

1 INTRODUCTION

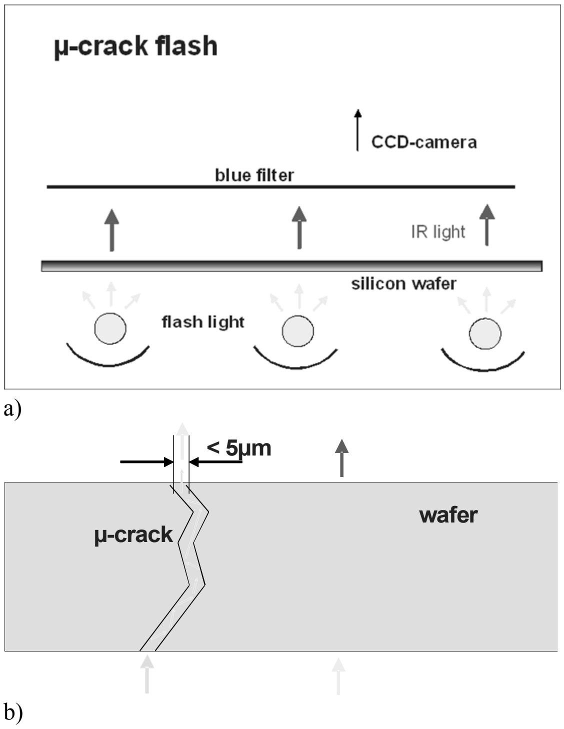
The characterisation of optical aspects in solar cell production lines becomes more and more important. Up to now the following properties of wafers and cells can be determined: geometry of wafer, edge intrusions, shape of corners, surface inspection (finger tips, stains, etc.), colour and homogeneity of ARC, metallization quality and classification of cells according to optical quality of cells.

Additional to these available hard- and software tools for optical inspection, there are still open questions regarding uneven wafer surface (e.g. saw marks), micro cracks in wafers and cells and determination of crystallinity of mc-wafer material. The latter can be solved by a new technique using an adapted flash to excite bright, white light from the rear side to “x-ray” the wafer. The intensity of the light is in the range of > 1.000 suns. With a special CCD camera system the infra-red light shining through the wafer is clearly visible, showing the crystallinity of the wafer. This picture can be used for detection of cracks. A blue filter can be used to suppress infrared light shining through the wafer, making it easy to detect light visible through the cracks.

2 PRINCIPLE OF μ-CRACK DETECTION

Detection of μ-cracks has been a topic in microelectronics and solar cell processing since high-throughput production is significant for cost reduction. 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. New high-resolution CCD cameras can be used to improve the minimal crack width to be detected.

Figure 1 a) shows the setup of such inspection system and a possible light path for detection of small μ-cracks. The high detection sensitivity allows finding even μ-cracks with multiple reflections within the crack edges (Fig. 1 b). This method is not limited to the middle area of the wafer and is able to detect cracks as far as the outer edges.



a)

b)

Figure 1: a) Principle of μ-crack detection system. b) multiple reflection within μ-crack (< 5μm) not visible with other optical systems available.

To show the intensity of the flash light and as a possible additional capability in figure 2 is shown the intensity of the transmitted IR-light measured with the CCD camera. This intensity of course is directly correlated with the thickness of wafer material. Using these images it could be possible to define wafer thickness and intrusions in the wafer material. Further investigations have to be carried out on these topics.

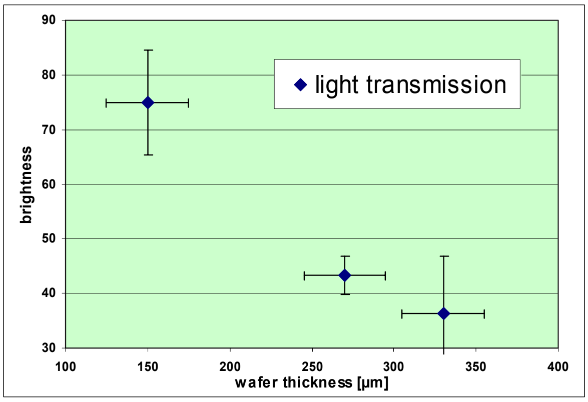


Figure 2: Intensity of transmitted light measured with a CCD camera over full wafer surface.

Results shown are made on a setup with light intensities around 1000 suns, using a flash with a high intensity in the blue area of the spectrum. In order to increase the contrast of the detected µ-cracks, a filter system is used. Only blue part of the spectrum will be visible.

Figure 3 show three examples of µ-crack detection. Figure 3 a) shows a µ-crack with a crack width of more than 30µm. The intensity of the detected light leads to an overload of the CCD camera system. This is the limit for optical systems already on the market.

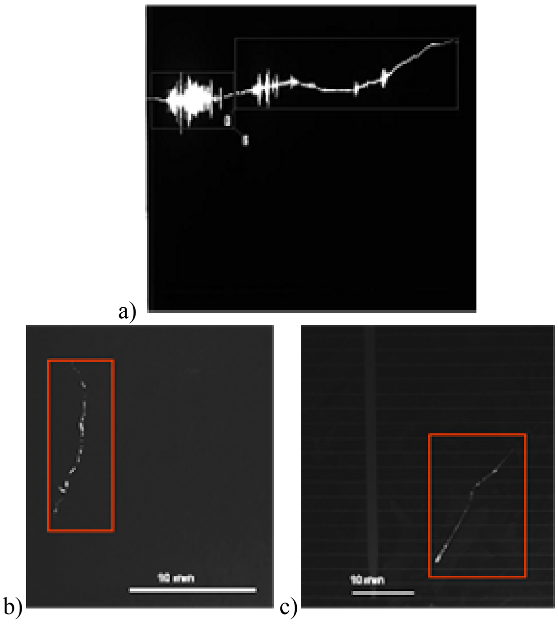


Figure 3: a) µ-crack with appr. 35µm crack width, resulting in an overload of the CCD camera. b) µ-crack (crack width < 5µm) detected on an as-cut multi-crystalline wafer. c) µ-crack (crack width <5 µm) detected on a finished solar cell (after firing).

The limit of the proposed system is below 5µm. Statistical analysis will be carried out in order to define this limit in detail. Figure 3 b) shows a detected µ-crack with a crack width of less than 5µm on an as-cut wafer.

The detection of cracks is not limited to wafer material. Figure 3 c) shows a µ-crack on a finished solar cell after firing. It seems to be a possible measurement technique to sort out “crackling” cells with a contactless method.

3 SAW MARK DETECTION

Uneven wafer surface can cause later processing problems especially during the screen printing process. A standard wafer specification is the TTV (total thickness variation) and wedge-like shape of the wafer. Additional to that wafer sawing process leads to defects like waviness of the wafer, saw grooves or saw marks.

This 3-D inspection of the wafer is performed by a projected laser line. The laser is installed under a tilted angle to detect height differences. Figure 4 shows different saw mark detections heights.

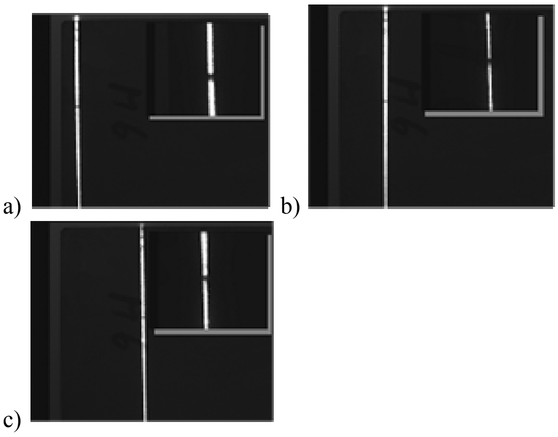


Figure 4: Saw marks of different height detected by a tilted laser system. Saw mark height: a) 6µm, b) 4µm, c) 3µm

Using different projection angles it is possible to define the detection limit of the saw mark angle.

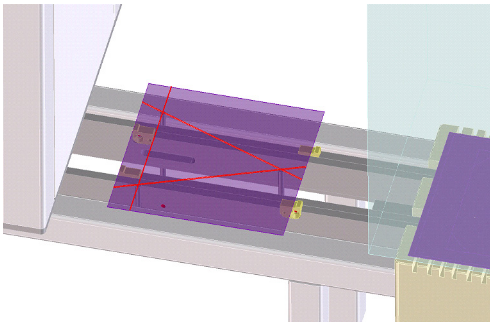
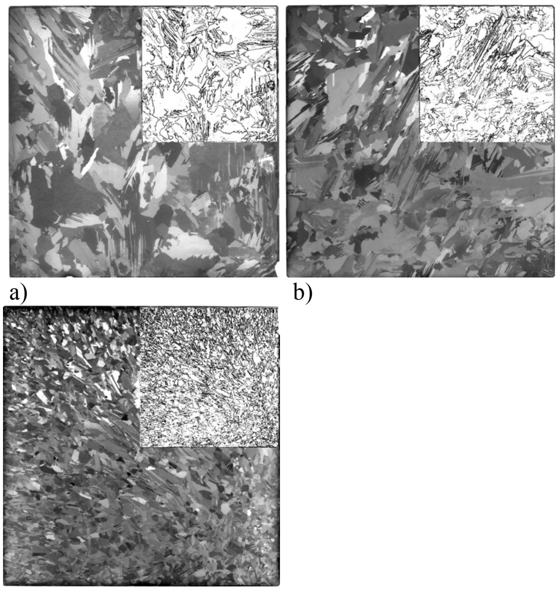


Figure 5: Picture of a possible system to detect 3-D surface defects on silicon wafers.

In a possible machine setup (fig. 5) three or four laser lines would be used to define all 3-D surface defects, which can arise on wafer material (e.g. saw marks). With this setup it would be possible to define TTV and waviness of wafer surface.

4 OTHER TECHNIQUES

The proposed setup for µ-crack detection allows the use of additional characterisation techniques. The full transparency of the wafers offers the chance to detect intrusions or crystallinity effects. One possibility is shown in figure 6.



a) b)

c)

Figure 6: Multi-crystalline silicon wafer illuminated to enhance crystal structure. Three types of mc-Si wafer types with different grade of crystallinity. Calculated crystallinity factor of a) 17,2 % b) 18,1 % c) 31,8 %.

Using the transparent IR-light or inhomogeneous light of the front side it is possible to enhance the grain boundaries of multi-crystalline wafers. With a software routine it is easily possible to define the amount of grain boundaries of the wafer. This can be defined as crystallinity factor of the material.

Comparing the three different wafers (fig. 6) there is only a little difference of the crystallinity factor between a) and b). But wafer b) consists of an area with a high density of grain boundaries. This is usually known as a material with higher recombination in this region and lower overall efficiency. Therefore additional classification data like homogeneity of the crystallinity could be a possible way to define wafer quality.

The correlation of the defined wafer quality with solar cell results is a coming topic of our research activities.

5 CONCLUSION

All presented techniques could be implemented into an inline characterisation tool (Fig. 7). The system would be a wafer inspector for comprehensive incoming (solar cell manufacturing) or outgoing (wafer supplier) inspection. The first experiments which were carried out on a prototype system show very valuable results and lead to the development of a real inline tool. This will allow the testing of greater quantities of wafers and therefore lead to more statistical data.

Additional systems for characterisation of wafers and solar cells during production are already in operation and presented by Fath et al. on this conference.

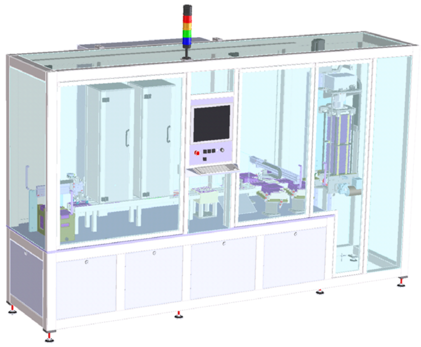


Figure 7: Possible set-up of a comprehensive wafer inspection tool.

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