Optical Setup for Solar Wafer Edge Chip Inspection

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Abstract Limitations of typical camera orientations used to image solar wafer edge chipping by existing systems are demonstrated. A new design with multi-angle light source and a camera set-up which would enable the top surface and the side of a wafer to be viewed simultaneously is proposed. The capability of the new design is demonstrated and it was found that the proposed set-up is able to overcome existing limitations and obtain images that show good contrast between the defective area and its background. This would simplify the requirements for image processing for automated detection systems.

Keywords Optical setup · Solar wafer · Chipping · Saw mark

1 Introduction

Solar wafer are silicon wafers used to manufacture photovoltaic (PV) solar cell. PV has been identified as one of the recent technologies in renewable energy with the highest generation and capacity potential compared to other methods [1]. As such, production is ever increasing to meet demand.

To improve production yield, wafers are increasingly sliced into much thinner pieces. As a result, they are more fragile and prone to edge chips which could easily occur along wafer edges. Edge chip is one of the main causes of wafer breakage and therefore should be detected and eliminated in the production process.

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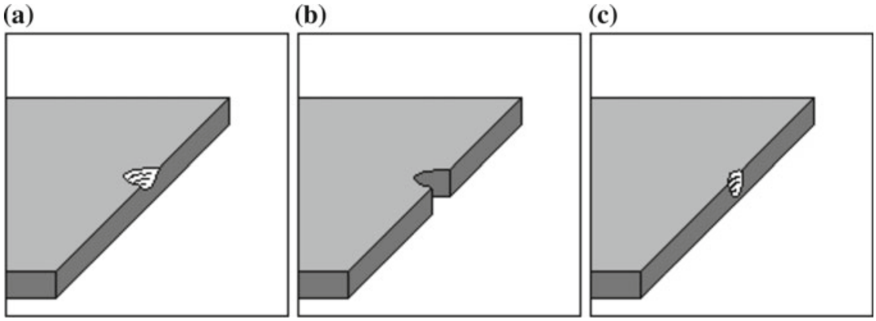


Fig. 1 Illustration of the three different types of edge chippings—**a** non-through chipping, **b** through chipping, and **c** side chipping

Examples of different types of edge chips are illustrated in Fig. 1. Non-through chips are due to the wafer material that was peel-off from the edge on only one side of the wafer. Another variation of an edge chip is a through chip, which is a more severe case as it involves a greater loss of material. Indentation for such chipping can be observed around the wafer outline from both sides of the wafer surface. The final variation would be the side chipping where it is geometrically similar to a non-through chip, except there is more material loss on the side wall surface.

There are several existing designs for edge chip imaging of a solar wafer each with its own advantages and disadvantages. Kim [2] proposed a set-up utilizing a top-view camera, in combination with a hybrid illumination device. The setup is capable of inspecting top surface chipping along with a few others defects.

Bockli et al. [3] emphasized on the importance of chipping which occurs on the side wall of a wafer and the authors proposed a method to inspect the side wall only. The emphasis of chipping on the side wall was concurred by Esser et al. [4] who also proposed another method which only inspects a wafer's side wall chipping.

These existing methods however will contain blind spots should the chip occur outside the camera's field of view due to the orientation of the camera. To increase the field of view, Watkins et al. [5] proposed the use of two cameras, where one will inspect the top surface, while the other for the side wall. This set-up however will be costly as it duplicates the imaging system.

To address the issue of blind spots with minimal costs, we propose a new optical system design by positioning the camera in such a way in that the wafer top surface and its side wall can be viewed simultaneously. This camera arrangement in combination with multiple light sources would also help to suppress surface saw mark textures that would be present in certain types of solar wafers and therefore improve the contrast of the defective area.

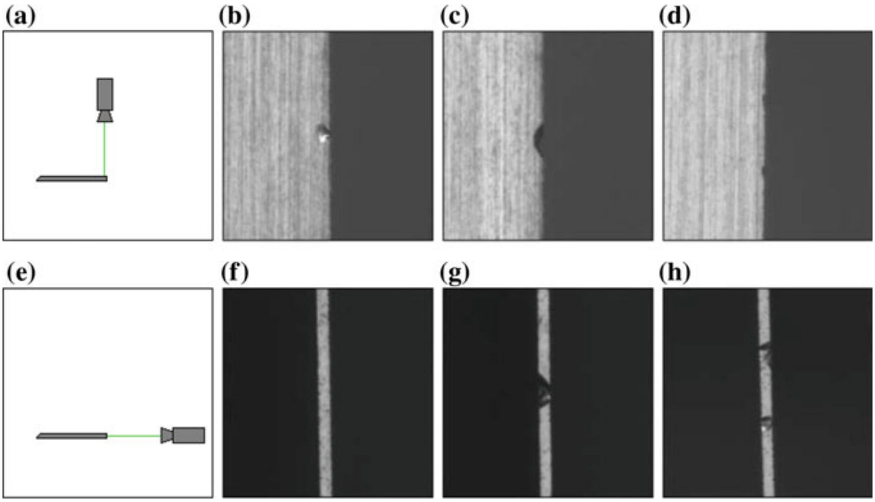


Fig. 2 Existing system with the camera providing a (**a**) top-view, and (**e**) side-view, together with their corresponding captured images of the different types of chipping

2 Limitations of Existing Set-Ups

Typically, cameras in a solar wafer edge chip detection system are set-up to provide either a top-view or a side-view of a wafer.

The top-view camera set-up is found in most existing systems. This set-up as illustrated in Fig. 2a, places the camera on the top of the wafer, allowing the top surface of the wafer to be captured. A non-through chip and a through chip can be distinctively observed using this set-up as shown in Fig. 2b, c respectively. However, a side chip as shown in Fig. 2d has very little indentation when viewed from the top. This limits the capability of the top-view set-up to effectively detect side chipping as the defective area is not clearly presented.

A side-view camera set-up on the other hand provides a clear view of a side chip. This set-up as illustrated in Fig. 2e places the camera on the side of the wafer, allowing the side of the wafer to be captured. However, with a side-view of a wafer, non-through chipping would be practically invisible as shown in Fig. 2f. Through chip and side chip however can be clearly observed as shown in Fig. 2g, h respectively.

3 Proposed Set-Up

The proposed set-up is as shown in Fig. 3, utilizing a set of multiple angled lighting sources along with a camera positioned in such a way that a beam splitter will skew the viewing angle and therefore will provide a view of both the top surface and the side of the wafer simultaneously.

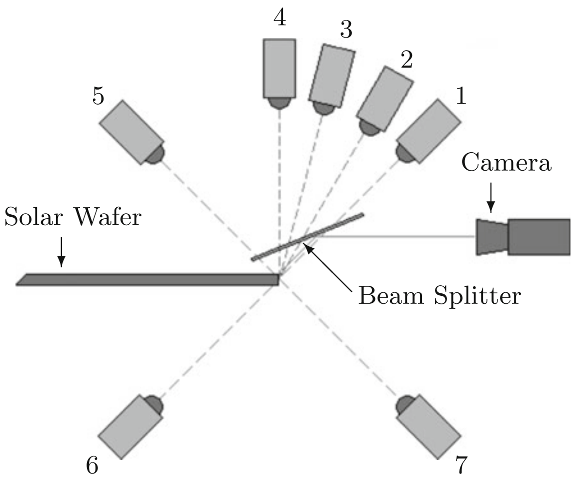


Fig. 3 Schematic showing the proposed set-up containing wafer sample, camera, beam splitter and multiple light sources (*1–7*)

On certain types of solar wafer, saw marks are visible on the surface and this could obscure certain types of chipping as the saw marks has an inhomogeneous texture. To smoothen out saw mark textures in the acquired image, light sources from multiple angles are required. In the proposed set-up, the illuminators are placed at angles between 45 and 135°.

To accurately illuminate the contour of a through chip, a back light is placed on the rear side of the wafer. This light source is positioned at −135° as indicated as illuminator number 6 in Fig. 3.

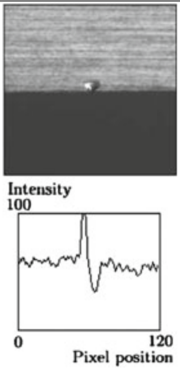
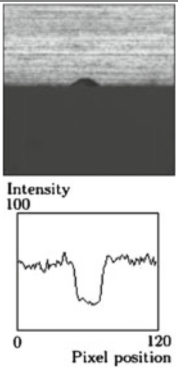
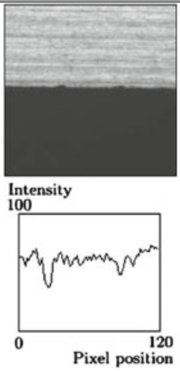
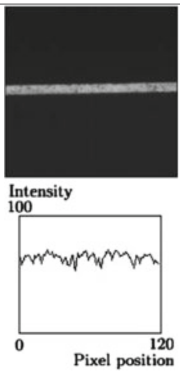
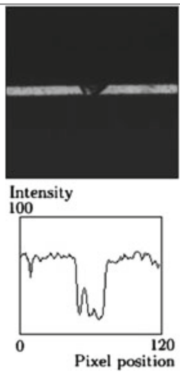
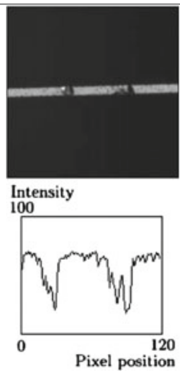
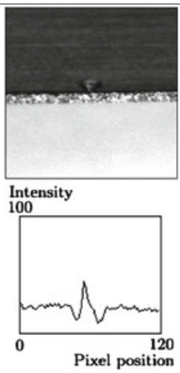
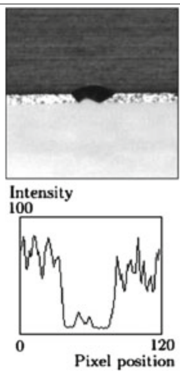
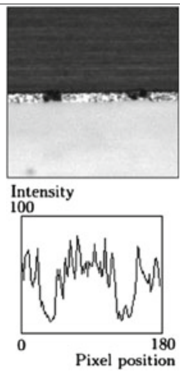
The ideal position of the camera would be at an angle of 45° from the solar wafer, allowing the wafer to be viewed from the top as well as from the side. However, at this angle, the camera will be blocking one of the light sources. Therefore, a beam splitter is used to overcome this limitation.

Since the wafer is viewed from the top and side of the wafer, another light source is required to enhance a side chip. An illuminator is placed at an angle of −45°, resulting in a specular reflection that is captured by the camera. The dented surface of side chip will reflect the light, creating an area with low gray values. This would improve the image contrast, allowing the side chip to be extracted.

4 Results and Discussion

Three different types of chippings (non-through, through and side chippings) were tested with the proposed set-up and the results are shown in Table 1 with comparison with existing set-ups.

Table 1 Sample crop-out images together with its horizontal intensity profile across each chipping. Images show three types of chippings under different image acquisition set-ups

	Non-through chip	Through chip	Side chip
Top-view camera			
Side-view camera			
Proposed set-up			

As shown in Table 1, the side chip is barely visible with the top-view camera, whereas the side-view camera set-up is unable to show non-through chipping. With the proposed set-up however, all three types of chipping as seen in the last row of Table 1 is clearly visible.

The proposed set-up is capable of acquiring an image which contains a combination of the wafer top surface, the side wall and also the background. The wafer top surfaces are represented by an area with low gray value with suppressed saw marks. As shown in the first image of proposed set-up in Table 1, a non-through chip is represented by an area with higher gray value as shown in its line profile and therefore has better contrast for segmentation compared to a side-view camera set-up.

The much bigger through chip of the proposed set-up in Table 1 appears as an area of very low gray value. With the use of a backlit illumination, the contrast between the wafer side wall and the background is significantly improved. From these figures, it is clear that the through chippings can be easily observed, as the edge contours are much more distinct.

The side wall area of the wafer has a higher average gray level value compared to the top surface. The side chip however has a relatively lower gray value in this area. Referring to the side chip image of the proposed set-up in Table 1, this set-up will produce better contrast as shown in the line profile of the chip from the side wall surface compared to a top-view camera set-up.

5 Conclusion

A new solar wafer edge chipping imaging method has been proposed, capable of producing a much better coverage of the side of solar wafer for the purpose of edge chipping inspection. This method is capable to imaging the three major types of chip defect (i) through, (ii) non-through, and (iii) side chipping with no blind spots. Noises in the form of saw mark lines are also significantly suppressed, resulting in much higher image-to-noise ratio and thus will greatly simplify image processing requirements for automated detection systems.

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