

## METHOD AND SYSTEM TO DETECT CHIPPINGS ON SOLAR WAFER

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention relates to a system and a method of detecting chipping on solar wafer chamfer side wall, more particularly, to a chipping detection system and method suitable for detecting chipping on any edge of a solar wafer which can lead to cracks and wafer breakage.

#### Description of the Related Art

Solar cell manufactures routinely perform inspection on solar wafers as part of the process of solar cell fabrication. This is to ensure that any defects on the solar wafers are identified in the beginning stages and the subsequent solar wafers produced are of a high quality.

A solar wafer is an extremely thin slice of silicon crystal that is commonly used in the fabrication of solar cells. In the fabrication of a solar cell, Solar Wafers undergoes many processes such as deposition, etching, and patterning etc., acting as a substrate for the solar cell before it becomes a functional solar cell during the fabrication process. Due to the brittle properties of solar wafers, a very small chipping on any edge of the solar wafer can lead to cracks and ultimately water breakage when used in the fabrication of the solar cell. Therefore, it is extremely critical to maintain the quality of solar wafers right from the beginning of the fabrication process in order to improve production yield and keep production costs low.

Chipping defects can appear on the top and/or bottom surfaces along straight and chamfer edges of solar wafers (as shown in Figure 1). This type of chipping can be detected by using two cameras viewing directly onto the top and bottom surface of solar wafers and images are taken while wafers are moving (i.e. on-the-fly image capture) (as shown in Figure 2). Both chippings along straight and chamfer edges can be detected.

Chipping defects also appear on the side wall surfaces along straight edges of solar wafers (as shown in Figure 3). This type of chipping is not visible from the top and/or bottom surface and therefore additional cameras have to be used. Typically two additional cameras are placed horizontally along the wafer moving direction to look onto the side wall and images are taken on-the-fly manner (as shown in Figure 4). To detect chippings on the side wall of leading/trailing edges, a mechanical rotator is used to rotate solar wafers 90 degrees and then pass through another two cameras which are arranged similarly to the cameras before rotation.

Additionally, chipping defects can also appear on the side wall surface along chamfer edges of solar wafers (as shown in Figure 5). This type of chipping is unique because it appears only on the side wall of the chamfer edges only, which is 45 degrees to the straight edges. Moreover, this type of chipping is not visible from the top and bottom surfaces. Although a  
5 typical depth of focus of a camera is about 2mm, but some mono-crystalline solar wafer can have chamfer size up to 25mm (depending on the wafer size and diameter) (as shown in Figure 6). Presently, no camera can detect the chipping even though it is positioned horizontally.

US Patent No. 5,157,735, entitled "Chipping detection system and method" discloses a  
10 system and a method of detecting a chipping of the rail part of a slider of a thin film magnetic head obtains the image of the object of detection and its boundary coordinates by tracing the boundary of the object of detection from the image. A chipping size is obtained from the coordinates of the points on the boundary, and the presence or absence of chipping is judged from the chipping size, thereby enabling the highly precise detection of a chipping defect  
15 generated on the boundary portion of the object of detection using a simple structure.

US Patent No. 8400630 relates to a method for detecting defects in an object, the method which comprises: locally illuminating the object by irradiating the object with incident light having a wavelength to which the object is transparent; detecting multiply reflected components of the incident light while at least partly avoiding a detection of directly transmitted  
20 components of the incident light and at least partly avoiding a detection of singly reflected components of the incident light; and identifying defects by evaluating intensity differences in the detected components of the incident light.

US Patent No. 8428337 discloses a method for wafer inspection comprising: directing light substantially along a first axis towards a first surface of a wafer to thereby obtain light  
25 emanating along the first axis from a second surface of the wafer, wherein the first and second surfaces of the wafer are substantially outwardly opposing and substantially extending parallel to a plane; and directing light substantially along a second axis towards the first surface of the wafer to thereby obtain light emanating along the second axis from the second surface of the wafer, the first axis being angled away from the second axis about a reference axis extending  
30 along the plane, wherein the orthographic projection of the first axis on the plane is substantially parallel to the orthographic projection of the second axis on the plane, and each of the orthographic projections of the first and second axes on the plane is substantially orthogonal to the reference axis.

Another chipping detection method is conventionally carried out with human eyes, but in place  
35 of such detection various techniques for automatically detecting chipping has been proposed.

Some of the conventional techniques relating to this kind of system are disclosed, for example, in Japanese Patent Laid-Open No. 255484/1986 and Japanese Patent Publication No. 13617/1987. In the former method, a straight line is applied by a least square method to the boundary of the straight line portion of a binary image obtained by the detection through a TV camera or the like and the values of the binary image are examined along the straight line. From the results, the presence or absence of a chipping is judged. In the latter method, scattered light produced by chipping is detected, and for this purpose, the incident angle and the disposition of a scattered light receptor are optimized.

## SUMMARY OF THE PRESENT INVENTION

Accordingly, it is an object of the present invention to eliminate the above-described problems in the prior art and to provide a method to on-the-fly detect chippings on solar wafer chamfer side wall which is capable of detecting chipping at a high speed without missing.

Another object of the present invention is to provide a system to on-the-fly detect chippings on solar wafer chamfer side wall which is capable of detecting chipping at a high speed without missing.

An object of the present invention is to provide a chipping defect detection system for detecting a chipping defect at chamfer edge of a solar wafer, said solar wafer being substantially rectangular or square shape having straight edge and chamber edges, comprising:

(a) a plurality of imaging means for pickup images of the position of the solar wafer and being positioned horizontally to the focusing plane of the solar wafer;

(b) a plurality of illumination means to provide light for the imaging means while in operation thereof;

(c) a conveyor belt for transporting the solar wafer horizontally in the course of chipping detection operation;

(d) a sensing means providing a signal to trigger the imaging means to start an image capture; and

(e) a strobe light driver which is triggered by the imaging means to drive the illumination means such that the imaging means provides an exposure time which coincides with the illumination means

thereby the chamfer edges are located at the out-of-focus position at the same position being sensed by the sensing means, and the image captured by the imaging means being not sharp is the chipping on the chamfer edges of the solar wafer.

Accordingly, it is an object of the present invention to eliminate the above-described problems in the prior art and to provide a chipping detection system and method which has a simple structure and is capable of detecting chipping at a high speed without missing and being influenced by the position or the situation of an object of detection.

It is another object of the present invention to provide a chipping detecting system and method which are capable of detecting solar wafer of square shape or configurations.

10 An object of the present invention is to provide a method of chipping defect detection for a solar wafer using the detection system comprising the step of:

(a) positioning a plurality of cameras horizontally with the camera focusing plane thereof being parallel to the chamfer edges of the solar wafer;

15 (b) mounting a presence sensor along the conveyor belt to detect solar wafer presence in such a way that the solar wafer is detected by the presence sensor before the chamfer edges enter the depth of focus (DOF) range of the camera;

(c) transporting the solar wafer by the conveyor belt in horizontal at a constant speed;

(d) detecting the solar wafer by the presence sensor to output a true signal;

20 (e) triggering the cameras by signals generated by the presence sensor to capture multiple images of the chamfer edge at a constant interval, and also triggering the strobe light driver to provide an illumination which coincides with the camera exposure time;

(f) transmitting the images that have been captured by the camera to a computer linked to the detection system;

25 (g) receiving a series of chamfer edges images by the computer, starting from outside DOF range, inside the DOF range, exiting DOF range and outside DOF range again;

(h) locating by the computer the image in which the chamfer edge that is inside the DOF range by selecting the images with maximum image sharpness; and

(i) analysing the sharpest image to perform image analysis to detect any presence of chippings.

The above and other objects, features and advantages of the present invention will become clear from the following description of the preferred embodiments thereof, taken in conjunction with the accompanying drawings.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

- 5     FIG. 1 shows chippings on the surface along edges of a solar wafer;
- FIG. 2 illustrates conventional system for detecting chippings as shown in FIG. 1, wherein a top and a bottom camera are placed over a solar wafer;
- FIG. 3 shows a typical solar wafer with chipping defects on the side wall surfaces along straight edges of solar wafer;
- 10    FIG. 4 shows a system for detecting chippings as described in FIG. 3;
- FIG. 5 shows chipping defects on the side wall surface along chamfer edges of solar wafer;
- FIG. 6 schematically shows the chippings appeared on the side wall surface on the chamfered edges of solar wafer, wherein the chamfer size is up to 25 mm, and the camera was at a horizontal position.
- 15    FIG. 7 schematically shows a system for detection of chipping in solar wafer in accordance with the present invention;
- FIG. 8 schematically shows the positioning of camera with respect to the position of the chamfer edge in accordance with the present invention;
- FIG. 9 schematically shows the positioning of camera with respect to the position of the
- 20    chamfer edge in accordance with the present invention, wherein the solar wafer has a position variation of  $\Delta x$  on the conveyor belt;
- FIG. 10 schematically shows the chamfer edge to fall within the camera focusing plane even though the solar wafer position variation is  $\Delta x$  in accordance with the present invention;
- FIG. 11 shows the solar wafer 103 positions that are being captured by the cameras 101 in
- 25    burst mode of up to N number in accordance with the present invention;
- FIG. 12 shows an example of chamfer side wall with chippings images taken by burst mode and their calculated edge sharpness in accordance with the present invention; and
- FIGs. 13A and 13B schematically shows another preferred embodiment of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to the drawings, embodiments of the invention described hereinafter relate to method and system to On-the fly detect chippings on solar wafer chamfer side wall.

5 As shown in figures, FIG. 1 schematically shows chippings formed on solar wafers in the course of fabricating solar cells. These common defects include chipping on the top and bottom surfaces 93 along the chamfered edges, chipping on the top or bottom surface only along straight edges 92 of the solar wafer, chipping on both top and bottom surfaces along straight edges 91 of the solar wafer, and chipping on top or bottom surface along chamfered  
10 edges 90 of the solar wafer. FIGs. 2-4 illustrate chippings formed on the solar wafer but not on chamfer edges. In the figures, reference number 101 indicates the cameras, 103 refers to the solar wafer, and the conveyor belt is referenced as 104.

Referring to FIG. 5, there is shown chipping formed on the side wall along chamfered edges 202 of a solar wafer. The conventional method of chipping detection for this is cannot be  
15 employed for the reason that this type of chipping is not visible from the top and bottom surface of the solar wafer, and that this type of chipping appears on the side wall surface on the chamfered edge which is 45 degree to the straight edges. Although a typical depth of focus of a camera is about 2 mm, some mono-crystalline solar wafer can have chamfer size up to 25 mm, which depends on the wafer size and diameter, and as a result, no camera can detect  
20 the chippings even though the solar wafer is positioned horizontally. FIG. 6 schematically shows the chippings appeared on the side wall surface on the chamfered edges of solar wafer, wherein the chamfer size is up to 25 mm, and the camera was at a horizontal position.

An exemplary embodiment of the invention is described in greater detail hereinafter in accordance to illustrations provided in FIGs. 7 to 13 of the drawings, wherein like elements  
25 are identified with like reference numbers.

Figure 7 schematically shows a system for detecting a chipping defect at chamfer edge of a solar wafer in accordance with the present invention. In a preferred embodiment of the present invention, the chipping defect detection system for detecting a chipping defect at chamfer edge of a solar wafer comprises a plurality of imaging means, such as cameras 101, for pickup  
30 images of the position of the solar wafer 103. Generally, the solar wafer 103 is substantially regular or square shape having straight edge and chamber edges. In this case, a total of four cameras 101 are employed for the chipping detection at the chamfer edge of the solar wafer 103. The system further includes a plurality of illumination means 102 to provide light for the

imaging means 101 while in operating in chipping detection. The chipping detection system further comprises a conveyor belt 104 for transporting the solar wafer horizontally in the course of chipping detection operation and a sensing means 105 (a presence sensor) to provide a signal to trigger the imaging means 101 to start an image capture. A strobe light driver 107 is provided in the system which is used to trigger the imaging means 101 to drive the illumination means 102 such that the imaging means 101 provides an exposure time which coincides with the illumination means 102. In other words, the chipping detection system of the present preferred embodiment provides a plurality of cameras, for instance at this case, four cameras, each equipped with lens 101, with 4 sets of illumination means (illuminators) 102. The cameras 101 are positioned horizontally and oriented in such a way that the camera focusing plane 202 is parallel to and coincide with each chamfer edge 102 of the solar wafer 103. The solar wafer 103 is loaded on a conveyor belt 104 and when the solar wafer 103 is transported by the conveyor belt 104, and sensed by the presence sensor 105 which is mounted around the conveyor belt 104 or any appropriate location enabling the detection of the presence of solar wafers at a time ( $t_0$ ), the presence sensor 105 triggers the cameras 101 to start an image capture. The cameras 101 also trigger the strobe light driver 107 which drives the illuminator 102 such that the camera exposure time coincides with the illumination.

In the present preferred embodiment, in view of the camera orientation, the chamfer edges 202 of the solar wafer 103 and the camera focusing planes 201 are parallel to each other, and therefore it is possible to obtain sharp images of chamfer side wall and therefore detects chippings on the chamfer side wall of the solar wafer 103.

Figure 8 schematically shows one corner of the chipping detection system in accordance with the preferred embodiment of the present invention. As shown, the camera focusing plane 201 is directly parallel to the chamfer edge of the solar wafer 103. In order to obtain sharp images of the chamfer side wall, it requires very precise control of the solar wafer position 103 on the conveyor belt 104. Figure 9 schematically illustrates the position variation of  $\Delta X$  of the solar cell 103 on the conveyor belt 104. When a solar wafer 103 has a position variation of  $\Delta X$  on the conveyor belt 104, the chamfer edges 202 can be located at the out-of-focus position at the same position being sensed by the presence sensor 105. As a result, the image captured by the cameras 101 is not sharp and chippings detection performance is affected.

Figure 10 schematically illustrates capturing sharp chamfer edges 202 in accordance with the present invention. In other words, the chamfer edges 202 images should fall within the camera focusing plane 201 even though the solar wafer 103 position variation is  $\Delta X$ . To accomplish this, the presence sensor 105 is moved forward so that camera image capture starts earlier. Once the camera is triggered by the presence sensor 105, it will capture images in burst mode

at fixed frame-per-sec (FPS) while the solar wafer 103 is moving at the speed  $v$ . The chamfer edges 202 do not need to be at the camera focusing plane 201 when the cameras 101 start the burst mode image capture.

Figure 11 shows schematically the positions of the solar wafer 103 positions being captured by the cameras 101 in burst mode of up to  $N$  number. The first position  $P1$  of the solar wafer 103 is where presence sensor 105 triggers the cameras 101, and the next image is triggered after an interval  $\rho$ , and the interval  $\rho$  can be calculated as below:

$$\rho = v/\text{FPS}$$

wherein  $\rho$  is the interval,  $v$  is the speed of the moving solar wafer, and FPS is the fixed frame-per-sec of the burst mode.

Referring to FIG. 11, as the cameras capture is continuously while the solar wafer 103 is being transported, it is possible to obtain an image  $P_n$  in which the chamfer edges 202 are positioned within the Depth-Of-Focus (DOF) range of the cameras 101 provided that the interval  $\rho$  is at least  $\frac{1}{2}$  of the DOF. As a result, it is calculated that the cameras 101 must have minimum FPS of based on equation below in order to ensure the cameras 101 must have minimum FPS of based on equation below in order to ensure chamfer edges 202 are being captured within the DOF range:

$$[\text{FPS}]_{\min} = (2 \times v \times \cos 45^\circ) / \text{DOF}$$

wherein FPS is the fixed frame-per-sec,  $v$  is the speed of the moving solar wafer, and DOF is the Depth-Of-Focus range of the cameras.

As an example, given a typical conveyor with a travelling speed of 200mm/s, and Depth-Of-Focus (DOF) of the cameras 101 is 2mm, the minimum FPS required to obtain a sharp chamfer side wall images is calculated to be about 141 frames-per-sec. This is easily achievable by using modern CMOS sensor cameras with Area-Of-Interest (AOI) set to a thin window just enough to cover the solar wafer 103 thickness plus some margin.

In the preferred embodiment of the present invention it is also important to calculate the number of images  $N$  required in the burst mode to make sure that the chamfer edges 202 of the solar wafer 103 has passed through the camera focusing plane 201 regardless of the position variation  $\Delta X$ .

$$N_{\min} = (\Delta X \times \text{FPS}) / (v \times \cos 45^\circ)$$

wherein N is the number of images,  $\Delta X$  is the position variation, FPS is the fixed frame-per-sec , and v is the speed of the moving solar wafer.

As an example, given a typical position variation  $\Delta X$  of  $\pm 5\text{mm}$ , the minimum number of image to be captured in the burst mode is found to be 10. The actual number should be larger after  
 5 considering the position of the presence sensor 105.

It has been mentioned earlier that the cameras 101 starts burst mode image capture when the presence sensor 105 senses a solar wafer 103. This results in transmitting N number of images to a computer 106 which is connected to the chipping detection system. It is to be noted that only one out of the collected N images needs to be selected for chippings detection.

FIG. 12 shows a series of chamfer side wall with chippings images taken by burst mode with  
 10 calculated edge sharpness in accordance with the present invention. As shown, image 7 of the series images is selected for chipping detection as this image has the highest edge sharpness. It is noted that the chamfer edge 202 has transitioned from out-of-focus to focus, and then from focus to out-of-focused again. Also, it is to be noted that the chamfer edge 202  
 15 does not stay at the same position as the result of the cameras being 45 degree orientated with respect to the solar wafer moving direction.

Accordingly, the present invention provides a method of chipping defect detection for a solar wafer using the detection system disclosed above. The method includes the following steps of: positioning a plurality of cameras horizontally with the camera focusing plane thereof being  
 20 parallel to the chamfer edge of the solar wafer. A presence sensor is mounted along the conveyor belt to detect solar wafer presence and positioned such that when the presence sensor detects a solar wafer, the chamfer edge of the solar wafer is detected first before the chamfer edge entering the depth of field (DOF) range of the camera is detected. The solar wafer is being transported by the conveyor belt 104 at a constant speed. While the solar wafer  
 25 103 is being transported and reaches the presence sensor 105, the presence sensor 105 detects the solar wafer 103, and therefore set the output signal of the system to be true. The output signal is connected to the cameras 101 and the signal triggers the cameras 101 to capture multiple images (or burst mode) of the chamfer edge at a constant interval. While the cameras 101 are capturing images, the cameras 101 also trigger a strobe light driver 107  
 30 to provide an illumination which coincides with the camera exposure time. The images that captured by the cameras are being transmitted to the computer. At the end of the multiple image capture, the computer 106 receives a series of chamfer edge images which start from outside DOF range, entering the DOF range, inside the DOF range, exiting DOF range and outside DOF range again.

In accordance with the present invention, software is loaded in the computer 106 which will locate the images in which the chamfer edge is inside the DOF range by selecting the images with maximum image sharpness. The software will then use the sharpest image to perform image analysis to detect and presence of chippings.

- 5 FIG. 13A and FIG. 13B schematically show possible modification of chipping detection system in another preferred embodiment of the present invention. It is to be noted that the number of cameras that employed can be reduced to two. This is achievable by placing two beam splitters 301 on each side of the conveyor 104. The beam splitter 301 allows the cameras 101 to capture the leading chamfer edges 302 first, and then follow by the trailing chamfer edges  
10 303 as long as the leading and trailing chamfer edges does not appear at the camera focusing plane at the same time, which can be done by controlling the gap between the solar wafers.

While there has been described what are at present considered to be preferred embodiments of the invention, it will be understood that various modifications may be made thereto, and it is intended that the appended claims cover all such modifications as fall within the true spirit  
15 and scope of the invention.

**What is claimed is:**

1. A chipping defect detection system for detecting a chipping defect at chamfer edge of a solar wafer, said solar wafer being substantially regular or square shape having straight edge and chamber edge, comprising:

5 (a) a plurality of imaging means for pickup images of the position of the solar wafer and being positioned horizontally to the focusing plane of the solar wafer;

(b) a plurality of illumination means to provide light for the imaging means while in operation thereof;

10 (c) a conveyor belt for transporting the solar wafer horizontally in the course of chipping detection operation;

(d) a sensing means providing a signal to trigger the imaging means to start an image capture; and

15 (e) a strobe light driver which is triggered by the imaging means to drive the illumination means such that the imaging means provides an exposure time which coincides with the illumination means

thereby the chamfer edges are located at the out-of-focus position at the same position being sensed by the sensing means, and the image captured by the imaging means being not sharp is the chipping on the chamfer edges of the solar wafer.

20 2. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the imaging means are positioned horizontally and oriented with the camera focusing plane thereof parallel to and coincide with each chamfer edge of the solar wafer.

3. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, further comprising a computer system with memory storage.

25 4. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein sharp images of chamfer side wall are obtained by the imaging means.

5. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the sensing means triggers the imaging means to take image along the chamfer edge of a solar wafer.

6. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the imaging means captures images in burst mode at fixed frame-per sec (FPS) while the solar wafer is moving at a speed.

7. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the chamfer edges do not position at the camera focusing plane when the imaging means start the burst mode image capture.

8. The chipping defect detection system for detecting a chipping defect as claimed in claim 7, wherein the solar wafer positons that are being captured in burst mode are up to N number.

9. The chipping defect detection system for detecting a chipping defect as claimed in claim 7, wherein the next image capture after an interval of time p is

$P=v/FPS$ , wherein v is the speed of the solar wafer on the conveyor and FPS is frame per second of the imaging means.

10. The chipping defect detection system for detecting a chipping defect as claimed in claim 7, wherein the minimum FPF by the imaging means is based on the equation

$$[FPS]_{min} = (2 \times v \times \cos 45^\circ) / DOF$$

wherein FPS is the fixed frame-per-sec, v is the speed of the moving solar wafer, and DOF is the Depth-Of-Focus range of the cameras being 2 mm.

11. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the imaging means is camera and is equipped with a CMOS sensor cameras with an Area of Interest set to a thin window enough to cover the solar wafer thickness plus some margin.

12. The chipping defect detection system for detecting a chipping defect as claimed in claim 1, wherein the number of images N required in the burst mode of imaging to make sure that the chamfer edges have passed through the camera focusing plane regardless of the position variation delta x is

$$N_{min} = (\Delta X \times FPS) / (v \times \cos 45^\circ)$$

wherein N is the number of images,  $\Delta X$  is the position variation, FPS is the fixed frame-per-sec, and v is the speed of the moving solar wafer.

13. A method of chipping defect detection for a solar wafer using the detection system as set forth in Claim 1 comprising the step of:

- (a) positioning a plurality of cameras horizontally with the camera focusing plane thereof being parallel to the chamfer edges of the solar wafer;
- (b) mounting a presence sensor along the conveyor belt to detect solar wafer presence in such a way that the solar wafer is detected by the presence sensor before the chamfer edges enter the depth of focus (DOF) range of the camera;
- (c) transporting the solar wafer by the conveyor belt in horizontal at a constant speed;
- (d) detecting the solar wafer by the presence sensor to output a true signal;
- (e) triggering the cameras by signals generated by the presence sensor to capture multiple images of the chamfer edge at a constant interval, and also triggering the strobe light driver to provide an illumination which coincides with the camera exposure time;
- (f) transmitting the images that have been captured by the camera to a computer linked to the detection system;
- (g) receiving a series of chamfer edges images by the computer, starting from outside DOF range, inside the DOF range, exiting DOF range and outside DOF range again;
- (h) locating by the computer the image in which the chamfer edge that is inside the DOF range by selecting the images with maximum image sharpness; and
- (i) analysing the sharpest image to perform image analysis to detect any presence of chippings.