METHOD TO INSPECT FRONT AND REAR SIDES OF SOLAR WAFER

BACKGROUND

In solar cell manufacturing process, a solar wafer typically goes through multiple stages of optical inspection to detect flaws or damages, for example,

- Top and bottom surface inspection to check for stain, scratches on wafer surface
- Micro-crack inspection to check for invisible cracks inside wafers
- Edge inspection to check for broken or chipping along wafer edges

As the market for solar cells become more competitive, solar cell manufacturers require higher quality solar wafers in order to obtain higher production yield and therefore reduce cost. Solar cell manufacturers have realized that some wafer side area defects (e.g. crystal peel-off, glue residue) can cause quality problems and therefore began to demand inspection of all sides of the solar wafer from the wafer supplier.

This invention describes a method to perform inspection of both ends (herein referred to " front side " and " rear side ") of a solar wafer with less complexity and lower setup costs.

PROBLEMS AND PRIOR SOLUTIONS

As shown in Fig 2, solar wafers 01 (Note: letter 'A' in the figure is to illustrate wafer orientation only, it does not exist in actual solar wafers) are normally transported using conveyor belts 12 during production. One should understand that the conveyor belt shown in the figure is for illustration purpose and actual design of conveyor belt varies. As wafers are transported in directional manner, the wafer sides parallel to the moving direction (left side 13 and right side 14) can be easily inspected using image devices 17. Problem arisen when one is trying to inspect the wafer sides which are perpendicular to the moving direction (front side 15 and rear side 16). As front side 15 and rear side 16 are facing the moving direction 18 and therefore putting an imaging device in that direction obstructs wafer movements.

A prior solution shown in Fig. 3 overcomes the problem using a three axes robot 20 along conveyor belts 12. The three axes robot 20 lifts a solar wafer 10 above the conveyor belt and

then rotates the solar wafer 10 by 90-degree before putting it back onto the conveyor belt 12. After the solar wafer 10 is rotated, the front side 15 and rear side 16 become parallel to the moving direction and therefore can be inspected using two more imaging devices 19. Problems with this solution are:

- It may cause wafer damage when it lifts/places wafers from/onto conveyor belts.
- High cost due to high speed and high precision three axis robot is needed.

Another prior solution shown in Fig. 4 uses additional conveyor belts 21 which is 90-degree angle with respect to the mentioned conveyor belts 12. As solar wafer 01 moved to the end of conveyor belt 12, it enters to the path of conveyor belt 21 and changes its moving direction to 90 while keeping the same orientation. Additional image devices 22 will then be able to inspect the wafer front side 15 and rear side 16 as these sides are now parallel to the moving direction. Main problems with this solution is that the system size become much larger due to additional conveyor belt in 90-degree direction.

SUMMARY OF THE INVENTION

A first object of the invention is an inspection method for a front side and a rear side of a solar wafer, the side inspection method consisting of continuously capturing a discrete number of images of the front side and rear side, consisting of the following steps:-

moving the solar wafer on a conveyor belt,

when the front side of the solar wafer approaches the line of sight of a line scan imaging device,

a first light source is turned on and a beam of light directed towards the front side of the solar wafer,

obtaining a first reflection of the light source from the front side of the solar wafer,

until the front side of the solar wafer passes the line of sight of the line scan imaging device,

and as the rear side of the solar wafer passes the line of sight of the line scan imaging device,

a second light source is turned on and a beam of light directed towards the rear side of the solar wafer,

obtaining a second reflection of the light source from the rear side of the solar wafer,

until the rear side of the solar wafer passes the line of sight of the line scan imaging device,

wherein the first reflection and the second reflection are merged by a beam splitting device to form a number of images of the front side and rear side respectively as it enters the line scan imaging device.

Preferably the inspection method for a front side and a rear side of a solar wafer further includes these steps:-

turn off the second light source and turn on the first light source when collecting the first reflection from the front side; and

turn off the first light source and turn on the second light source when collecting the second reflection for the rear side;

Preferably, the number of images n captured by the inspection method for a front side and a rear side of a solar wafer, wherein n can be calculated :-

$$n = \frac{\tau}{\varphi \tan \theta} \quad (Eq.1)$$

where τ is the thickness of the solar wafer and θ is the viewing angle of the linescan imaging device and φ is set to the same the image resolution as the linescan imaging device.

Preferably φ the focusing range can be calculted as follows:-

$$\omega = \frac{\tau}{\sin\theta} \quad (Eq.2)$$

Prerferably θ should be selected so that ω does not exceed allowable depth of focus of the linescan image device.

Alternatively the inspection method for a front side and a rear side of a solar wafer, uses one or more line scan imaging devices.

A second object of the invention is a system for the inspection of the front side and rear side of a solar wafer, said system moving the solar wafer on a conveyor belt,

turns on a first light source and directs said light beam towards the front side of the solar wafer,

obtaining a first reflection of the light source from the front side of the solar wafer,

as the front side of the solar wafer approaches the line of sight of a line scan imaging device,

continously obtaining a series of first reflections until the front side of the solar wafer passes the line of sight of the line scan imaging device,

and as the rear side of the solar wafer passes the line of sight of the line scan imaging device,

turnis on a second light source and directs said light beam towards the rear side of the solar wafer,

continously obtaining a series of second reflections of the light source from the rear side of the solar wafer,

until the rear side of the solar wafer passes the line of sight of the line scan imaging device,

wherein the series of first reflections and the series of second reflections are merged by a beam splitting device to form a merged series of images.

Preferably the system for inspection of a front side and a rear side of a solar wafer, is controlled and monitored by a microprocessor.

Preferably the system for inspection of a front side and a rear side of a solar wafer, has a sensor to detect the entry and exit of a wafer into the system, said sensor mounted at the position where the wafer enters and detects whether the wafer has entered and exited the system by sending a signal to the microprocessor.

Preferably the system for inspection of a front side and a rear side of a solar wafer receives the merged series of images of the front side and rear side of a solar wafer and uses algorithms to sort out those solar wafers with defects above a tolerated level.

Preferably the beam splitting device is a plate beam splitter.

Alternatively, the beam splitting device is a cube beam splitter.

Optionally, the beam splitting device is a dichroic mirror.

Optionally, the beam splitting device is a dichroic color filter.

Alternatively, the system for inspection of a front side and rear side of a solar wafer has a folding mirror is placed in between the linescan imaging device and the beam splitting component to fold an optical path of the beam of light so that the overall length of the system can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

It will be appreciated that the method of inspecting the front side and rear side of a solar wafer may be implemented in various forms. A preferred embodiment of the invention will now be described, by way of example only and without intending to be limiting, and with reference to the accompanying drawings, wherein like numbers refer to like elements.

Fig. 1 shows the side and front side of a solar wafer.

Fig. 2 is an illustration of how solar wafers are transported using conveyor belts during production.

Fig. 3 is a prior art solution proposed to inspect the sides of solar wafers using a three axes robot as the solar wafer moves along the conveyor belts.

Fig. 4 is a variation of the prior art solution to inspect the sides of solar wafers using a three axes robot in which an additional conveyor belt which is 90-degree angle with respect to the fore-mentioned conveyor belts.

Fig. 5 is an overall view of the invention illustrating a linescan imaging device viewing at an angle θ onto an optical beam splitting component 2 along the mentioned conveyor belts.

Fig. 6 is an enlarged side view of the invention in which a solar wafer is moving on conveyor belt and the solar wafer front side has just entered the line of sight of the line scan imaging device.

Fig. 7 is an enlarged side view of the invention in which the rear side of the solar wafer is about to leave the line of sight of the linescan imaging device

Fig. 8 is an illustration of how a series of images of the front side of a solar wafer is obtained. (The rear side of the solar wafer is the same except that the direction is reversed).

Fig. 9 shows the light sources are typically LED bar lights with focusing element to focus light onto the are of the front side or rear side to get maximum image brightness.

Fig. 10 shows that the beam splitting component is replaced with a dichroic color filter and the light source will have different color wavelength λ1 and λ2.

Fig. 11 is a schematic of the detection process for the front side and rear side.

Fig. 12 shows line images captured by the line scan imaging device. The upper white area is the front side captured by the linescan imaging device and the lower white area is the rear side.

Fig. 13 shows a closed up portion of the front side image from Fig. 12.

Fig. 14 shows a closed up portion of the front side from Fig. 12 with a side area defect can be seen clearly as the dark patch along the white area.

Fig. 15 illustrates the invention with two cameras used side-by-side.

Fig. 16 shows the use of a folding mirror placed in between the linescan imaging device and the beam splitting component to fold the optical path so that the overall length of the system can be reduced.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An overall view of the invention is illustrated in Fig. 5. A wafer present sensor 61 mounted at the position where wafer 01 is entering and is used to detect whether wafer 01 has entered and exited the system by sending a digital signal to computer 60.

Light source 53 and 54 are typically LED (light emitting diode) linear array which can be turned on independently by the computer 60 through a lighting amplifier 62.

The invention consists of a linescan imaging device 51 viewing at an angle θ onto an optical beam splitting component 52 along the mentioned conveyor belts 12. The optical beam splitting component 52 can be plate beam splitter, cube beam splitter, dichroic mirror, dichroic color filter etc. Since typical image resolution of side area inspection using image

device 17 is about 15μm/pixel and the solar wafer size can be upto 156mm, therefore the linescan imaging device 51 should have at least 10,400pixels in order to achieve the same image resolution as using imaging device 17 for inspection.

Fig. 6 shows an enlarged side view of the invention in which a solar wafer 01 is moving on conveyor belts 12 and the solar wafer 01 front side 15 has just entered into line of sight 55 of the line scan imaging device 51. A light source 53 is turned on and pointing towards the solar wafer 01 front side 15. Reflection 56 from the light source 53 enters the line of sight 55 after being reflected again by beam splitting component 52 before entering to the linescan image device 51.

Fig. 7 shows an enlarged side view of the invention in which the solar wafer 01 rear side 16 is about to leave the line of sight 55 of the linescan imaging device 51. A lighting source 54 is turned on and pointing towards the solar wafer 01 rear side 16. Reflection 57 from the light source 54 enters light of sight 55 after transmitted through the beam splitting component 52 before entering to the linescan image device 51.

The beam splitting component 52 is typically used to split a light beam into two paths. However in this invention, the beam splitting component 52 is used reversely to merge two beams. As such the reflections 56 and 57 will merge into 55 and enter the linescan imaging system 51. However one should understand that reflection 56 and 57 do not happen at the same time and therefore either reflection 56 or 57 or none will be seen by the linescan imaging device 51 at any point of time. As such an image taken by the linescan imaging device 51 will discrete side view image of front side 15 and rear side 16 so that processing can be done independently. Although reflection 56 and 57 do not occur at the same time, but stray reflections from other surfaces (e.g. conveyor belts) can also enter line of sight 55 together with reflection 56 or 57 and create unwanted noise in a image. Therefore to remove the stray reflection, the invention will turn on light source 53 and turn off light source 54 when collecting reflection 56 for front side 15 (Fig. 6). Similarly when collecting reflection 57 for rear side 16, light source 54 will be turned on and light source 53 will be turned off (Fig. 7)

Fig. 8 illustrates further how to obtain an image of solar wafer side area using front side 15 as an example (rear side 16 is the same except that the direction is reversed). A solar wafer is transported by conveyor belts 12 and when it intersected with the reflection 56 path at p0,

first line image of the front side 15 will be seen and captured by the linescan image device 51. One should understand that in practical the linescan image device 51 should start to capture much earlier than this so that the first position P0 is not missed. By setting line pitch setting φ of the linescan imaging device 51, image of the front side 15 will be captured consecutively across p0 to pn and different height level h0 to hn of the front side 15 will be seen and captured by the linescan imaging device 51. As such the total number of line images captured is n where it can be calculated as Eq.1 below:

$$n = \frac{\tau}{\varphi \tan\theta} \quad (Eq.1)$$

Where τ is the thickness of the solar wafer 01 and θ is the viewing angle of the linescan imaging device 51.

Typically φ is set to the same the image resolution as the linescan imaging device 51 (e.g. 15μm) and solar wafer thickness τ is about 180μm. This results in about n=12 if we set the viewing angle to be 45 degree. N can be increased further by decreasing the viewing angle θ. However when θ decreased, the focusing range ω, which can be calculated by Eq.2, will also be increased.

$$\omega = \frac{\tau}{\sin\theta} \quad (Eq.2)$$

Therefore θ should be selected so that ω does not exceed allowable depth of focus of the linescan image device 51, otherwise the line images captured will not produce the same sharpness across the side area. Depth of focus can be increased by using smaller lens aperture setting but the light source 53/54 intensity will need to be increased too in order to obtained the same image brightness.

Fig. 9 shows the light source 53 and 54 are typically LED bar lights with focusing element to focus light onto the side area to get maximum image brightness. The color wavelength of the light source 53 and 54 is the same $\lambda 0$. However when reflection 56 is being reflected by the beam splitter component 52, the light intensity I1 of reflection 56 will also be splitted into I1' and I1" (i.e. I1=I1'+I1"), as such the reflected light intensity is reduced by half. Similarly to reflection 57, the light intensity will be splitted into I2' and I2".

To overcome the lighting intensity reduction, Fig. 10 shows that the beam splitting component 52 is replaced with a dichroic color filter 58 and the light source 53/54 will have different color wavelength $\lambda 1$ and $\lambda 2$. In this arrangement, the dichroic color filter should be selected to pass $\lambda 2$ and reject $\lambda 1$. Since the reflection and transmission of the dichroic color filter is wavelength specific, therefore I3″ and I4″ is very small and this result in almost 100% reflection and transmission for I3 and I4.(I3'≈I3 and I4'≈I4). This will help to increase the image brightness and depth of focus of the linescan image device 51 since a smaller lens aperture can be used.

Fig. 11 shows the process of obtaining front and rear side image.

When a wafer 01 arrived and detected by the wafer present sensor 61, the computer 60 turns on light source 53 and initiates the linescan imaging device 51 to capture line images to form the front side image. The number of lines captured should be at least n+p, where n is the number mentioned in Fig.8 to cover the wafer side, p is the number lines of required to cover the distance between the wafer present sensor 61 to the reflection 56. After front side image is captured, light source 53 will be turned off.

When rear edge of the wafer 01 left the wafer present sensor 61, the computer 60 turns on light source 54 and initiates the linescan imaging device 51 to capture lines images to form the rear side image. The number of lines captured should be at least n+q, where q is the number of lines required to cover the distance between the wafer present sensor 61 to the reflection 57. After rear side imahge is captured, light source 54 will be turned off.
The system returns to the state to wait for the next wafer to enter and the process repeats.

Fig. 12 shows line images captured by the line scan imaging device. The upper white area is the front side captured by the linescan imaging device and the lower white area is the rear side.

Fig. 13 shows a closed up portion of the front side image from Fig. 12.

Fig. 14 shows a closed up portion of the front side from Fig. 12 with a side area defect can be seen clearly as the dark patch along the white area.

As a conclusion, the invention allows the front side 15 and rear side 16 to be inspected without using additional inspection robots or conveyor belts as proposed in current solutions. The invention also comprises of an optical design such that only one imaging device is needed for both front side 15 and rear side 16, as such cost and system complexity are reduced further.

DIFFERENT EMBODIIMENTS OF THE INVENTION

Eq.1 indicates the number of line images n can be increased by decreasing φ and φ is typically equal to the image resolution of the linescan imaging device 51. As such multiple linescan imaging devices can be used to increase the image resolution and hence total number of line images. Fig. 15 illustrates the invention with two cameras putting side-by-side.

Fig. 16 shows that a folding mirror 59 can be placed in between the linescan imaging device 51 and the beam splitting component 52 to fold the optical path so that the overall length of the system can be reduced.

While a preferred embodiment and other embodiments have been described, it should be apparent, however, that various modifications, rearrangements, substitutions alterations and adaptations to those embodiments may occur to persons skilled in the art with the attainment of some or all of the advantages of the present invention. Accordingly, it should be clearly understood that the present invention is not intended to be limited by the particular features and structures hereinbefore described and depicted in the accompanying drawings. It is therefore intended to cover all such modifications, alterations and adaptations without departing from the scope and spirit of the present invention as defined by the appended claims.

ADVANTAGEOUS EFFECTS OF THE INVENTION

This invention describes a method to perform inspection of the front side and rear side of a solar wafer with less complexity and lower setups.

CLAIMS

1. An inspection method for a front side and a rear side of a solar wafer as it moves on a conveyor belt, the side inspection method consisting of continuously capturing a discrete number of images of the front end and back end, consisting the following steps:-

as the front side of the solar wafer approaches the line of sight of a line scan imaging device,

turning on a first light source and directing a beam of light towards the front side of the solar wafer,

obtaining a first reflection of the light source from the front side of the solar wafer,

continously obtaining a series of first reflections until the front side of the solar wafer passes the line of sight of the line scan imaging device,

and as the rear side of the solar wafer passes the line of sight of the line scan imaging device,

turning on a second light source and directing a beam of light towards the rear side of the solar wafer,

obtaining a second reflection of the light source from the rear side of the solar wafer,

continously obtaining a series of second reflections until the rear side of the solar wafer passes the line of sight of the line scan imaging device,

wherein the series of first reflections and the series of second reflections are merged by a beam splitting device to form a number of images of the front side and rear side of the solar wafer

2. An inspection method for a front side and a rear side of a solar wafer as claimed in Claim 1, further including these steps:-

turn off the second light source and turn on the first light source when collecting the first reflection from the front side;and

turn off the first light source and turn on the second light source when collecting the second reflection for the rear side;

to remove stray reflections.

3. An inspection method for a front side and a rear side of a solar wafer as claimed in Claim 1, wherein the number of images captured is n where n can be calculated :-

$$n = \frac{\tau}{\varphi \tan \theta} \quad (Eq.1)$$

where τ is the thickness of the solar wafer and θ is the viewing angle of the linescan imaging device and φ is set to the same the image resolution as the linescan imaging device.

4. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 2, wherein

$$\omega = \frac{\tau}{\sin \theta} \quad (Eq.2)$$

5. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 2, wherein θ should be selected so that ω does not exceed allowable depth of focus of the linescan image device.

6. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 1, using one or more line scan imaging devices.

7. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 1, wherein the linescan image device starts to capture a number of images of the front end much earlier before the first position P_0 and setting line pitch setting φ of the linescan imaging device, to capture a number of images of the front end consecutively across p_0 to p_n and different height level h_0 to h_n of the front side.

8. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 1, wherein the linescan image device starts to capture a number of images of the rear side much earlier before the first position P_0 and setting line pitch setting φ of the linescan imaging device, to capture a number of images of the rear side consecutively across p_0 to p_n and different height level h_0 to h_n of the front side.

9. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 1, wherein the beam splitting device is a dichroic color filter and the first light source and second light source have different color wavelength λ_1 and λ_2, so that the dichroic color filter passes λ_2 and rejects λ_1 resulting in almost 100% reflection and help to increase the image brightness and depth of focus of the linescan image device since a smaller lens aperture can be used.

10. An inspection method for a front side and a rear side of a solar wafer, as claimed in Claim 1, wherein the line scan imaging device has at least 10,400 pixels.

11. A system for the inspection of the front side and rear side of a solar wafer, as the solar wafer moves on a conveyor belt and the front of the solar wafer approaches the line of sight of a line scan imaging device,

turning on a first light source and directing a beam of light towards the front side of the solar wafer,

obtaining a first reflection of the light source from the front side of the solar wafer,

continously obtaining a series of first reflections until the front side of the solar wafer passes the line of sight of the line scan imaging device

and as the rear side of the solar wafer passes the line of sight of the line scan imaging device,

turning on a second light source and directing a beam of light towards the rear side of the solar wafer,

obtaining a second reflection of the light source from the rear side of the solar wafer,

continously obtaining a series of second reflections until the rear side of the solar wafer passes the line of sight of the line scan imaging device,

wherein the series of first reflection and the series of second reflection are merged by a beam splitting device to form a number of images of the front side and rear side of the solar wafer.

12. A system for inspection of a front side and a rear side of a solar wafer, as claimed in Claim 11, wherein the system is controlled and monitored by a microprocessor.

13. A system for inspection of a front side and a rear side of a solar wafer, as claimed in Claim 11, having a sensor to detect the entry and exit of a wafer into the system, said sensor mounted at the position where the wafer enters and detects whether the wafer has entered and exited the system by sending a signal to the microprocessor.

14. A system for inspection of a front side and a rear side of a solar wafer, as claimed in Claim 11, wherein the system receives the merged series of images of the front side and rear side of a solar wafer and uses algorithms to sort out those solar wafers with defects above a tolerated level.

15. A beam splitting device as claimed in Claim 1 or Claim 11, wherein the beam slitting device is a plate beam splitter.

16. A beam splitting device as claimed in Claim 1 or Claim 11, wherein the beam slitting device is a cube beam splitter.

17. A beam splitting device as claimed in Claim 1 or Claim 11, wherein the beam slitting device is a dichroic mirror.

18. A beam splitting device as claimed in Claim 1 or Claim 11, wherein the beam slitting device is a dichroic color filter.

19. A system for inspection of a front side and rear side of a solar wafer as claimed in Claim 11 wherein a folding mirror is placed in between the linescan imaging device and the beam splitting component to fold an optical path of the beam of light so that the overall length of the system can be reduced.