simulation image monitor, a digital image collection card, a computer and analysis process and display software.

Additionally, EP 2 699 071 A2 discloses an optoelectronic method for recording a heat diagram form of the temperature distribution of land in which an infrared line scan system is used in an aircraft. The apparatus utilizes a rotary scanning mirror system receiving heat radiation through windows. The mirror system has four reflecting sides and is rotated about an axis by an electric motor. The radiation is directed by mirrors to an IR lens and then to a row of optoelectronic receiver elements. The row of receiver elements is parallel to the axis of rotation of the mirror system, each receiver element being individually connected by a lead and an amplifying device to a corresponding one of a number of luminescent diodes.

US Patent 8,154,718 B2 discloses a device to analyze micro-structured samples of a wafer. The aim of the device is to increase the possible uses of said devices, i.e. particularly in order to represent structural details, e.g. of wafers that are structured on both sides, which are not visible in VIS or UV because coatings or intermediate materials are not transparent. IR light is used as reflected light while creating transillumination which significantly improves contrast in the IR image, among other things, thus allowing the sample to be simultaneously represented in reflected or transmitted IR light and in reflected visible light.

Typical defects are side cracks created by the dicing process or embedded cracks created by internal stress in the device between the dielectric layer and the silicon structure.

Figure 1 shows a prior art method for finding side defects 9 in a semiconductor device 2 by doing a four sided or a five sided inspection. The semiconductor device 2 has a first side face 3_1, a second side face 3_2, a third side face 3_3, a fourth side face 3_4, a top face 4 and a bottom face 5. In the setup of figure 1 a camera 6 with a lens 7 looks to the bottom face 5 of the semiconductor device 2. A mirror 8 is arranged under 45 degrees with each of the first side face 3_1, the second side face 3_2, the third side face 3_3 and the fourth side face 3_4 of the semiconductor device 2, respectively. In figure 1 only the

mirrors 8 arranged with respect to the second side face 3_2 and the fourth side face 3_4 of the semiconductor device 2 are shown.

The setup of figure 1 is used to obtain an image 10 (see **figure 2**) of the first side face 3_1, the second side face 3_2, the third side face 3_3, the fourth side face 3_4 and the bottom face 5, respectively. Additionally, the setup of figure 1 has significant drawbacks. The optical length 11 of the bottom face 5 view differs from the optical length 12 of the first side face 3_1 view, the second side face 3_2 view, the third side face 3_3 view and the fourth side face 3_4 view. Therefore, the focus is always a trade-off between focus on the bottom face 5 of the semiconductor device 2 and focus on the first side face 3_1, the second side face 3_2, the third side face 3_3 and the fourth side face 3_4, respectively. Additionally, the image resolution of the four-sided view requires a large field of view and this will limit the pixel resolution that can be used. For side views <10µm there is no working setup available, even by using a high resolution camera of 20 or 25 megapixels. Therefore it is not possible to have good focus and a high resolution in order to discriminate a real defect from non-critical contamination.

Figure 3 is another embodiment of a prior art set-up for detecting interior defects 9 (side defects) by looking onto the top face 4 of a semiconductor device 2. For detecting interior defects 9 (that are invisible from the outside) there is no solution for high volume inspection. There is a slow method by using IR light 13 and optics 14 and looking to the back face of the semiconductor device 2 ("IR back view"). A camera 6 detects the IR-light 15 returning from the semiconductor device 2. A schematic representation of an image 16, obtained with the setup of figure 3 is shown in **figure 4**. The "IR back view" method with IR light 13 for detecting the interior defects 9 has drawbacks as well. First of all the method is slow. It only exists as manual, low volume method. If one wanted to automate this and make it faster there is an important limitation in the size and the number of pixels of the available IR cameras 6. Additionally, it only works for a limited set of devices where there is a bare silicon side to apply the IR light. An increasing number of devices have a coating to protect the device, which coating is not transparent for IR light. A further drawback is the signal to noise ratio. The top face 4 of the semiconductor device 2 will also create a reflection which makes it hard to distinguish a top defect from an interior defect 9.

This prior art method, described above, has significant drawbacks by inspecting five sides of a work piece (singulated semiconductor device). One drawback is the differing focus between the side face and the bottom face of the work piece. The optical length is different for bottom and side view, therefore the focus is always a trade-off between focus on the bottom of the work piece and focus on the edges (side faces) of the work piece. A further drawback is the image resolution. A view of the four side faces requires a large field of view and this will limit the pixel resolution that can be used.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an apparatus which makes it possible to detect side defects and internal defects in singulated work pieces with a high resolution and to distinguish between actual defects and contaminations on the faces of the work pieces. Additionally, the apparatus should have high throughput in order to do time-efficient quality control on such workpieces.

The above object is achieved by an apparatus for defect detection in work pieces wherein the apparatus comprises:

at least one light source for providing an illumination light of a wavelength range at which the work piece is transparent;

a camera with a lens, for imaging the light from at least one face on the work piece on a detector of the camera; and

a stage for moving the work piece and for imaging the at least one face of the work piece completely.

The advantage of the inventive apparatus is that it possible to reliably detect side defects and internal defects in singulated work pieces, for example semiconductor devices, also known as die. The inventive apparatus can be used to do quality control on such work pieces with high throughput.

It is a further object of the invention to provide a method for detecting side defects and internal defects in singulated work pieces at a high resolution, so that one can

illuminate at least one face of the work piece with illumination light of a wavelength range at which the work piece is transparent;

direct light, from the at least one face of the work piece, with an optical setup to at least one line sensor of a camera for imaging a line of light of the least one face of the work piece;

move the stage, which holds the work piece, such that the at least one face of the work piece is imaged completely by the line sensor of the camera and is in the focus of the camera during the movement of the stage.

Typical defects to be detected by the present invention are side cracks created by the dicing process of the work pieces or embedded cracks created by internal stress in the work piece. In case the work piece is a semiconductor device, the internal stress can exist for example between the dielectric layer and the silicon structure. It is noted that the invention (apparatus, method and computer program) is not restricted to semiconductor devices and is applicable for side and internal defects in general.

Typically one would use infrared (IR) light to be able to penetrate through the silicon based semiconductor device, but the source of the light could change depending on the wavelength range for which the material of the work piece is transparent.

According to an aspect of the present invention, the at least one light source is arranged such that the illumination light is directed to one side face of the work piece and the camera receives the light exiting from a further side face of the work piece. This further side face of the work piece is opposite to the side face of the work piece which receives the illumination light, in order to obtain back-light illumination.

Another possibility is that the further side face of the work piece is oriented such to the side face of the work piece which receives the illumination light that a dark field image of the further side face is obtained.

A further aspect of the invention is that the at least one light source is arranged such that the illumination light is directed to a top face of the work piece, and the camera receives the light shining out of the top face of the work piece.

An advantageous embodiment of the invention is, if the detector of the camera is a line sensor and the camera is configured as a line scan camera. In the new apparatus or method the use of a line scan camera, which is perpendicular to the side face of the work piece (semiconductor device) creates images by moving the work pieces on a X,Y,Theta-stage. Through the inventive optical setup it is possible to create a simultaneous view of at least a portion of the top face and at least one side face of the work piece. This optical setup allows for coaxial and external illumination as well, so the two modes can have the same or individual illumination.

A lens of the camera images a line of light exiting from a side face of the work piece onto the line sensor. The exiting light originates from at least one light source arranged such that a back-light illumination is obtained.

A stage, which holds the work piece, is moved along a scan direction, which is perpendicular to the line to be imaged. With the scanning motion a complete image of at least one of the side faces of the work piece is generated.

It is also possible that a lens of the camera images a line of light from at least a portion of a top face of the work piece onto the line sensor, wherein the line of light is positioned adjacent to one of the side faces of the work piece, and the at least one light source is arranged such that the light from the top face is coaxial to the light directed onto at least a portion of the top face of the work piece. In order to generate an image of at least a portion of the work piece, a stage, which holds the work piece, is moved along a scan direction, which is perpendicular to the line to be imaged. Accordingly, a complete image of the at least one portion of the top face is obtained. The portion of the top face is adjacent to at least one of the side faces of the work piece.

The stage and the camera also can carry out a relative motion to capture, for example, the complete image of the respective face of the work piece. The scan of the respective face can be carried out with various speed profiles along the scan direction. A preferred embodiment is a constant velocity along the length of the respective face. The selection of a constant requires less software effort and provides best image quality. It is clear for a skilled person that the selection of a constant velocity does not block other speed

view (image of a portion of the top face) may be done under an angle as well in order to create a darkfield-like inspection mode.

The inventive method shows advantageous effects, for example in case the work pieces are semiconductor devices. With the inventive method it is possible to create images of the defects by using IR light that travels through the semiconductor device under inspection and by looking directly at one side face of the semiconductor device. For both the light source and the camera a perpendicular setup (looking/shining straight to the edges) or an angular setup can be used. Because of the high refractive index of silicon ($n = 3.5$ for $\lambda = 1200nm$) and the rough edge of the device almost all light will go into the device. While the rays will travel under small angles through the device they will exit the device at the other side face as a diffuse ray of lights. In this way the device itself acts like a diffuse illumination.

The inventive method uses in one embodiment the physical characteristic of silicon (which is the base material for all semiconductor devices) that silicon becomes transparent for light with wavelengths above 1200nm.

Based on this, the method builds further onto the "IR back view" but because the device itself acts like a diffuse illuminator the inventive method increases signal to noise and creates possibilities for fast inspection solutions. Typically, edge variations of the dicing process are smoothed out by the diffuse rays of lights. Material defects (like e.g. the crack which should be detected) will result in high contrast since that internal part of the semiconductor device will not receive light and will hence show as a dark part on the diffuse illuminating device.

One important technical aspect of the present invention is that the edges of the semiconductor devices are not nice and clean (due to the dicing process of the semiconductor devices); therefore the light will not travel straight and predictably through the semiconductor devices but rather gets scrambled creating a diffuse illuminator. Another important technical aspect is that by looking only at the side face, the area to inspect becomes factors smaller than by looking at the whole device (be it with the "IR back view" or the "5 sided solution") and this creates opportunities to

In the figures like reference numerals are used for like elements or elements of like function. Furthermore, for the sake of clarity, only those reference numerals are shown in the figures which are necessary for discussing the respective figure. The methods and apparatus described herein may be employed advantageously in conjunction with IR – light for defect inspection in semiconductor devices. Typically one would use IR light to be able to penetrate through the silicon of the semiconductor device. In other embodiments of the invention the wavelength of the light source could change. The only prerequisite is that the material of the work piece (semiconductor device) under inspection must be transparent for the wavelength range used. The description below refers to semiconductor devices, which should not be understood as a limitation of the invention. As is clear for a skilled person, the principles and ideas of the present invention are applicable to any inspection of internal or side defects of work pieces. The application of the present invention to semiconductor devices should not be regarded as a limitation.

Figure 5 shows a schematic representation of an arrangement 20 for carrying out inspection of the semiconductor device 2 with IR light 13. The arrangement 20 is in side view with back-light illumination. The IR light 13 generated by a light source 18 impinges perpendicularly on one selected side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. It is also possible that the IR light 13 is not collimated and does not impinge perpendicularly on one selected side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. With the arrangement 20 shown here it is possible to create images of the defects 9 by using IR light 13 that travels through the semiconductor device 2. The advantage of the use of IR light 13 is that one can find interior defects 9 and/or improve the signal to noise ratio for specific defects 9 of the semiconductor device 2.

The camera 6 looks with its lens 7 directly at one selected side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. Because of the high refractive index of the silicon ($n = 3.5$ for $\lambda = 1200nm$) and the rough side face 3_1, 3_2, 3_3 or 3_4 (edge) of the semiconductor device 2 almost all the IR light 13 will enter the semiconductor device 2. While the rays of the IR light 13 will travel under small angles through the semiconductor device 2, they will exit at the opposite side face 3_1, 3_2, 3_3 or 3_4 as a diffuse ray 21 of light. In this way the semiconductor device 2 itself acts like a diffuse illuminator. However, when reaching an

interior defect 9 or a side crack the normal light propagation is blocked resulting in a 'defective' part in the diffuse illumination. The blocking of the IR light 13 is represented by a dashed arrow 22. The lens 7 and the camera 6 image the side face 3_1, 3_2, 3_3 and 3_4, respectively and the interior defect 9 appears as a high contrast dark section in the camera image. The crack or the interior defect 9 is typically a disturbance in the silicon structure of the semiconductor device 2. At this disturbance the IR light 13 is reflected and does not propagate. Because of this, a detector 26 in the camera 6 will see no light coming through at the location of the interior defect 9.

Another embodiment of the arrangement 20 for carrying out inspection of the semiconductor device 2 with IR light 13 is shown in **Figure 6**. Here, the inspection of the semiconductor device 2 is carried out with IR light 13 from the light source 18. The camera 6 with the lens 7 is arranged such that the camera 6 registers a dark field image of the respective side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. At the second face 3_2 a direction 23 of IR-light propagation is perpendicular to an optical axis 24 of the lens 7 of the camera 6.

A further embodiment of the inventive arrangement 20 is shown in **Figure 7**. The IR light 13 is sent from the light source 18 to the top face 4 of the semiconductor device 2 and into the semiconductor device 2 under an angle α. The IR-light 13 propagates through the semiconductor device 2 and is focused on one of the side faces 3_1, 3_2, 3_3 and 3_4 of the semiconductor device 2, respectively. The interior cracks or defects 9 block the IR-light 13 and change the normally diffuse illumination from one of the rough side faces 3_1, 3_2, 3_3 and 3_4 (see Fig. 5). The arrangement shown in Fig. 7 offers large resolution but still makes fast inspection of one of the side faces 3_1, 3_2, 3_3 and 3_4 of the semiconductor device 2 (here the fourth side face 3_4 is inspected) possible. Every internal or side defect 9 appears bigger and higher in contrast in the image taken by camera 6 as such defects block normal internal light propagation. A diffuse IR-light 33 shining out the semiconductor device 2 has a reduced response to external contamination of semiconductor device 2 and hence increases the signal to noise ratio for the real defects 9.

As an advantageous alternative, one can move the focus of the IR-light 13 inside the semiconductor device 2, so that one can resolve interior defects 9 further away from the side faces 3_1, 3_2, 3_3 and 3_4 of the semiconductor device 2. Accordingly, one can even scan through the complete semiconductor device 2.

Figure 8 shows a schematic representation of a further embodiment of an arrangement 20 of the present invention. The camera 6 has a line sensor 36 and the lens 7 images a line 35 of one of the side face 3_1, 3_2, 3_3 or 3_4 on the line sensor 36. The camera 6 is configured as a line scan camera. The camera 6 is moved along a scan direction 37. The movement can be achieved by a relative motion between the respective side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2 and the camera 6 along the scan direction 37, which is perpendicular to the line 35 to be imaged on the line sensor 36. The relative motion between the respective side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2 and the camera 6 should not be regarded as a limitation of the invention. It is clear that also only the camera or only the semiconductor device can be moved.

The semiconductor device 2 is positioned on a X, Y, Theta-stage (not shown here). The X, Y, Theta-stage is moved such that images of all four side faces 3_1, 3_2, 3_3 or 3_4 are created with the line sensor 36 of the camera 6. In the embodiment shown here, the semiconductor device 2 is composed of a bulk semiconductor layer 40 (BSL), which is optional, silicon substrate 41, a dielectric layer 42 and a metal layer 43. With the line scan camera setup high resolution images are possible which would be impossible with an area scan camera. For the side view (analog to the arrangement of Fig. 5) external IR-light 13 is shining from the light source 18 through the semiconductor device 2 (die). The IR-light 13 comes from one side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2 and is captured at the opposite side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2 by the line scan camera 6. A high resolution image is created from each side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. In order to shine through the semiconductor device 2, a wavelength range is used for which the semiconductor device 2 is transparent. For a typical semiconductor device 2 (or die) this will be IR light 13.

Figure 9 is a schematic representation of an arrangement 20 for carrying out edge inspection of a semiconductor device 2 with IR illumination in side view and a scanning

motion of the semiconductor device 2. Here the camera 6 has as well a line sensor 36 and the lens 7 images a line 35 of the top face 4 close to one of the side faces 3_1, 3_2, 3_3 or 3_4 on the line sensor 36. A beam splitter 27 directs the IR-light 13 from the light source 18 onto the top face 4 of the semiconductor device 2. Coaxial returning IR light 34 from the top face 4 of the semiconductor device 2 is captured by the line sensor 36 of the camera 6. Again the movement of the semiconductor device 2 along the scan direction 37 is perpendicular to the line 35 which is imaged on the line sensor 36 of the camera 6. The movement of the semiconductor device 2 enables the creation of a top view of an edge portion 30 of the top face 4 of the semiconductor device 2 at one of the side faces 3_1, 3_2, 3_3 or 3_4. In Fig. 9 the edge portion 30 of the top face 4 is adjacent to the fourth side face 3_4 of the semiconductor device 2.

The embodiment shown in **Figure 10** shows an arrangement 20 for carrying out side view and top view inspection of the semiconductor device 2, simultaneously. A special optical setup 25 is provided which allows a simultaneous view on the top face 4 and one of the side faces 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. This optical setup 25 also allows for illumination of the top face 4 (coaxial illumination) and for illumination of one of the side faces 3_1, 3_2, 3_3 or 3_4 (external illumination) of the semiconductor device 2. The two illumination modes (coaxial and external illumination) can have the same light source or individual light sources.

By combining the view on the top face 4 and one of the side faces 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2, the images of the top face 4 and the side faces 3_1, 3_2, 3_3 or 3_4 contain much more information in order to extract the exact location and origin of the defects. By integration on a moving stage setup, high speed inspection can still be obtained although with two high resolution views.

Through the arrangement 20 and the special optical setup 25, as shown in **Figure 10**, it is possible to create a simultaneous view of the edge portion 30 (see Fig. 9) of the top face 4 and one side face 3_1, 3_2, 3_3 or 3_4 of the semiconductor device 2. Additionally, two individual line sensors 36 are provided. One is used for capturing the image of a portion of the top face 4 and the other is used to capture an image of one of the side faces 3_1, 3_2, 3_3 or 3_4 which is neighboring the top face 4.

21. Method of claim 18, further comprising:

directing the illumination light of the at least one light source to a top face of the work piece; and

imaging with the camera light shining out of the top face of the work piece.

22. Method of claim 21, wherein the camera images the light exiting from the top face of the work piece onto a line sensor by means of a lens.

23. Method of claim 18, further comprising:

providing the camera with a line sensor; and

generating simultaneously with an optical setup a line image of light exiting from a side face of the work piece and a line image of light from a portion of a top face of the work piece, wherein the portion of the top face is positioned adjacent to the respective side face of the work piece.

24. Method of claim 23, wherein a front end of the optical setup carries a top mirror and two bottom mirrors, the top mirror captures the line image of light from a portion of the top face of the work piece and the two bottom mirrors capture a line image of light exiting from a side face of the work piece.

25. Method of claim 23, wherein the optical setup is designed such that the line image captured from the side face of the work piece and line image of the portion of the top face of the work piece are simultaneously in focus.

26. Method of claim 18, further comprising:

coupling light from at least one light source seperately to one side face of the work piece and the top face of the work piece.

27. Method of claim 18, wherein a light guide is positioned between the at least one light source and a top face and/or a respective side face of the work piece.

28. Method of claim 18, the moving a stage for imaging at least two side faces and the portion of the respective top face further comprising:

a) carrying out a linear, relative movement between the stage with the work piece and the camera so that an image plane of the camera is parallel to one of the side faces;

b) rotating the stage with the work piece; and

c) repeating step a) and b) until all side faces of the work piece are imaged by the camera.

29. Method of claim 28, wherein the linear, relative movement between the stage and the camera is realized by a linear movement of the camera only and the linear movement of the camera is oriented in opposite directions between the rotating steps.

30. Method of claim 18, the moving a stage further comprising: rotating the stage and in parallel carrying out a movement of the stage in the X/Y –plane, such that a focus point of the camera is kept during the rotational movement of the stage on a respective side face.

31. Method of claim 18, wherein the work piece is a semiconductor device.

32. Method of claim 31, wherein the wavelength range of the illumination light is the wavelength range of IR light.

33. An apparatus for defect detection in work pieces comprises:

at least one light source for providing an illumination light of a wavelength range at which the work piece is transparent, wherein the at least one light source is arranged such that the illumination light enters the work piece at one side face;

a camera with a lens, for imaging the light exiting from a further side face of the work piece on a line sensor of the camera;