

**SYSTEM AND METHOD FOR INSPECTING DEVICES FOR INTERNAL DEFECTS  
AT ABOUT SIDEWALLS THEREOF CAUSED BY WAFER SINGULATION  
PROCESSES**

**CROSS-REFERENCE TO RELATED APPLICATION**

[1] This application claims the benefit of U.S. Provisional Application No. 63/614,937, titled 'SYSTEM AND METHOD FOR INSPECTING DEVICES FOR INTERNAL DEFECTS AT ABOUT SIDEWALLS THEREOF CAUSED BY WAFER SINGULATION PROCESSES' (Attorney Docket No.: STIP2023PRO23US0), which was filed on December 27, 2023, and which is incorporated herein by reference in its entirety for all purposes.

**FIELD**

[2] The present disclosure relates to a system, device, and method for inspecting internal cracks at the internal edge portions (zones or regions of interest) of sidewalls of semiconductor devices for defects caused by, for example, wafer singulation processes. The inspection can be performed in association with simultaneously directing illumination, such as infrared illumination, through the bottom (inactive) surface of the device along optical travel paths such that the illumination is incident upon the internal sidewall edge portions of the die. Reflected illumination from the internal edge portion of the sidewalls travels along similar optical travel paths in a reverse direction to an image capture device to capture images of the internal sidewall edge portions of the device.

**BACKGROUND**

[3] A typical wafer undergoes many processes such as doping, ion implantation, etching, thin-film deposition of various materials, photolithographic patterning as well as wafer-level packaging (WLP) processes before the wafer is singulated or diced. The finished wafer before singulation is typically mounted on a dicing tape. For example, a bottom

surface of the wafer is mounted on the dicing tape while the top wafer surface (opposing surface) includes wafer bumps. Singulation of the wafer to individual dies can be achieved by a number of methods, such as mechanical sawing, laser ablation or plasma etch dicing. After singulation, the individual dies are then picked from the tape for further back end or downstream processes.

[4] In mechanical saw or laser dicing, the wafer is prepared for singulation by first cutting grooving kerfs along and between the uniform array of dies. As the dies of the die array are tightly packed on the wafer, these dicing grooves are close to seal rings that surround the active areas of the dies. When completed, the grooving kerfs will form an array of orthogonal (x-y) intersecting grooves or streets on the wafer, with each of the streets disposed at an equidistance between two adjacent lines (rows or columns) of dies. The grooving kerfs are where the wafer will be further cut to singulate the wafer into individual dies while held on the tape. In most instances, the grooving kerfs have a depth which is deeper than the active layers of the dies. For example, the grooving kerfs extend into the inactive substrate, such as silicon, below the active layers.

[5] In plasma dicing, singulation is achieved using a chemical reaction involving plasma to etch the areas not protected by a mask layer.

[6] Mechanical sawing involves a rotating saw being pressed against the wafer along the dicing grooves. Apart from the debris from sawing, the impact of high rotational speed imparts stress on the wafer, causing cracks and chips to form near or along the edge or sidewalls of the singulated dies, especially in areas where the perpendicular dicing grooves intersect.

[7] Laser dicing involves delivering high concentrations of photon streams onto the wafer, generating a spot of high localized temperature to remove the dicing groove area between the chips. The laser heats the material to a high temperature, causing the area under the laser spot to be blown away (ablated) or simply vaporized. The high temperature of the lasers can cause heat stress to adjacent dies and result in cracks being formed.

[8] One of the key challenges of plasma etch dicing is the potential for thermal damage to the surrounding areas of the diced wafer. The high temperatures generated during the plasma etch process can cause stress and induce defects in neighboring devices.

[9] While different methods may be preferred for any given type and size of the dies, no matter which method of singulation is deployed, unintended cracks can arise due to the tensile stress, pressure and high temperatures involved in these singulation processes. Such cracks are most prevalent near where the grooving kerfs were first cut and also near the corners of a chip where two perpendicular grooving kerfs meet. However, cracks can also advance along the crystal axes of the wafer. The crystal orientation that is optimal for chip production also has the unintended effect of advancing cracks along and perpendicular to the singulated edges of the dies.

[10] The presence of cracks in the die is undesirable because such cracks can advance unpredictably into the core circuitry of the die, destroying active silicon structures, dielectric layers, metal wiring layers, and other structures therein. Such cracks are also conduits for the introduction of destructive contaminants into the die. During encapsulation in a metal, ceramic, or resin package, the die is subjected to further pressure and stress. This additional pressure and stress can cause cracks to form or existing cracks to progress.

[11] With advancements in technology, more than billions of transistors can be processed into smaller and smaller ICs. Consequently, the natural geometry of the cracks has a greater impact on chip integrity, performance and quality than ever before. The intrusion of a crack beyond the seal ring is likely to affect more transistors and circuitry than ever before.

[12] A protective structure, such as a seal ring is provided between the core circuitry and the edges of the die. The seal ring is typically constructed at the same time as the construction of the core circuitry. The intended purpose of the seal ring is to limit the intrusion of any cracks into the vital interior core circuitry and to prevent moisture penetration or

chemical damage, like acid or alkaline-containing chemicals, or the diffusion of contaminating species.

[13] Cracks can be external as well as internal. For example, external cracks are located on the die sidewalls. The external cracks may or may not extend inward towards the seal ring. Internal cracks are disposed within the die. The internal cracks also may or may not extend inward towards the seal ring.

[14] Inspection to determine the size and the location of cracks, external as well as internal, and their proximity to the seal ring becomes necessary. Cracks within the seal ring of the die may cause a die failure. For example, a crack piercing or traversing the seal ring may reach the core circuitry of an IC, potentially causing a die failure. Further, if the seal ring is broken, the die becomes vulnerable to contaminants from further backend processes, creating reliability issues. As for a crack that is close to the seal ring, it has the potential to progress further across the seal ring if subjected to further stresses from further backend processes.

[15] The detection of cracks is important because their presence can result in die failures. Particularly, it is important to determine how far cracks extend towards or beyond the seal ring. Early detection and removal mean less time and expense wasted on these faulty chips for further backend processes. More importantly, their removal prevents their deployment in end products.

[16] Conventional detection systems, however, are only capable of detecting external cracks on the die sidewalls. Such conventional detection systems are incapable of detecting internal cracks as well as how far the external and internal cracks extend towards the seal ring.

[17] From the foregoing discussion, it is desirable to provide effective and efficient detection of how far defects (internal and external) caused by the wafer singulation process extend towards or beyond the seal ring of a die to assess die failure or potential die failure.

## SUMMARY

[18] Embodiments generally relate to systems and methods for detecting the presence of internal cracks in a region of interest (ROI) of a die. The presence of such internal cracks determines whether the die passes or fails the inspection. Dies that failed inspection may undergo further testing to determine whether they are still functional. Functional dies may be then sold at a reduced price or as lower-quality dies.

[19] In one embodiment, a die inspection system is disclosed. The die inspection system includes an inspection module. The inspection module includes an illumination module for generating collimated illumination to illuminate a region of interest (ROI) at an internal die sidewall of the die. The ROI includes a grooving kerf and a die seal ring surrounding core circuitry of the die, where the illumination has an inspection bandwidth which is transparent to a substrate of the die. The inspection module also includes an image capture module. The inspection module further includes an optical sub-system for directing the collimated illumination from the illumination module through an inactive surface of the die at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the die to the ROI and directing internally reflected illumination from the ROI to the image capture module to image the ROI. The image detects the presence of and extent that cracks, if any, extend internally toward and beyond the seal ring of the die in the ROI.

[20] In another embodiment, a die inspection system is disclosed. The die inspection system includes a first inspection module. The first inspection module includes a first illumination module for generating a first illumination, a first image capture module, and a first optical sub-system. The first optical sub-system is configured to direct the first illumination to inspect a first pair of first and second ROIs at first and second internal die sidewalls of a 4-sided die, through the inactive surface of the die at the angle  $\theta$  with respect to the orthogonal axis of the inactive surface of the die to the first and second ROIs, and direct internally reflected

first illumination from the first and second ROIs to the first image capture module to capture a first image of the first and second ROIs in a first single image capture. The image of the first and second ROIs detects the presence of and extent that cracks, if any, extend internally toward and beyond the seal ring of the die in the first and second ROIs. The die inspection system also includes a second inspection module. The second inspection module includes a second illumination module for generating a second illumination, a second image capture module, and a second optical sub-system. The second optical sub-system is configured to direct the second illumination to inspect a remaining or second pair of third and fourth ROIs at the third and fourth internal die sidewalls of the 4-sided die, through the inactive surface of the die at the angle  $\theta$  with respect to the orthogonal axis of the inactive surface of the die to the third and fourth ROIs, and direct internally reflected second illumination from the third and fourth ROIs to the second image capture module to capture a second image of the third and fourth ROIs in a second single image capture. The second image of the third and fourth ROIs detects the presence and extent that cracks, if any, extend internally toward and beyond the seal ring of the die in the third and fourth ROIs.

[21] In another embodiment, a die inspection system is disclosed. The die inspection system includes a first inspection module disposed at a first inspection station of the inspection system. The first inspection module includes a first illumination module for generating a first illumination for imaging first and second regions of interest (ROIs) at first and second opposing internal die sidewalls of a plurality of dies at the first inspection station arranged in a line, the first and second ROIs include a grooving kerf and a die seal ring surrounding core circuitry of the dies. The first inspection module also includes a first image capture module. The first inspection module further includes a first optical sub-system for directing the first illumination from the first illumination module through an inactive surface of the dies at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the dies to the first and second ROIs of

the dies, and directing reflected first illumination from the first and second ROIs to the first image capture module to produce a first image the first and second ROIs of the dies at the first inspection station. The first image detects an extent that cracks, if any, extend internally toward and beyond the seal ring of the dies in the first and second ROIs.

[22] In another embodiment, a method for inspecting a die is disclosed. The method includes generating illumination for imaging a region of interest (ROI) of a die at an internal die sidewall of the die. The ROI includes a grooving kerf and a die seal ring surrounding core circuitry of the die. The method also includes directing the illumination through an inactive surface of the die at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the die to the ROI. The method also includes directing reflected illumination from the ROI to an image capture module to image the ROI. The method further includes determining from the image extent that cracks, if any, extend from internally toward and beyond the seal ring in the ROI.

[23] These and other advantages and features of the embodiments herein disclosed will become apparent through reference to the following description and the accompanying drawings. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[24] In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of various embodiments. In the following description, various embodiments of the present disclosure are described with reference to the following, in which:

[25] Fig. 1a shows a simplified top view of a processed semiconductor wafer;

[26] Fig. 1b shows a simplified cross-sectional view of a processed wafer with grooving kerfs;

[27] Fig. 1c shows a simplified cross-sectional view of a portion of a processed wafer with a grooving kerf between adjacent rows or columns of dies;

[28] Fig. 1d illustrates a simplified cross-sectional view of a portion of a die proximate to one of the die sidewalls;

[29] Fig. 2a shows a simplified isometric view of a die;

[30] Figs. 2b-2c show simplified isometric and side views of a portion of a die proximate to one of the die sidewalls;

[31] Fig. 2d shows a simplified side view of a die illustrating some of the possible illumination paths of the illumination source for inspecting a ROI of the die;

[32] Figs. 3a shows a simplified side view of a die on a die holder of an embodiment of a single-sided inspection system;

[33] Figs. 3b-3c show simplified top and side views of a die illustrating the zone of interest of a single-sided die inspection system;

[34] Fig. 3d shows an image captured by an embodiment of a single-sided inspection system;

[35] Fig. 4a shows a simplified isometric view of a die for an embodiment of two opposing sides die inspection system;

[36] Figs. 4b-4c show simplified top and side views of a die illustrating zones of interest of an embodiment of a double-sided die inspection system;

[37] Figs. 4d-4e show simplified top and side views of a die illustrating zones of interest of another embodiment of a double-sided die inspection system;

[38] Fig. 4f shows an image captured by various embodiments of a double-sided inspection system;

[39] Figs. 5a-5b show simplified diagrams of embodiments of a double-sided inspection system;

[40] Figs. 5c-5d illustrate simplified isometric and side views of illumination paths of an embodiment of a double-sided inspection system;

[41] Fig. 5e shows a simplified diagram of another embodiment of a double-sided inspection system;

[42] Fig. 5f illustrates a simplified isometric view of illumination paths of an embodiment of a double-sided inspection system;

[43] Figs. 6a-6b show embodiments of double-sided illumination systems capturing adjacent sides of a die;

[44] Fig. 6c shows a simplified embodiment of a high-aperture illumination setup;

[45] Fig. 7a shows an embodiment of a high-speed inspection system deploying double-sided inspection;

[46] Fig. 7b-7c show another embodiment of an inspection system deploying double-sided inspection;

[47] Fig. 8 shows a simplified block diagram of the architecture of an embodiment of an inspection system; and

[48] Fig. 9 shows an embodiment of a process flow for inspecting dies with an inspection system.

#### DETAILED DESCRIPTION

[49] The disclosure provides systems, devices, and methods for inspecting dies to detect internal defects and cracks located at zones or ROIs on the sides of singulated dies. In particular, the systems, devices and methods enable the detection of internal cracks in the ROIs at the internal sidewalls of the chips resulting from, for example, die singulation processes with minimal false alarms. The systems, devices and methods can be configured to sequentially

inspect at least one sidewall of the die at a time until all sidewalls are inspected, to inspect multiple sidewalls of the die at a time until all sidewalls are inspected, to inspect a combination of one sidewall at a time and multiple sidewalls at a time until all sidewalls of the die are inspected or to simultaneously inspect all sidewalls of the die at a time. The systems, devices and methods are configured for high-speed and accurate inspection of ROIs of die sidewalls to determine die failures or potential die failures.

[50] In some embodiment, the systems, devices and methods are configured to simultaneously inspect the ROIs at two sidewalls of a die for internal cracks. For example, the two sidewalls of the die are inspected in one inspection pass. In one embodiment, the two sidewalls are adjacent to one another and in another embodiment, the two side walls are on opposite sides of each other. In yet another embodiment, the two sets of two sidewalls (opposing or adjacent) of a die can be inspected together simultaneously at one inspection station. In other embodiments, two sets of two sidewalls of a die may each be inspected sequentially, each pair at separate inspection stations. In yet other embodiments, other configurations of inspecting the sidewalls of the die may also be employed. For example, the ROI at the opposing sidewalls of multiple dies (at least two or more) arranged linearly may be inspected simultaneously at one station, and the other pair of opposing sidewalls would be inspected simultaneously at another station. Other configurations may, for example, include each sidewall of the die being inspected sequentially or sidewalls of the die being inspected in a combination of individual sidewall inspections and a pair of sidewall inspections.

[51] For purposes of brevity and clarity, the embodiments of the present disclosure are directed to systems, devices, and methods for detecting internal defects, such as internal cracks or voids at the ROIs located at the sides of a die. For the avoidance of doubt, this is not an external sidewall die inspection system but an inspection system particularly focused on detecting *internal cracks or voids* in the zones or ROIs (volumetrically) located at about or

abutting the seal ring and laser groove of a die. It will however be apparent to a person skilled in the art that this disclosure does not preclude the embodiments from being applied to other inspection applications where fundamental principles prevalent among the various embodiments of the present disclosure such as operational, functional or performance characteristics are required.

[52] Fig. 1a shows a simplified top view of a processed wafer 100 and Fig. 1b shows a simplified cross-section view of a processed wafer. The processed wafer is processed with a plurality of dies 120 arranged in rows (x-direction) and columns (y-direction). The processed wafer includes a wafer 110. The wafer includes an active wafer surface 110<sub>A</sub> and an inactive wafer substrate with surface 110<sub>I</sub>. The wafer, with its inactive surface 110<sub>I</sub>, may be mounted on a dicing tape 109 for processing.

[53] Referring to Fig. 1b, the active wafer surface 110<sub>A</sub> includes active layers 130 formed thereon. The bottom of the active layers 130 is separated from the thicker inactive substrate layer by an isolation layer 111 made from silicon oxide. The active layers, for example, may include circuit features and metal interconnects formed in a back-end-of-line (BEOL) dielectric over the circuit features. Other types of active layers may also be useful. The interconnects, which include metal lines and via contacts formed in multiple dielectric layers of the BEOL dielectric interconnect the circuit features. Separating the dies are saw streets 112. For example, x and y saw streets 112<sub>X</sub> and 112<sub>Y</sub> separate the dies in the x and y directions. Within a saw street is a grooving kerf 114. For example, x-direction grooving kerfs are disposed within saw streets 112<sub>X</sub> and y-direction grooving kerfs are disposed within saw streets 112<sub>Y</sub>. Typically, the active layers form a small percentage of the overall thickness (z-direction) of the processed wafer or of singulated dies after a singulation process to separate the wafer into individual dies.

[54] Fig. 1c shows a simplified cross-sectional view of a portion of the processed wafer 100 of Figs. 1a-1b. Common elements may not be described or described in detail. As shown, the portion of the processed wafer includes a substrate wafer 110 with active layers 130 on an active substrate wafer surface 110<sub>A</sub>. A top surface of the active layers serves as the active processed wafer surface 100<sub>A</sub> and an inactive wafer substrate surface 110<sub>I</sub> serves as the inactive processed wafer surface 100<sub>I</sub>.

[55] The processed wafer includes adjacent rows or columns of dies. The cross-sectional view of the portion of the processed wafer shows first and second dies 120<sub>1</sub> and 120<sub>2</sub> of adjacent rows or columns of dies. The dies include die contacts 129 on die pads on the top surface of the active layers 130. For example, the dies are wafer-level packaged dies. The dies include a seal ring 132 in active layers 130. The seal ring surrounds the active region of a die. The active region, for example, includes circuit components of the die.

[56] The seal ring is a protective structure between the core circuitry and the edges of the die. The seal ring is typically constructed at the same time as the construction of the core circuitry. For example, the seal ring is formed of metal in active layers, such as the metal and via levels of the BEOL dielectric. Other types of active layers may also be useful. The intended purpose of the seal ring is to limit the intrusion of cracks into the vital interior core circuitry and to prevent moisture penetration or chemical damage like acid, alkaline-containing chemicals or the diffusion of contaminating species.

[57] The region 112 between the seal rings of adjacent rows or columns of dies may be referred to as an inactive region of the wafer. The inactive region, for example, may be a saw street of the wafer. A dicing tape 109 is attached to an inactive bottom wafer substrate surface 110<sub>I</sub> for processing. Processing includes forming grooving kerfs (cutting grooves) 114 in the inactive region 112 between adjacent rows and columns of dies. Various techniques may be employed to form the grooving kerfs, as described in earlier sections. For example, laser

ablation may be employed to form the grooving kerfs. Laser-formed grooving kerfs may be referred to as laser grooves. Other techniques for forming grooving kerfs may also be useful. The grooving kerfs usually extend below the active layers 130 and a little more into the inactive substrate wafer 110, such as a silicon wafer. A saw or laser may then be used to cut along the dicing kerf 116, separating or singulating the wafer into individual dies. A gap 117 exists between the dicing kerfs and the edges of the grooving kerfs. This results in portions of the dies below the grooving kerfs to extend beyond the sides of the grooving kerfs.

[58] As illustrated, the grooving kerfs are made in proximity of and preferably centrally between and parallel to the seal rings of adjacent dies. For example, the grooving kerfs are preferably disposed centrally in the inactive region between seal rings of adjacent rows and columns of dies. The purpose of forming grooving kerfs on a wafer 100 is to facilitate the final dicing or singulation process, for example, with a saw 166. The grooving kerfs are intended to minimize damage to the top edges of the singulated dies. However, such grooving kerfs 114 do not render the dies completely safe from damage during singulation.

[59] Fig. 1d shows a portion of a singulated die 120 from the processed wafer of, for example, Figs. 1a-1c. Common elements may not be described or described in detail. The die, for example, includes an inactive die surface 120<sub>I</sub> (bottom of the substrate 110) and an active die surface 120<sub>A</sub> (top of the active layers 130). It has been observed that both external and internal defects 133 present themselves in a region 131 near where the grooving kerf 114 was first made. These cracks (both external and internal) near the grooving kerf may be aggravated further by further singulating processes. Cracks, for example, could progress and subsequently pierce through the seal ring 132 or it may stop where it is drawn. There may also be multiple internal cracks near the sidewall and may include one or more originating from the external sidewall. Cracks that are of particular interest in this disclosure are cracks near grooving kerfs, at the top surface in the proximate elevation of the active layers of a die proximate to the seal

ring. This region 131 is the ROI, which is the focus of inspection because cracks here tend to cause die failures. If these internal defects are not detected, these dies will undergo further costly back-end processes, wasting both time and money. If these defective dies are deployed in finished products, there will be costly product recalls. In contrast, cracks at the bottom of the silicon base of the die have lesser potential to cause failure of the die.

[60] Conventional inspection systems can detect external defects on the side die surfaces. Internal cracks, when present, however, are not detectable by conventional sidewall inspection systems. Thus, conventional systems are unable to ascertain whether internal defects exist and whether they may or may not cause reliability issues. Furthermore, even if conventional systems can detect existing external defects, such systems cannot reliably determine the extent to which such external defects extend into the internal portions of the die. Again, conventional systems cannot ascertain whether these external defects may or may not cause reliability issues. However, the present systems can accurately detect the amount of intrusion of external and internal defects to ascertain whether they will cause die reliability issues.

[61] Figs. 2a-2c show various simplified views of a die 120. Fig. 2a shows a simplified isometric view of the die with the top surface being faced down (not drawn to scale), Fig. 2b shows a simplified isometric view of a portion of a die with the top surface being faced down, Fig. 2c shows a simplified side view of a portion of a die with the top surface being faced down and Fig. 2d illustrates illumination paths through the die. The active surface of the die may include solder ball contacts (not shown). The die, for example, is similar to the die shown in Fig. 1d. Common elements may not be described or described in detail.

[62] Referring to Figs. 2a-2c, an illumination path of illumination 242 from an illumination unit of an inspection system for illuminating an ROI of the die is depicted. The illumination 242 is a collimated illumination. Generating collimated illumination may be

achieved by, for example, using a collimator. The collimated illumination maintains uniform intensity and uniform illumination for the targeted inspection area (e.g., ROI). This enhances contrast between defects and surrounding areas and improves resolution to detect smaller crack defects. On the other hand, uncollimated illumination may have dispersions into colors, causing distortion and well as resulting in non-uniform intensity of the illumination. The illumination path shown is for a single-sided inspection of the die. Providing illumination paths for a multi-sided inspection of a die may also be useful. The wavelength of the illumination is selected to be transparent to the substrate (processed wafer) of the die, such as silicon. This enables imaging of the ROI of the die for die inspection.

[63] In one embodiment, the illumination unit is configured to generate a broad range of illumination wavelengths. For example, the illumination unit can be configured to generate infrared illumination in the near-infrared and mid-infrared ranges, such as between about 800-2700 nm. Providing an illumination unit with a broad bandwidth (broadband) of illumination is useful to support simultaneous multi-sided inspection of dies of embodiments in this disclosure. The useful wavelength bandwidth of IR illumination for the purposes of embodiments in this disclosure may be about 1100-2500 nm and above, which makes silicon transparent to the illumination. When the silicon substrate is transparent to the IR illumination, the illumination traveling through the substrate is able to show up internal defects.

[64] The optical path of illumination through the optical assembly to the ROI on each side of the die can be considered a channel. With the use of appropriate filters, it is possible to restrict only illumination of a certain band of wavelength to pass through each channel as may be required. Filters employed may be optical bandpass filters. Thus, although the source of illumination is the same, each channel can be configured using filters to allow illumination of only a certain band of wavelength to pass through, the bandwidth for each channel being different from the other. For example, in opposing side inspection, each channel to the ROI of

opposing sidewalls will use different bandwidths. The first channel may use a first inspection bandwidth of about 1200-1500 nm to inspect a first die side while the second channel may use a second inspection bandwidth of about 1550-1700 nm. The bandwidth for each channel should not overlap and should have sufficient buffer from one another. The objective of using different filters is to reduce optical cross-talk, e.g., when unwanted illumination from another channel enters the optical path of a channel. When such a filter is used for one channel, only illumination of pre-determined bandwidth will pass through the channel, reducing or eliminating noise from other channels and ensuring a picture with better contrast. This can also apply to the 4 channels to inspect the ROIs at the 4 sides of a die simultaneously. Thus, even when the ROIs at the respective channels are captured in a single image simultaneously, the image of the ROIs will not be affected by optical crosstalk; i.e. illumination from one channel will not be allowed to pass through the other channel/s and thus will not affect the image quality obtained from each channel of inspection. This will significantly reduce any optical crosstalk that can otherwise arise. This is important as the die surface is very small. Optical crosstalk negatively affects the image quality of the ROI captured. Optical crosstalk can occur when some of the illuminations reflected off the back surface of the inactive silicon layer from one channel are inadvertently captured by another channel. The use of filters for each channel of the optical assembly allowing different illumination of different wavelengths to pass through each channel eliminates such optical crosstalk.

[65] Polarizers, like filters may be used. In such cases, illumination of different polarizations will only be allowed to pass through each channel as may be configurable by those skilled in the art.

[66] In yet other embodiments, multi-sided inspection may include a combination of simultaneous and sequential inspection of ROIs. For example, a four-sided inspection may include inspecting a first pair of sidewalls simultaneously followed by inspecting (sequential

inspection) a second pair of sidewalls simultaneously, each of the inspections being carried out at separate inspection stations. As discussed, the first and second pairs may be two pairs of adjacent sidewalls or two pairs of opposing sidewall. Other configurations of inspecting the sides of the die may also be useful.

[67] As shown in Fig 2a and 3a, illumination 242 is directed to pass through a virtual plane 248. The virtual plane is perpendicular to the bottom die surface. The virtual plane is located at a center of the die. The illumination passes through the virtual plane at angle  $\theta$  from a first side of the die. The illumination penetrates a die substrate 110 and active layers 130 to image the ROI located at about a second side of die. The first and second die sides are opposing sides.

[68] Referring to Figs. 2b-2c, the ROI 140 on a side (e.g., second side) of the die to be inspected is illustrated. For embodiments in this disclosure, an ROI 140 of the die includes the seal ring 132 and active layers 130 of the die near the grooving kerf. In one embodiment, the ROI 140 is the volume of the die bounded by the near and far depth of focus (DoF) planes 147<sub>N</sub> and 147<sub>F</sub> of the camera unit of the inspection system. The planes form the depth of field or view of the camera unit. The volume includes the part of the side wall and the top surface of the die falling within the DoF planes. In one embodiment, the DoF planes of the camera unit encompass the complete ROI 140.

[69] Anything falling within the DoF planes or depth of field of the inspection system would be captured as a 2D image. The DoF planes, for example, are normal to the direction of illumination. The ROI 140 within the depth of field extends the complete length of the sidewall of the die, creating an elongated triangular ROI 140 along the sidewall of the die to be inspected. The depth of field encompasses the ROI 140 which includes the seal ring 132, the active layers 130 on the active substrate surface 110<sub>A</sub> and a portion of the substrate 110 near the laser groove where minute cracks may emanate, causing die failures. This is true for a single-sided, a double-

sided or a four-sided inspection. The camera unit can be adjusted to capture the desired region or ROIs within the depth of field.

[70] In various embodiments, an ROI 140 to be inspected is always on the opposite side of the virtual plane from which the illumination crosses. From experiments performed, an angle of between 35-65° has been found to be optimal for the detection of defects in the ROI 140. Other angles may also be useful. The angle, for example, may depend on the size and features of the bottom die surface to be inspected.

[71] As described, the inspection system is configured with a camera unit with a bigger field of view (FoV) capable of capturing the entire ROI of the sidewall in a single image capture. The resolution of the image from such camera units may not be comparable to that obtained by line-scanning image capture units. However, the resolution of the image obtained by such camera units of the ROI is sufficient for purposes of detecting the presence of internal defects therein. In addition, and more importantly, the present system can achieve a significantly higher throughput, compared to line scanning methods. This is highly desirable and necessary for commercial production.

[72] Fig. 2d shows a side-view of a portion of one side of a die. In particular, Fig. 2d illustrates the illumination path of the illumination from the illumination unit (not shown) to the ROI 140 of the die 120 and back to the image capture or camera unit (not shown) of the inspection system, as indicated by the direction of the arrows. An optical sub-system (not shown) may be employed to direct illumination from the illumination unit to the ROI 140 and back to the camera unit. As shown, the IR illumination passes through the bottom surface, the inactive silicon, and towards the focal planes encompassing the ROI 140 (shaded area). The illumination undergoes internal reflection in the ROI 140. Some of the illumination that is reflected out of the bottom surface is directed back to the image capture unit to image the ROI 140. Under normal circumstances, this reflection will show up in the image captured as a

regular pattern peculiar to the die internal structures at the ROI 140 inspected. However, any defects that are present in the ROI 140 will disrupt the regular pattern of reflection since the rough surface of the cracks will reflect light away from the camera unit and will show up as aberrations or darkened areas against the regular patterned image captured, indicating the presence of cracks.

[73] Fig. 3a shows a configuration 300 for a single-sided inspection of a die 120 by the inspection system. The die, for example, is similar to the die shown in Fig. 1d. Common elements may not be described or described in detail. As shown, the die is held by a die holder 350 of the inspection system. The die holder, for example, holds the die in position by vacuum pressure. Other techniques for holding the die in position may also be useful. Illumination 242 from an illumination unit (not shown) is directed to the ROI on a first die side or sidewall 322 of the die for inspection. The illumination crosses a virtual plane 348 located at a center of the die which is perpendicular or normal to the bottom die surface at an angle  $\theta$ . The angle  $\theta$ , for example, is about 35-65°. Other angles may also be useful.

[74] The inspection system may be configured to accommodate dies of different sizes. In one embodiment, an optical sub-system (not shown) of the inspection system can be lowered or raised in the z-direction to accommodate different-sized dies. In one embodiment, an optical module of the optical sub-system can be lowered or raised in the z-direction to accommodate different-sized dies. Alternatively, the die holder 350 can be lowered or raised in the z-direction to accommodate different-sized dies. In yet another embodiment, both the optical sub-system and die holder can be lowered or raised in the z-direction to accommodate different-sized dies.

[75] Figs. 3b-3c show simplified top and side views of the die 120. The die includes an ROI 340 inspected by an inspection system configured for single-sided inspection in one image capture. As shown, the ROI includes a triangular portion of the die on the first die side 322 bound by the focal planes and within the FoV.

[76] Fig. 3d shows an example of an image 346 captured by the illumination system configured for a single-sided inspection. As shown, the image includes an image of the ROI 340 depicted by the dark area of the image. The ROI includes the grooving kerf 343, depicted by a lighter strip within the ROI. Defects 349 within the ROI are depicted as darkened regions punctuating the regular pattern of the grooving kerf. The image reveals that there are cracks present near the grooving kerf and the seal ring region. The cracks would be classified as defects on the die.

[77] Fig. 4a shows a configuration of an inspection for inspecting two opposing sides of a die 120 with one single image capture. The die, for example, is similar to the die shown in Fig. 1d. Common elements may not be described or described in detail. The die is held by a die holder (not shown) of the inspection system. The die holder may hold the die on the die holder by, for example, vacuum pressure. Other techniques for holding the die in position on the die holder may also be useful. First and second Illuminations 242<sub>1,2</sub> from an illumination unit (not shown) are directed to first and second ROIs 340<sub>1</sub> and 340<sub>3</sub> on first and second die sides 322<sub>1</sub> and 322<sub>3</sub> of the die for inspection.

[78] In one embodiment, the optical module of the optical sub-system is configured to split the illumination from the illumination unit into first and second illuminations. Other configurations of generating first and second illuminations are also useful. In one embodiment, the first and second sides are opposing sides of the die.

[79] The first and second illuminations cross a virtual plane 348 located at a center of the die which is perpendicular to the bottom die surface at an angle  $\theta$ . The angle  $\theta$ , for example, is about 35-65°. Other angles may also be useful. The first illumination 242<sub>1</sub> crosses the virtual plane 348 from a first virtual plane side 348<sub>1</sub> to an ROI on the first die side 322<sub>1</sub> located on the other (second) side 348<sub>2</sub> of virtual plane. Likewise, the second illumination 242<sub>2</sub> crosses the virtual plane 348 from a second virtual plane side 348<sub>2</sub> at the same angle  $\theta$  to a ROI on the

second die side 322<sub>3</sub>. As shown, the first and second sides are opposing sides of the die. In other embodiments, the first and second sides may be adjacent sides of the die. The illuminations penetrate through the bottom or inactive die surface 120<sub>I</sub> to the top or active die surface 120<sub>A</sub> at the angle  $\theta$  to inspect the ROIs.

[80] Figs. 4b-4c show simplified top and side views of an embodiment of the die 120 subjected to opposing side inspection. For example, the inspection is a two-sided or double-sided inspection of opposing die sides. The die includes first and second ROIs 340<sub>1</sub> and 340<sub>3</sub> on opposing first and second die sides 322<sub>1</sub> and 322<sub>3</sub> inspected by an inspection system configured with opposing-side inspection. As shown, the ROIs include triangular portions of the die on the first and second die sides, each being within the DoF focal planes and depth of focus.

[81] In another embodiment, the inspection system may be configured to inspect first and second ROIs of adjacent sides of a die. This can be easily achieved by configuring the optical sub-system to direct first and second illuminations to adjacent sides of the die.

[82] Figs. 4d-4e show simplified top and side views of the die 120 subjected to an inspection of adjacent sides. For example, the inspection is a two-sided or double-sided inspection of adjacent die sides. As shown, the first and second ROIs 340<sub>1</sub> and 340<sub>2</sub> are on adjacent first and second die sides 322<sub>1</sub> and 322<sub>2</sub>. The ROIs include triangular portions of the die on the first and second die sides, each being within the DoF focal planes and depth of focus.

[83] Fig. 4f shows an illustrative image 346 captured by the illumination system configured for double-sided inspection. Preferably, the double-sided inspection may be for two adjacent sides, as illustrated by Figs. 4d-4e. Inspecting adjacent sides advantageously reduces or avoids optical cross-talk. For example, reduced or avoidance of optical cross-talk can be attributed to orthogonal illumination paths of the collimated illuminations to orthogonal ROIs. The use of orthogonal collimated illuminations reduce or avoid one illumination from entering

into the other's illumination path, reducing or preventing optical cross-talk. In addition, filters or polarizers may be employed provide different bandwidths for the different illuminations. In other embodiments, two-sided inspection is performed for two opposing sides, as illustrated by Figs. 4b-4c. In two opposing-sided inspection, optical cross-talk can be avoided with the use of different illumination bands for the different sides. Different illumination bands can be achieved with band filters or multiple illumination units. Other techniques for generating different illumination bands may also be useful.

[84] As shown, the image includes images of the first and second ROIs 340<sub>1</sub> and 340<sub>3</sub> for first and second opposing sides or the first and second ROIs 340<sub>1</sub> and 340<sub>2</sub> for first and second adjacent sides. The ROIs are depicted by the first and second dark areas of the image. An ROI includes an image of the grooving kerf 343 near the seal ring area. The grooving kerf is the ROI illustrated by a lighter strip within the ROI while defects 349 therein are depicted as darkened regions. As for the seal ring, by comparison, it is much narrower than the grooving kerf. As such, the seal ring would not be visible or show up in the image. As shown, the image reveals that there are internal cracks at or near the grooving kerf region in the first and second ROIs, indicating a failure or a potential failure of the die.

[85] Figs. 5a-5b show embodiments of an inspection system 500 for inspecting a die 120 for internal cracks in first and second ROIs 340<sub>1</sub> and 340<sub>3</sub> at about first and second opposing side die surfaces 322<sub>1</sub> and 322<sub>3</sub> in a single image capture or single pass, as described in Figs. 4a-4c. The systems of Figs. 5a-5b are similar and will be described together.

[86] The inspection system of Figs. 5a-5b includes an imaging sub-system 560. The imaging sub-system includes an illumination unit 380, a camera unit 390, an optical sub-system 570 with an optical module 582 and an optical unit 572. The inspection system also includes a die holder or pedestal 350 for holding a die 120 in position for inspection. In one embodiment, the die holder is a retractable and rotatable pedestal. For example, the pedestal may be

retractable or extendable along the x-y plane and rotatable around the z-axis. Providing a retractable and rotatable pedestal is advantageous as it ensures the correct positioning and orientation of the die for inspection. Other types of die holders may also be useful.

[87] The illumination unit 380 provides illumination for imaging the ROIs. In one embodiment, the illumination unit generates collimated illumination. For example, the illumination unit, for example, includes a collimator which collimates the illumination. The illumination generated has a wavelength range which is transparent to the substrate of the die to inspect internal cracks or defects. "Inspection wavelength range" refers to the wavelength range of the illumination which is transparent to the substrate of the die for inspecting internal cracks or defects. In the case of a silicon substrate, the inspection wavelength range is about 1100 nm or greater. In one embodiment, the inspection wavelength range for silicon is about 1100-2500 nm. Generating illumination having other inspection wavelength ranges may also be useful. The inspection wavelength range used to inspect the die may depend on the material of the wafer or substrate. For example, in the case of silicon-germanium, the inspection wavelength range may be greater than 1850 nm.

[88] The capability of generating a broad range of wavelengths is desirable as it provides flexibility for application to different types of die substrates. As discussed, different substrate materials employed to form the dies may have different inspection wavelength ranges which makes them transparent to the IR illumination. For example, the illumination unit is configured to generate broadband illumination in the range of about 800-2700 nm.

[89] Furthermore, the inspection wavelength range of a specific material may be separated into multiple bands or spectra to avoid optical crosstalk when multiple sides are captured in a single image capture or pass. The number of bands that the inspection wavelength range is separated into may depend on the number of sides of a single capture. For example, for a two-sided single capture, the inspection wavelength range may be separated into two

distinct bands. For a four-sided single capture, the inspection wavelength range may be separated into four distinct bands. Separating the inspection wavelength range of the illumination into bands may be achieved by using filters. The wavelengths of a band may depend on the material of the substrate as well as the number of bands needed.

[90] As discussed, the inspection wavelength range that makes silicon transparent for inspection purposes is about 1100-2500 nm. For purposes of this disclosure, the various embodiments generate illumination having a wavelength bandwidth of about 1100-2500 nm, making silicon transparent to the illumination. By being transparent to the illumination, the presence of any cracks in the ROI will break the normal propagation of light, the uneven surfaces of the crack would reflect light away from the camera and show up as a black line or crack.

[91] As discussed, the illumination unit is capable of generating illumination of about 800-2700 nm. In the case of a two-sided inspection for silicon, a first band or channel of about 1200-1500 nm may be used to inspect a first die side and a second band of about 1550-1700 nm may be used to inspect a second die side. In the case of a four-sided inspection for silicon, a first band of about 1200-1500 nm, a second band of about 1550-1700 nm, a third band of about 1750-2000 nm and a fourth band of about 2050-2300 nm may be used to inspect first, second, third and fourth sides of the dies. Other band configurations may also be employed for multi-sided die inspections.

[92] As for the optical sub-system 570, it is configured to direct illumination from the illumination unit 380 to the ROIs of the die and to direct reflected illumination 242 from the ROIs to the camera unit 390 to image the ROIs. In one embodiment, the optical sub-system 570 is configured to split the illumination 242 from the illumination unit 380 into first and second illumination beams and direct them to the first and second ROIs of the die. Alternatively, the optical sub-system is configured to direct first and second illumination beams from first

and second illumination units to the first and second ROIs of the die. The illumination beams undergo internal reflection in the ROIs, as shown in Fig. 2d.

[93] Referring back to Figs. 5a-5b, reflected illumination beams from the first and second ROIs are directed by the optical sub-system to the camera unit for imaging the first and second ROIs. As described, the illumination beams are applied to inspect internal defects at the ROIs near the die sidewalls. This is achieved by passing the illumination beams obliquely, crossing the normal virtual plane 348 at angle  $\theta$ , through the surface of the silicon die to illuminate the inside at the ROIs at the die sidewalls.

[94] In one embodiment, as illustrated in Figs. 5a-5b, the optical unit 572 of the optical sub-system 570 is configured to direct the illumination 242 from the illumination unit 380 to the optical module 582. The optical module 582 is configured to split the illumination 242 into first and second illumination beams 242<sub>1</sub> and 242<sub>2</sub> and to direct them to the first and second ROIs at opposite sides of the die. Reflected illumination beams from the ROIs are directed by the optical module to the optical unit, which then directs the illumination beams to the camera unit 390 for imaging the ROIs.

[95] In one embodiment, the optical unit 572 includes first and second optical unit reflectors or mirrors 574<sub>1</sub> and 574<sub>2</sub>. The first reflector 574<sub>1</sub> is configured to be reflective on one side while transparent to illumination on the other. The first reflector 574<sub>1</sub> (facing the illumination unit) is configured to allow the illumination 242 from the illumination unit 380 to pass through to the first optical unit reflector. The first optical unit reflector of the optical unit 572 reflects the illumination 242 to the optical module 582. In alternative embodiments, beam splitters may be used. In the case of the beam splitters, only a portion of the illumination is reflected while the remaining portion is transmitted therethrough.

[96] As for the optical module 582, it includes first and second optical module reflectors 584<sub>1-2</sub> and a prism 586. The prism, in one embodiment, includes first and second

prism faces 586<sub>1-2</sub>. The first prism face 586<sub>1</sub> is in optical communication with the reflector 584<sub>1</sub> while the second prism face 586<sub>2</sub> is in optical communication with reflector 584<sub>2</sub>. The first and second prism faces may be, for example, mirrors or reflectors. The optical module 582 serves to split the illumination 242 from the optical unit 572 into first and second illumination beams 242<sub>1</sub> and 242<sub>2</sub> and to direct them to the first and second ROIs at opposing sides of the die at an angle  $\theta$  normal to the axis of the bottom surface.

[97] To illuminate the ROIs, the optical unit 572 directs the illumination 242 to the prism 586. The prism 586 splits the illumination from the optical unit 572 into first and second illumination beams 242<sub>1</sub> and 242<sub>2</sub>. The first prism face 586<sub>1</sub> directs the first illumination 242<sub>1</sub> to the first optical module reflector 584<sub>1</sub> which then directs it to the first ROI 340<sub>1</sub>; at the same time, the second prism face 586<sub>2</sub> directs the second illumination 242<sub>2</sub> to the second optical module reflector 584<sub>2</sub> which then directs it to the second ROI 340<sub>3</sub>. For example, the optical module 582 splits the illumination from the illumination unit into first and second illuminations 242<sub>1</sub> and 242<sub>2</sub> which cross the normal virtual plane 348 at predetermined angle  $\theta$  to illuminate the first and second ROIs 340<sub>1</sub> and 340<sub>2</sub> at opposing sides of the die.

[98] The first and second illumination beams undergo internal reflection in the first and second ROIs as illustrated in Fig. 2d. Referring back to Figs. 5a-5b, internally reflected illumination from the first ROI 340<sub>1</sub> is reflected back to the first optical module reflector 584<sub>1</sub> to the prism 586 and directed to the optical unit 572 to the camera unit 390. Likewise, internally reflected illumination from the second ROI 340<sub>3</sub> is reflected back to the second optical module reflector 584<sub>2</sub> to the prism 586 and directed to the optical unit 572 to the camera unit 390. This results in capturing an image of the first and second ROIs.

[99] As described, the optical sub-system utilizes optical elements, such as a beam splitter/prism 586 and reflectors 584<sub>1-2</sub>, to split the illumination unit into first and second illumination beams 242<sub>1-2</sub>, directs the illumination beams to the first and second ROIs 340<sub>1</sub> and

340<sub>3</sub> and directs reflected illumination from the first and second of ROIs to the camera unit 390 for capturing the images of the ROIs for inspection. Other configurations of the optical sub-system, such as different optical components or arrangements of optical components, can be employed to direct first and second illumination beams to the ROIs and reflected illumination beams to the camera unit. In addition, the optical sub-system can be configured to direct first and second illumination beams from first and second illumination units to the ROIs.

[100] The inspection system may be configured to capture first and second ROIs simultaneously with one single image capture. To avoid optical crosstalk, first and second filters 588<sub>1</sub> and 588<sub>2</sub> may be employed. For example, first and second filters may be disposed in first and second illumination paths to the first and second ROIs of the die. As shown in Fig. 5a, the first and second filters are disposed between the prism 586 and the optical module reflectors 584<sub>1</sub> and 584<sub>2</sub>. In another embodiment, the first and second filters are disposed between the optical module reflectors 584<sub>1</sub> and 584<sub>2</sub> and the ROIs of the die, as shown in Fig. 5b. Other configurations of locating the first and second filters may also be useful. Alternatively, first and second polarizers may be employed.

[101] As described, the optical sub-system of Figs. 5a-5b is configured to split the illumination 242 from the illumination unit 380 into first and second illumination beams 242<sub>1</sub> and 242<sub>2</sub> to image first and second ROIs of the die. In alternative embodiments, first and second illumination units may be employed to generate first and second illumination beams with first and second inspection bands for inspecting first and second ROIs. The optical sub-system may be configured to direct illumination from the first and second illumination units to the first and second ROIs and reflect illumination therefrom to the camera unit for image capture.

[102] Alternatively, polarizers may be employed. A first polarizer is configured to pass illumination while the second polarizer is configured to block illumination. The polarizers can

be mechanically switched between first and second illumination paths to inspect one ROI while blocking the other ROI.

[103] In some embodiments, first and second illumination units are employed. The first illumination generates illumination to inspect the first ROI while the second illumination unit is off. After inspecting the first ROI the first illumination unit is turned off while the second illumination is on to generation illumination to inspect the second ROI. Other techniques for sequentially inspecting first and second ROIs may also be useful.

[104] Figs. 5c-5d illustrate isometric and side views of the illumination 242 into the optical module 582 from the optical unit (not shown). The optical module 582 is similar to the one described in Figs. 5a-5b. Common elements may not be described or described in detail. As shown, the illumination 242 is split into first and second illumination beams 242<sub>1-2</sub> which are directed to the ROIs 340<sub>1</sub> and 340<sub>3</sub> on first and second sides 322<sub>1</sub> and 322<sub>3</sub> of the die 120 via first and second reflectors 584<sub>1-2</sub> and through the inactive die surface 120<sub>1</sub>, with the filters 588<sub>1-2</sub> located between the reflectors and ROIs. It is understood that the filters can be located between the prism 586 and the reflectors 584<sub>1-2</sub>, as shown in Fig. 5a.

[105] To accommodate dies of different sizes, the optical module 582 can be elevated or lowered (z-direction) with respect to the die 120. For example, the optical module can be elevated with respect to the die to accommodate a larger-sized die; conversely, the optical module can be lowered with respect to the die to accommodate a smaller-sized die. In other embodiments, the die holder can be elevated or lowered to accommodate dies of different sizes. In yet other embodiments, either or both the die holder and optical module can be elevated or lowered to accommodate dies of different sizes. After adjustment of the optical module 582, the camera unit 390 will be elevated or lowered to achieve optimal focus with respect to the die. In one embodiment, autofocus is built into the camera 390.

[106] Fig. 5e shows an illustrative diagram of an inspection system 500 for inspecting ROIs at two adjacent sides of the die. The system is similar to the system of Figs. 5a-5b, except that the optical module 582 of the optical sub-system 570 is configured to direct illumination to first and second adjacent side die surfaces 322<sub>1-2</sub> instead of opposing first and second side die surfaces. Common elements may not be discussed or discussed in detail. The method of detecting defects in the ROIs 340<sub>1-2</sub> of adjacent sidewalls may advantageously reduce optical crosstalk significantly compared to detecting defects of opposing sidewalls.

[107] In one embodiment, the optical module 582 is configured to direct illumination 242 from the optical unit 572 to adjacent sidewalls 322<sub>1-2</sub> of the die and back therefrom to the optical unit and to the camera unit 390. Illumination (first illumination 242<sub>1</sub>) is directed by the first reflectors 584<sub>1</sub> at an angle  $\theta$  across a first virtual plane 348<sub>1</sub> to a first ROI 340<sub>1</sub> at a first side 322<sub>1</sub>. At the same time, illumination (second illumination 242<sub>2</sub>) is directed by a second reflector 584<sub>2</sub> at an angle  $\theta$  across a second virtual plane 348<sub>2</sub> to the other or second ROI 340<sub>2</sub> at an adjacent second side 322<sub>2</sub>. The first and second virtual planes are orthogonal planes through the center of the die and are perpendicular (or normal) to the bottom surface of the die.

[108] Fig. 5f illustrates the illumination paths from the optical unit to the first and second adjacent side die surfaces of the optical system of Fig. 5e. Although not shown, filters, including polarizers, may be employed, similar to Figs. 5a-5b, to enhance image quality. For example, multi-band inspection may be employed to avoid crosstalk. Similar to embodiments of Figs. 5a-5b, the optical module 582 and/or die holder can be elevated or lowered to accommodate dies of different sizes.

#### **DEPLOYMENT ON TURRET SYSTEM – TWO INSPECTION SYSTEMS**

[109] Figs. 6a-6b show first and second inspection systems 600a-b configured to capture images 346a-b of two sets of distinct ROIs on adjacent sides of a die 120. Each system can be configured to simultaneously capture ROIs on both adjacent sides.

[110] In one embodiment, an inspection system includes an integrated illumination/camera unit 569. For example, the integrated illumination/camera unit of an inspection system includes a camera unit 390 and an illumination unit 380 integrated into a single integrated imaging unit. Other configurations of the camera and illumination units may also be useful. In one embodiment, the integrated imaging unit is configured with a collimator to collimate the illumination from the illumination unit. The use of collimated illumination improves contrast of defects in images captured.

[111] In one embodiment, system 600a and 600b as shown in Fig 6a and Fig 6b respectively are deployed in separate stations of the turret of an equipment. A series of dies on the pick and place of the turret are brought to station 600a and station 600b consecutively and sequentially. As shown, the first system 600a of Fig. 6a deployed at one turret station, is configured to detect defects in ROIs 340<sub>1-2</sub> on adjacent first and second sides 322<sub>1-2</sub> (first set of adjacent sides) of a die with one image capture; the second system 600b of Fig. 6b, deployed at a separate turret station, is configured to detect defects in ROIs 340<sub>3-4</sub> on adjacent third and fourth sides 322<sub>3-4</sub> (second set of adjacent sides) of the die. For example, the optical sub-system 570a of the first inspection system of Fig. 6a is configured to direct first and second illumination 242<sub>1-2</sub> to capture an image 346a of the first and second ROIs 340<sub>1-2</sub> on the first and second adjacent sides 322<sub>1-2</sub> of the die while the optical sub-system 570b of the second inspection system of Fig. 6b is configured to direct third and fourth illumination 242<sub>3-4</sub> to capture an image 346b image of the third and fourth ROIs 340<sub>3-4</sub> on the third and fourth adjacent sides 322<sub>3-4</sub> of the die. In this way, the ROIs at all 4 sides of a series of dies on the turret brought to inspection systems 600a and 600b are inspected.

[112] Fig. 6c shows a simplified embodiment of a high-aperture illumination setup 600 for collimated illumination. The setup includes a high-aperture lens 683 through which illumination 242 passes to the camera unit (not shown). The high-aperture lens produces angled

illumination 644 at the edge of the lens. The high-aperture illumination setup advantageously allows more illumination to pass through, producing a sharper image of the ROI. However, such a setup results in a shallower depth of field. The lens position (distance between lens and camera unit) can be adjusted to obtain the desired focus.

[113] Fig. 7a shows the deployment of an inspection system in a high-speed turret machine (HSTM) or inspection system 700. The HSTM includes a turret 705 which is configured to rotate in a first direction, for example, a clockwise direction. Rotating the turret in a counterclockwise direction may also be useful. The turret is configured to rotate in steps. For example, each step corresponds to an index position 729. Other turret rotation configurations may also be useful.

[114] The turret includes a plurality of die pick and place (PNP) units 708 located at the circumference of the turret. Although only 4 PNP units are depicted in Fig. 7a to simplify the drawing, it is understood that there may be more PNP units (not shown) distributed along the dotted circle. For example, the PNP units are distributed equidistant on the periphery of the turret. A PNP head is configured to pick, hold and place a die in the z-direction (up and down relative to the turret).

[115] As shown, the HSTM configuration includes a load station 729<sub>L</sub> where dies to be inspected are picked up by a PNP unit of the turret equipment, a first inspection station 729<sub>11</sub>, a second inspection station 729<sub>12</sub> and an unload station 729<sub>U</sub> where dies that have been inspected will be sorted to different bins or to output media (not shown). The first inspection station and the second inspection stations are deployed underneath selected suitable index positions along the turret in sequence, depending on availability of the limited space on the turret platform.

[116] Typically, each of the PNP units of the rotating turret holds a die. Each of these dies is indexed around the turret through all the inspection stations on the equipment platform beneath the turret before they are unloaded to sorting bins or to an output media.

[117] The first inspection station 729<sub>11</sub> includes a first inspection system 760<sub>1</sub> and the second inspection station 729<sub>12</sub> includes a second inspection system 760<sub>2</sub>. The first inspection system is configured to inspect a first pair of sides of a die at the first inspection position; the second inspection system is configured to inspect a second pair of sides of a die (different or distinct from the first pair of sides) at the second inspection index position.

[118] When a die is indexed to the first inspection index position corresponding to the first inspection station, 729<sub>11</sub> beneath the turret, a first pedestal from the first inspection system will extend outward toward a position directly beneath the PNP unit at the first inspection index position. For example, a first PNP unit of the turret with a first die is indexed to the first inspection index position. The first PNP unit will extend downward in the z-direction to place the first die on the first pedestal. The first die on first pedestal will be inspected for orientation before it is moved to the first inspection position. It is necessary to properly orientate the die  $x-y-\theta$  before inspection takes place (whether it is opposing or adjacent sides inspection).

[119] After the first die is inspected, the first pedestal moves the first die to beneath the first PNP unit for pick up and transportation by the turret to the next process or inspection station (e.g., the second inspection station). At the same time, the first pedestal is in position to receive the next die from the next PNP unit on the turret for inspection by the first inspection system.

[120] When the first die (same die inspected at the first inspection station) is indexed or rotated to the second inspection index position, the first PNP head lowers the first die to the second pedestal of the second inspection system for inspection. The process is similar to that described at the first inspection index position, except that a second set of sidewalls is inspected.

[121] After the second inspection system inspects the second set of sidewalls, inspection of the first die is completed. The die is returned to the first PNP on the turret by the second pedestal. For example, the second pedestal with the first die is positioned under the first PNP which then picks up the first die. The second pedestal after unloading the first die is then in position to receive the next die for inspection brought by the next PNP on the turret.

[122] As described, the turret is configured to rotate continuously in steps to index positions. At the load index position, a PNP at the load index position picks up a die for inspection by the inspection stations. At the first inspection station, a PNP at the first inspection index position unloads a die onto the first pedestal in preparation for inspection. At the second inspection station, a PNP at the second inspection index position unloads a die onto the second pedestal for inspection by the second inspection system. At the unload station, an inspected die is unloaded from the PNP and sorted to different bins or output media. In this manner, the ROI on all four sides of each die on the turret PNP will be fully inspected as they pass through the two inspection stations.

[123] When the inspection of a die is completed, the images captured of the die will be analyzed. The die will be classified based on the analysis. For example, a die without cracks is classified as passing inspection and a die with cracks is classified as failing inspection or as defective. For example, by the time the turret with the inspected die reaches the unload station 729<sub>U</sub>, the analysis may be completed. The analysis classifies the die as passing inspection or failing inspection. For example, a die without cracks is classified as passing inspection while a die with cracks is classified as failing inspection.

[124] The unload station 729<sub>U</sub> includes a die unloader 754. When the turret indexes to the unload index position, a fully inspected die on the die holder is unloaded from the turret. To unload a die from the turret, an unload PNP head moves or extends downward to pick the die up. After picking up the die, the unload PNP head moves or retracts upward. An unload

pedestal extends to under the unload PNP head with the die. The unload PNP head unloads the die onto the unload pedestal.

[125] In one embodiment, the unload pedestal is configured to drop the die in a passed inspection bin or failed inspection bin, based on the die's classification from the analysis. For example, passed dies are unloaded to a tray or a tube for the next manufacturing process or processes. In some embodiment, separate passed inspection and failed inspection unload stations may also be provided. Regarding failed dies, they may be subjected to further testing to determine whether they are functional or not. If they pass functional tests, these dies may be categorized as lower-quality dies that can still be sold.

[126] In other embodiments, analysis of the inspected dies may be performed offline. For example, inspected dies may be placed on a tray, with the location of each inspected die known. After the analysis of the inspected dies is completed, failed dies are removed from the tray. The passed dies are then provided for the next manufacturing process or processes.

[127] As described, once proper positioning and orientation are confirmed, inspection by the inspection system is performed. For example, when the die is loaded onto the pedestal, it may be rotated to confirm proper positioning and orientation prior to inspection. They can be performed prior to or after retraction. In some embodiments, as in the case where the die is a regular square type, the die on the pedestal may be rotated after inspection of the first pair of sides to inspect the other pair of sides at the same inspection station, completing inspection of 4 sides of the die. In the case of non-square dies, the inspection system may be adjusted to inspect the second pair of sides. For example, the optical module and/or pedestal may be adjusted in the z-direction. This avoids the need for a second inspection station. Other configurations of inspecting dies and inspection stations may also be useful.

[128] The HSTM, as described, may be configured for simultaneous capture of a pair of sidewalls at each inspection station for inspection of the ROIs on four sides. Filters or

polarizers may be employed, as described in Figs. 5a-5b, to significantly reduce or avoid crosstalk. For example, filters may be used to shield one channel from the illumination of the other channel. In other embodiments, the system may be configured to capture one sidewall at a time at each inspection station. Other configurations of capturing the sidewalls of the die may also be useful.

[129] As described, the HSTM is configured with two inspection stations, each with an inspection system for 2-sided inspection. In some embodiments, the HSTM may be configured with one inspection station with two inspection systems, each configured to inspect a distinct pair of sides of the die. The two systems may be configured for sequential or simultaneous capturing of sides. In inspection equipment involving dies transported on trays, it is possible for 4 sides to be inspected using: (a) 1 system with 4 distinct channels of illumination; (b) using two separate systems (with separate illumination) to be deployed in one location, for each system to inspect two distinct pairs of the ROI; or (c) using two separate systems in two separate locations to inspect two distinct pairs of the ROI.

[130] As described, the HSTM system continuously loads a die for inspection at the load station, inspects a die at the first inspection station, inspects a die at the second inspection station and unloads an inspected die at the unload station as the turret is indexed from one index position to the next. In addition, the system can be configured to analyze the images of the inspected die to classify it prior to unloading. This enables high speed inspection of dies.

#### **SIMULTANEOUS INSPECTION OF ROIs ON OPPOSING SIDEWALLS OF MULTIPLE DIES**

[131] Figs. 7b1 and 7c1 show another embodiment of an inspection system with first and second inspection systems 700b-c for first and second inspection stations implemented at different locations of an equipment to simultaneously inspect ROIs at opposing sidewalls of multiple dies gang-picked by a gang pick-and-place (PNP) unit from dies arrayed in rows and

columns on a die carrier. The die carrier may be, for example, a tray. For example, the first inspection system 700b of Fig. 7b1 is configured to simultaneously inspect a first set of opposing sidewalls 322<sub>1</sub> and 322<sub>3</sub> of multiple dies and the second inspection system 700c of Fig. 7c1 is configured to simultaneously inspect a second distinct set of opposing sidewalls 322<sub>2</sub> and 322<sub>4</sub> of multiple dies.

[132] Referring to Figs. 7b1 and 7c1, a die carrier or tray 722 containing multiple dies is provided to the system for inspection of opposing side walls of multiple dies. For example, the die trap is transported to the system. The die carrier or tray may be a Joint Electronic Device Engineering Counsel (JEDEC) compliant tray (JEDEC tray). Other types of die carriers or trays may also be useful. The tray is configured to hold a matrix of dies arranged in rows and columns (MxN matrix). As shown, the tray is a 4x8 tray, holding 4 rows and 8 columns of dies. Other sized-matrix for the tray may also be useful.

[133] The tray may be held and transported by a tray holder, for example, by a translatable and rotatable tray holder. For example, the tray holder may be configured to translate in any direction along the x-y plane as well as being able to rotate the tray. This facilitates moving the tray to the inspection stations, including unloading the dies from the tray and loading the inspected dies onto the tray, and transporting the tray with the fully inspected dies to the sorting station for sorting. The tray may be held onto the tray holder by a physical gripper, vacuum pressure or a combination thereof. Other techniques for holding the tray to the tray holder may also be useful.

[134] Furthermore, it is understood the inspection system may include a plurality of tray holders for continuous inspection of trays of dies. For example, after the dies of the first tray has been inspected at the first inspection station, the first tray is moved to the second inspection station for inspecting the second set of sidewalls of the dies. The first and second inspection stations are at first and second locations of the equipment. A second tray is moved

to the first inspection station for inspection dies thereon while the dies of the first tray are being inspected at the second inspection station. This means that dies at the first inspection station and dies at the second inspection system may be simultaneously and independently inspected to ensure high throughput. After inspection is completed for dies at the second inspection station, the first tray is moved to the sorting station for sorting. After the inspection of the dies of the second tray is completed at the first inspection station, the second tray is moved to the second inspection station. A third tray is moved to the first inspection station. The process continuously inspects and sorts the dies on the trays.

[135] To improve throughput at each of these first and second inspection stations, it is possible to deploy two gang PNP units at each of these stations. For example, an inspection system may be provided with a gang PNP unit A and a gang PNP unit B. The gang PNP units A and B can be configured to operate together to improve throughput. For example, one gang PNP unit, such as gang PNP unit A, picks a row/column of new dies from the tray and transfers them to the inspection platform. While gang PNP unit A is loading the dies onto the inspection platform, the other gang PNP unit, such as gang PNP unit B, is positioned over the tray and is free to pick the next row of dies on standby. The inspection system inspects the loaded dies for the current ROIs and after inspection, gang PNP unit A retrieves the inspected dies from the pedestals and returns them to the tray at their original positions. While gang PNP unit A is unloading, gang PNP unit B begins loading the next set of dies onto the same pedestals.

[136] Having unloaded the previous batch of dies back to the tray, gang PNP unit A will pick the next row for standby loading to the pedestal. At no point are the pedestals idle, ensuring continuous operation. This cycle continues with higher throughput until all the dies of the tray are inspected. It is possible to deploy two gang PNP and two pedestals as well which can increase throughput even more as one skilled in the art can configure.

[137] Referring to Fig. 7b1, the first inspection system 700b includes a first inspection unit 707 configured to inspect a first set of opposing sidewalls of a plurality of dies. The first inspection unit may be similar to the inspection system described in Fig. 5a or Fig. 5b. For example, the inspection system includes a camera unit, an illumination unit and an optical sub-system 770. The IR illuminator should have a wide bandwidth of between 800- 2500 nm. The optical sub-system is configured to direct illumination to inspect opposing sides 322<sub>1</sub> and 322<sub>3</sub> of multiple dies disposed on a first inspection platform 750 located in an inspection position 752. To illuminate multiple dies, the illumination unit is configured to generate an elongated collimated illumination beam and the optical sub-system is adapted with elongated reflectors and an elongated prism (e.g., similar to reflectors 574<sub>1-2</sub>, 584<sub>1-2</sub> and 586 of Fig. 5a or Fig. 5b) are employed. For example, one or more collimators may be employed to collimate the IR illumination for the illumination unit. In addition, filters may be used to prevent illumination from one channel from entering another channel to the ROIs at opposing sides of the dies to reduce or eliminate crosstalk.

[138] The illumination and image units may be an integrated unit, as described in Fig. 6a or 6b, except that it is configured to illuminate and image the ROIs of opposing sidewalls of multiple dies.

[139] In the case the FOV of the camera unit is insufficient to image the ROIs of the multiple dies on the inspection platform, multiple camera units may be employed to ensure the ROIs of the multiple dies are captured. In such cases, multiple image captures are performed. On the other hand, a single image capture is used if the FOV of the camera unit is sufficient to image the ROIs of the multiple dies.

[140] Prior to inspection, the system is adjusted or configured to inspect opposing ROIs of multiple dies based on the dimension of the dies. For example, the system is adjusted to inspect ROIs at opposing sides 322<sub>1</sub> and 322<sub>3</sub> of the dies, as previously discussed, such as in

Figs. 5a-5b. For example, the optical module (e.g., module with reflectors and prism) of the optical sub-system may be adjusted in the z-direction with respect to the inspection platform.

[141] The first inspection platform 750 includes a plurality of first pedestals for holding a plurality of dies. For example, the first inspection platform is configured with P first pedestals for holding P dies for inspection, where P is a whole number greater than 2. Typically P may be from 4-8. Providing P having other values may also be useful. Each first pedestal is configured to translate and rotate to correctly orient (x-y- $\theta$  alignment) the die thereon for inspection. This helps to reduce interference in the image captured of the ROIs of multiple dies.

[142] The inspection platform includes first inspection partitions 758 disposed between first pedestals. The inspection partitions separate adjacent dies from each other. The inspection partitions, along with the use of collimated IR illumination, help to prevent illumination reflected from a die from interfering with light reflected from another die when the reflected illumination is traveling to the image capture device.

[143] The first inspection platform 750 is configured to move between a first inspection position 752 for inspecting the dies to a first inspection load/unload (L/U) position 754 where dies are loaded or unloaded from the inspection platform. For example, dies are loaded at the L/U position and then moved to the inspection position for inspection. After inspection, the first inspection platform moves to the L/U position for unloading the inspected dies. As shown, the first inspection platform is configured to translate in the y-direction between the inspection and inspection L/U positions.

[144] The first inspection system also includes a first gang PNP unit 732. The first gang PNP unit is configured to pick up a plurality of dies from a tray 722 which are presented for inspection. The first gang PNP unit may be configured to pick up P dies from the tray. For example, the first gang PNP unit is configured to pick up the same number of dies as the

number of pedestals in the first inspection platform. As discussed, the first inspection system may be deployed with two gang PNP units and/or 2 inspection platforms.

[145] As discussed, the tray is configured to hold a  $M \times N$  matrix. As shown,  $M$  corresponds to the row direction and  $N$  corresponds to the column direction. Other configurations of the matrix may also be useful. The gang PNP unit may preferably be configured to pick up a column of dies. For example, in the case of a matrix of dies is a  $4 \times 8$  matrix, there are 4 rows and 8 columns. A column of dies is equal to 4 dies. For example,  $P = M$ . Other configurations of the gang PNP unit and trays may also be useful. For example,  $P$  need not be a factor of  $M$  or  $N$ .

[146] The tray is presented for inspection at a tray L/U position 721 of the first inspection system. The first gang PNP unit may be mounted on a translatable frame, enabling the gang PNP unit to move between the first tray L/U and first inspection L/U positions. For example, the translatable frame is an x-y translatable frame to enable the first gang PNP unit to move in the x-y plane between the tray and first inspection L/U positions. As shown, the tray is presented in a first orientation. For example, the first orientation has the row direction parallel to the x-direction, which is orthogonal to the direction of the movement of the inspection platform, which is in the y-direction. Other configurations of the orientation of the tray with respect to the translational direction of the inspection platform may also be useful.

[147] The components of the first inspection system, such as the first inspection unit, the first inspection L/U position, the first gang PNP unit and tray L/U position, including the orientation of the die tray, are configured to maximize inspection throughput. For example, for the first inspection unit, placement of the first inspection L/U position, first gang PNP unit, first tray L/U position are configured to preferably minimize travel distance to maximize inspection throughput. Other configurations of the placement of the different components of the first inspection system may also be useful.

[148] Figs. 7b2-7b7 illustrate an embodiment of a process performed by the first inspection system 700b for inspecting a first set of opposing sides 322<sub>1</sub> and 322<sub>3</sub> of a plurality of dies 120. Referring to Fig. 7b2, the tray in the first orientation is translated in the x-direction (positive x-direction). The die tray is translated in the x-direction such that a column (e.g., first column) of dies are disposed below the gang PNP unit 732. The gang PNP unit picks up the column of dies from the tray 722.

[149] As described in Fig. 7b2, the tray is translated under the first gang PNP unit. Other configurations of disposing the dies of the die tray under the first gang PNP unit may also be useful. For example, the gang PNP unit may be translated (instead of the tray) in the x-direction to pick up the dies from the tray. In this case, the first gang PNP unit is positioned over the dies instead of the die tray being translated.

[150] As shown in Fig. 7b3, after picking up the dies from the tray, the gang PNP unit then transports the dies to the first inspection L/U position. For example, the first gang PNP unit is translated in the y-direction (positive y-direction) to the first inspection L/U position. Likewise, the first inspection platform is translated to the first inspection L/U position. For example, the first inspection platform is extended outward from the first inspection position in the y-direction (negative y-direction) to the first inspection L/U position. The first pedestals of the first inspection platform are positioned under the dies of the first gang PNP unit. The first gang PNP unit places the dies onto the first pedestals.

[151] Once the first gang PNP unit has placed the multiple dies all at once on the corresponding first pedestals of the first inspection platform, each of the dies on the first pedestals is then inspected for orientation. As discussed, each of the pedestals on the inspection platform is configured to be able to correct the orientation of each of the dies independently in the x-y- $\theta$  directions.

[152] An image of the orientation of the dies on the first pedestal is captured and processed for analysis to determine if any adjustments are required for each die. The adjustment information of each die is relayed to a pedestal controller, which carries out the adjustments. Once all the dies on the pedestals have been corrected for orientation, the first inspection platform with the multiple dies retracts to the inspection position, as shown in Fig. 7b4. For example, the first inspection platform with the correctly oriented dies on the first pedestals is retracted in the y direction to the first inspection position.

[153] At the first inspection position, the inspection system inspects the multiple dies. Once inspection is completed, the inspection platform is translated to the inspection L/U position, as shown in Fig. 7b5. Since the gang PNP unit 732 is already at the L/U position (from placing the dies onto the inspection platform prior to inspection), the dies having the first opposing sides inspected are under the gang PNP unit. The gang PNP unit picks up the dies from the inspection platform.

[154] In Fig. 7b6, the gang PNP unit with the dies is translated to the tray. For example, the gang PNP unit is translated in the y-direction (negative y-direction) to over the tray where the dies were picked up (in Fig. 7b2). The gang PNP unit places the dies onto the tray.

[155] After the dies are placed back onto the tray, the tray is translated so the gang PNP unit can pick up the next set of dies for inspection, as shown in Fig. 7b7. For example, the tray is translated in the x-direction (positive x-direction) so the gang PNP unit is under the next set of dies to pick up. After the dies are picked up, the gang PNP unit is translated to the inspection L/U position to place the dies on the inspection platform. The process then continues, as previously described, to inspect the ROIs at the opposing sides of the dies. The process described is repeated until all dies of the tray have been inspected.

[156] After all the dies in the tray in the first orientation have had the first set of opposing side walls 322<sub>1</sub> and 322<sub>3</sub> inspected at the first inspection station, the tray will be

transported to a second inspection station so that the second set of opposing side walls 322<sub>2</sub> and 322<sub>4</sub> can be inspected.

[157] As described, the tray is configured to translate under the gang PNP unit for pick up by the gang PNP unit. For example, the tray is translated in the x-direction. In other embodiments, the tray may be stationary while the gang PNP unit is translated over the tray for picking up a set of dies for inspection. Other configurations of movements by the tray and/or gang PNP unit may also be useful for picking up dies from the tray.

[158] In addition, the arrangement of the various components, such as the inspection unit, inspection L/U position, gang PNP unit and tray L/U position may be rearranged. As discussed, the locations of the components should be strategically configured to maximize inspection throughput. For example, the components are positioned to minimize travel distance between the components.

[159] Fig. 7c1 illustrates the components of the second inspection system 700c at the second inspection station. The second inspection system is similar to the first inspection system. Common components may not be described or described in detail. The second inspection system is configured to inspect

[160] As shown, the second inspection system includes a second inspection unit 707 and a second gang PNP unit 732. The inspection unit includes an inspection system with an illumination unit, image capture unit and an optical sub-system 770 for direction illumination to ROIs at a second set of opposing sides 322<sub>2</sub> and 322<sub>4</sub> of the dies on a second inspection platform 750 at an inspection position 752. As previously discussed, the second inspection station may be configured with 2 gang PNP units and/or 2 inspection platforms.

[161] Prior to inspection, the system is adjusted based on the die dimension of the dies to inspect the ROIs at opposing sides 322<sub>2</sub> and 322<sub>4</sub> of the dies. For example, the optical module

of the optical sub-system 770 may be adjusted in the z-direction with respect to the second inspection platform to inspect the second set of opposing sides 322<sub>2</sub> and 322<sub>4</sub> of the dies.

[162] The second inspection platform includes second pedestals for holding and orienting (x-y-θ) dies thereon. Second inspection partitions 758 are provided on the second inspection platform between second pedestals to separate the second pedestals. The second inspection platform is configured to translate in the y direction between the inspection position and an inspection L/U position 754.

[163] The second inspection system includes a second gang PNP unit 732 configured to pick up a plurality of dies 120 from a tray 722. As shown, the gang PNP unit is configured to translate in the x-direction. The gang PNP unit is positioned adjacent and parallel to the inspection L/U position. For example, the gang PNP unit is translated along the x-direction (positive x-direction) to the inspection L/U position and an opposing x-direction (negative x-direction) to pick up dies from the tray.

[164] The tray transported by the tray holder from the first inspection station is presented at the tray L/U position adjacent and parallel to the gang PNP unit. For example, the gang PNP unit may be translated in the x-direction (negative x-direction) to pick up dies from the tray and then in the opposite x-direction (positive x-direction) to the inspection L/U position 754.

[165] As shown, the tray is presented in a second orientation which has been rotated 90° from the first orientation. For example, the row direction of the tray is in the y-direction and the column direction is in the x-direction. This facilitates inspecting ROIs of a second set of opposing sidewalls 322<sub>2</sub> and 322<sub>4</sub> of multiple dies. The tray may be configured to translate in the y-direction.

[166] Figs. 7c2-7c7 illustrate an embodiment of a process performed by the second inspection system 700c for inspecting a second set of opposing sides 322<sub>2</sub> and 322<sub>4</sub> of a

plurality of dies 120. Referring to Fig. 7c2, the second gang PNP unit 732 is in the x-direction (negative x-direction) until it is over a first set of dies on the die tray. For example, the gang PNP unit is translated until it is over a first set of dies of a first row of the die tray. As shown, the gang PNP unit is only configured to pick up a portion of the first row of dies, for example, the first 4 dies of the first row of dies. The gang PNP unit picks up the first set of dies from the die tray.

[167] As described in Fig. 7c2, the gang PNP unit is translated over the tray 722. Other configurations of aligning the first set of dies under the gang PNP unit may also be useful. For example, the gang PNP unit may be translated (instead of the tray) in the x-direction to pick up the dies from the tray. In this case, the second gang PNP unit is positioned over the dies instead of the tray being translated.

[168] In Fig. 7c3, after picking up the dies from the tray 722, the second gang PNP unit then transports the dies to the first inspection L/U position. For example, the second gang PNP unit is translated in the x-direction (positive x-direction) to the second inspection L/U position. The second inspection platform is also translated to the second inspection L/U position. For example, the second inspection platform is extended outward from the second inspection position in the y-direction (negative y-direction) to the second inspection L/U position. The second pedestals of the second inspection platform are positioned under the dies of the second gang PNP unit. The second gang PNP unit places the dies onto the second pedestals.

[169] After placing the multiple dies on the corresponding second pedestals of the second inspection platform, each of the dies on the second pedestals is then inspected for orientation. As discussed, each of the pedestals on the inspection platform is configured to be able to correct the orientation of each of the dies independently in the x-y- $\theta$  directions.

[170] Orienting the dies includes capturing an image of the orientation of the dies on the second pedestals and processing it for analysis to determine if any adjustments are required

for each die. The adjustment information of each die is relayed to a pedestal controller, which carries out the adjustments. Once all the dies on the pedestals have been corrected for orientation, the second inspection platform with the multiple dies retracts to the inspection position, as shown in Fig. 7c4. For example, the second inspection platform with the correctly oriented dies on the second pedestals is retracted in the y direction to the second inspection position.

[171] At the second inspection position, the second inspection system inspects the multiple dies. Once inspection is completed, the second inspection platform is translated to the second inspection L/U position, as shown in Fig. 7c5. Since the second gang PNP unit 732 is already at the L/U position (from placing the dies onto the inspection platform prior to inspection), the dies having the second set of opposing sides inspected are under the second gang PNP unit. The second gang PNP unit picks up the dies from the inspection platform.

[172] In Fig. 7c6, the gang PNP unit with the dies is translated to the tray. For example, the gang PNP unit is translated in the x-direction (negative x-direction) to over the tray where the dies were picked up (in Fig. 7c2). The second gang PNP unit places the dies onto the tray.

[173] After the dies are placed back onto the tray, the second gang PNP unit is translated so that it can pick up the next set of dies for inspection, as shown in Fig. 7c7. As shown, the tray is translated in the x-direction (positive x-direction) so the gang PNP unit is under the next set of dies to pick up in the second row of dies. After the dies are picked up, the second gang PNP unit is translated to the second inspection L/U position to place the dies on the second inspection platform. The process then continues, as previously described, to inspect the ROIs at the second set of opposing sides of the dies. The process described is repeated until all dies of the tray have been inspected. This completes the inspection of the dies on the tray. For example, the dies of the trays have all four sides 322<sub>1-4</sub> inspected.

[174] After all the dies in the tray have had the second set of opposing side walls 322<sub>2</sub> and 322<sub>4</sub> inspected at the second inspection station, inspection of the dies is completed. The tray will be transported to a sorting station where they will be sorted based on the results of the inspection.

[175] As described, the tray is configured to be stationary while the second gang PNP unit translates over the dies of the tray for pickup. When all rows are complete, the tray may be translated in the y-direction for pickup by the gang PNP unit of other sets of dies of the rows. For example, the tray is translated in the y-direction (positive y-direction) for picking up another set of dies of the rows of dies. Other configurations of picking up the dies of the tray by the second gang PNP unit may also be useful,

[176] In addition, the arrangement of the various components, such as the inspection unit, inspection L/U position, gang PNP unit and tray L/U position may be rearranged. As discussed, the locations of the components should be strategically configured to maximize inspection throughput. For example, the components are positioned to minimize travel distance between the components.

[177] Fig. 7d shows another embodiment of an inspection system 700d at, for example, the second inspection station. The inspection system is similar to the inspection system of Figs. 7b1-7b7 and 7c1-7c7. Common elements may not be described or described in detail.

[178] As shown, the tray 722 is transported to the second inspection station still in the first orientation. For example, unlike in Figs. 7c1-7c7, the tray holder does not rotate the tray to the second orientation. For example, the rows of dies of the tray are oriented along the x-direction. However, the second inspection unit 707, the second inspection L/U position 754 and the second gang PNP unit 732 are re-positioned or re-orientated to be along or parallel to the x-direction. For example, the rows of dies of the die tray are parallel to the second inspection unit, the second inspection L/U position and the second gang PNP unit.

[179] The inspection system is configured to inspect the ROIs at the second set of opposing sidewalls 322<sub>2</sub> and 322<sub>4</sub>. For example, the height of the optical module of the optical sub-system is adjusted so that the FOV of the second inspection system can cater to the width of the side walls 322<sub>1</sub> and 322<sub>3</sub> to ensure that the illumination will be directed to the ROIs of the opposing sidewalls 322<sub>2</sub> and 322<sub>4</sub>.

[180] As described, the first inspection system is configured to inspect a column of dies of the die tray and the second inspection system is configured to inspect a portion of a row of dies of the die tray. Alternative configurations, such as inspecting rows of dies by the first inspection station and columns of dies by the second inspection station, may also be useful.

[181] Furthermore, the gang PNP unit is configured to have the same number of pick and place (PNP) heads as the number of dies in a column. It is understood that the number of PNP heads for the gang PNP unit need not be the same or a factor of the number of dies in a row of dies or a column of dies. Each inspection station is configured to inspect all the dies on the trays.

[182] In addition, it is understood that the components of the first and second inspection systems of the first and second inspection stations can have other configurations. As already discussed, the components are preferably arranged to facilitate high inspection throughput. For example, the components are arranged to minimize travel distances between the components.

[183] As previously discussed, the sequential inspection of a first set of opposing sidewalls 322<sub>1</sub> and 322<sub>3</sub> at one station, followed by the other set of opposing sidewalls 322<sub>2</sub> and 322<sub>4</sub> at another station ensures that a series of trays with dies can be simultaneously inspected at the two stations as the trays are continuously fed to the equipment, ensuring higher throughput.

[184] In other embodiments, in the case that the dies of the tray are rectangular, the second set of opposing sidewalls of the tray may be inspected by the first inspection system. For example, the first inspection system can be configured to inspect both the first and second sets of opposing sidewalls. This can easily be achieved by controlling the pedestals to rotate the dies by 90°. In such cases, both the first and second inspection systems may perform inspection of different trays of dies simultaneously.

[185] Fig. 8 shows a simplified block diagram of the system architecture 800 of an embodiment of the inspection system. The system, for example, may be a HSTM, as shown in Fig. 7a.

[186] Referring to Fig. 8, the system architecture includes an inspection control module 810, an inspection module 840, a turret module 850, a load module 885, an unload module 895 and a PNP module 875. In one embodiment, the turret module includes a turret which is configured to rotate. The turret, for example, is rotatable around the z-axis. The turret may rotate, for example, in a clockwise direction. Alternatively, the turret may rotate in the counterclockwise direction. The turret is configured to rotate in steps, for example, from one index position to the next. Other configurations of rotating the turret may also be useful. A plurality of die holders are located at the periphery of the turret. A die holder is configured to hold a die on the turret as it is rotated. The die holder may be configured to hold the die using, for example, vacuum pressure.

[187] The PNP module 875 includes PNP heads. The PNP heads may be disposed at the periphery of the turret. For example, the PNP heads are positioned above the periphery of the turret. The PNP heads may be located at index positions of the turret. Other configurations of PNP heads may also be useful. A PNP head is configured to move in z-direction.

[188] The load module 885, for example, may be located at a load station. The load station may be located at a load index position. The load module includes a loader with a load

pedestal. The load module is configured to load a die onto the die holder. For example, a die from a die tray may be positioned onto the load pedestal by the loader. The pedestal is then extended for a load PNP head to pick the die up. The pedestal is then retracted away from the turret followed by the load PNP head placing the die onto the die holder. The pedestal includes an extendable or retractable module in the x-y plane.

[189] The unload module 895 may be located at an unload station, which may be located at an unload index position. The unload module includes an unloader with an unload pedestal. The unload module is configured to unload a die from a die holder. For example, the unload module unloads an inspected die from the turret. The inspected die may be classified as passing or failing inspection. A die that passed inspection may be dropped in a passed inspection bin while a die that failed inspection may be dropped in a failed inspection bin. Other configurations of the unload module may also be useful.

[190] The inspection module 840, in one embodiment, is configured with first and second inspection systems 860<sub>1-2</sub> located at first and second inspection stations at first and second inspection index positions. An inspection system, as shown, includes an optical sub-system 870, an illumination unit 880 and a camera unit 890. The optical sub-system, the illumination unit and camera unit may be similar to those described in, for example, Figs. 5a-5f.

[191] Referring back to Fig. 8, the optical sub-system 870, for example, includes an optical module and an optical unit. The optical sub-system 870 is configured to direct light from the illumination unit 880 to the ROIs. For example, light is directed to the ROIs of a pair of sidewalls of a die. In one embodiment, the optical sub-system 880 of the first inspection system 860<sub>1</sub> is configured to direct illumination to inspect a first set of sidewalls of the die at the first inspection station while the optical sub-system 880 of the second inspection station 860<sub>2</sub> is configured to direct illumination to inspect a second set of distinct sidewalls of the die.

In one embodiment, the first and second sets of sidewalls are first and second sets of adjacent sidewalls of the die. Alternatively, the first and second sets of sidewalls are first and second sets of opposing sidewalls. Other configurations of the inspection systems may also be useful.

[192] An optical sub-system 870, in one embodiment, includes a motorized unit for raising and lowering it (in the z-direction) to adjust for the size of the die. This enables the HSTM to accommodate inspecting different-sized dies. In one embodiment, the optical module of the optical sub-system is motorized to raise or lower it to accommodate different-sized dies. In other embodiments, the inspection pedestal may be adjusted in the z-direction to adjust for the size of the die. In yet other embodiments, both the pedestal and optical module may be moved in the z-direction to accommodate different die sizes.

[193] As for the camera unit 890, it may include a motor to move the camera along the z-direction for auto-focusing. Auto-focus may include the camera capturing a sequence of images while moving in the z-direction in fine steps. The images at the various z-steps are analyzed. An inspection algorithm is used to determine the best focus position based on the images. The best focus position may be based on a set of criteria in accordance with the inspection algorithm.

[194] The inspection control module, in one embodiment, is configured to control the operation of the HSTM. For example, the control module controls the various modules of the system to effect inspection of dies. This may include controlling the turret module to rotate the turret in steps as well as the die holders of the turret, the loader to load a die onto a die holder on the turret at the load station, the inspection systems for inspecting the dies on the die holders on the turret at the inspection stations and the unload module to unload a die from the die holder on the turret at the unload station. In one embodiment, the system may include an analytics module (not shown). The analytics module may perform analytics on the inspection results to determine whether a die has passed or failed inspection.

[195] In one embodiment, the inspection control module 810 includes a user interface 813 and a processor unit 815. The processor unit 815 may include one or more processors for processing information and controlling the operation of the HSTM. The processor unit may include storage or memory for storing programs and results. Other configurations of the processor unit may also be useful. The inspection control module 810, for example, may include receiving input information for setting up the system for inspection, rotating the turret with the die holders in steps, loading the dies, inspecting the dies, unloading the dies, as well as analyzing and classifying the results of the inspection.

[196] In one embodiment, the user interface 813 enables a user to input parameters of the inspection, such as the dimension of the die, defect size, defect contrast and seal ring pattern template for comparison. In one embodiment, the seal ring pattern template is the actual seal ring pattern without defects. Other input parameters pertinent to the inspection may also be useful. The user interface may also be configured to display the images captured during the inspection as well as the results of the analysis.

[197] The system may be set up or configured based on input parameters, such as die dimensions. For example, the system is set to the correct z-position to capture the ROIs of the die based on the die dimensions input by the user. This may include setting the optical modules of the inspection systems, die holders, or turret in the correct z-position. Alternatively, any combination of the optical modules, die holders and the turret is set in the correct z-position. Auto-focusing may also be performed during setup. In some embodiments, auto-focusing is performed prior to each inspection.

[198] During operation, the processor unit 815 controls the load module 885 to cause the loader to load dies onto the die holders on the turret at the load station. For example, as the turret is rotated in steps, each time a die holder is rotated to the load station, a die is loaded by the loader thereon. When a die on a die holder reaches an inspection station, the processor unit

controls the inspection unit to capture images of the ROIs on a first pair of distinct sides. The orientation of the die may be checked and adjusted, as necessary, to inspect first and second ROIs on the die. The first and second ROIs may be located at adjacent sides or opposing sides of the die. After the die is inspected at the first inspection station, the turret is rotated. When the die reaches the second inspection station, a second pair of distinct sides are inspected, completing the die inspection. It is understood that there may be more than one step of rotation from the first inspection station to the second inspection station. Depending on the setup, an inspection system may be configured to capture two sides simultaneously or sequentially.

[199] The images of the ROIs of the die are analyzed by the analytics module and the image and results may be displayed on the user interface. The analytics module may be integrated into the control module 810. For example, the processor unit 815 may be configured to execute a program for analyzing the images. In some embodiments, the analytics module may include an artificial intelligence (AI) program or analyzer to analyze the image or images captured to determine whether the die passes or fails inspection. For example, the AI may analyze the image to determine if defects cause a failure or pose a potential failure. The AI, in principle, includes an inspection algorithm to handle multiple images captured by the inspection system to determine defects and to reject bad dies and or accept good dies. Machine learning tools can be used to train to detect and classify defects using intelligent algorithms to reduce false alarms.

[200] When an inspected die reaches the unload station, the processor unit 815 controls the unloader to remove the inspected die from the die holder. Depending on whether the die passed or failed inspection, it is placed in the passed inspection bin or failed inspection bin. During operation, the system rotates the turret and continuously loads, tests, analyzes and unloads dies as it is stepped through the rotation at the appropriate stations.

[201] As described, the architecture is that of an HSTM, such as that described in Fig. 7. In such an architecture, dies are continuously loaded at the load station, inspected at the inspection stations and unloaded at the unload station as the turret is stepped through the rotation. The minimum number of die holders or steps is equal to the number of stations. Of course, more die holders or steps may be implemented for the turret. Other configurations of the HSTM, such as other numbers of inspection stations may also be useful.

[202] In other embodiments, the inspection system may be a non-HSTM system. For example, the system may include a die holder for holding a single die and first and second inspection systems configured to each image a distinct pair of internal sidewalls of the die. The distinct pair of internal sidewalls may be adjacent internal sidewalls or opposing sidewalls. The inspection systems may be configured to image the sidewalls simultaneously, sequentially or a combination thereof. For example, a first pair of distinct internal sidewalls may be imaged simultaneously, followed by simultaneously imaging the second pair of distinct internal sidewalls. Alternatively, each internal sidewall is imaged sequentially. Other configurations of imaging the internal sidewalls may also be useful.

[203] Fig. 9 shows an embodiment of a process flow 900 for setting up a system for inspecting internal die sidewalls. The setup process flow may be for first and second inspection systems at first and second inspection stations for the HSTM of Fig. 7. At 910, the user inputs test parameters for inspecting the dies. The user, for example, inputs the test parameters in a user interface of a control module which includes a processor. Other techniques for providing the test parameters to the inspection system may also be useful. The test parameters may include, for example, the dimension of the die, defect size, defect contrast, seal ring pattern template for comparison. Other types of test parameters may also be useful.

[204] At 920, the processing unit adjusts the z-position of the die relative to the optical sub-system of the first inspection system according to the die size parameter input by the user.

For example, the processing unit may adjust the z-position of the optical module relative to the die on the die holders according to the die size parameter. Alternatively, the z-position of the die holders or pedestals on the turret may be adjusted according to the die size parameter. In other embodiments, the z-position of the turret may be adjusted according to the die size parameter. Adjusting the z-positions of the optical module and the die holders or the optical module and the turret based on the die size parameter may also be useful.

**[205]** After the z-position of the die relative to the optical sub-system has been adjusted, the processor commences to perform auto-focusing of the camera. In one embodiment, the camera unit is set at a first (e.g.,  $n=1$ ) z-position of a plurality of z-positions at 930. The number of z-positions should be sufficient to enable focusing according to the system. Based on the test parameters, the process performs setup procedures on the inspection system. The setup procedures of the system, in one embodiment, include adjusting the distance in the z-direction between an optical module of an optical sub-system of an inspection module and the die. In one embodiment, the optical module may be adjustable in the z-direction. In another embodiment, the die holder may be adjustable in the z-direction. In yet another embodiment, both the optical module and die holder are adjustable in the z-direction.

**[206]** At 940, a test image of the ROIs is captured. For example, a first pair of distinct internal die sidewalls is imaged. The first pair of distinct internal die sidewalls may be adjacent internal die sidewalls or opposing internal die sidewalls. After the test image is captured,  $n$  is incremented. For example,  $n = n + 1$ .

**[207]** The setup process proceeds to 950 to determine if the camera has taken a test image at all  $z$  positions. For example, the processor determines if  $n$  is greater than the last  $z$ -position. If  $n$  is not greater than the last  $z$ -position, the process returns to 930 where the camera is adjusted to the next  $z$ -position and captures an image at 940. The process repeats from 930 to 950 until test images are captured of the internal die sidewalls at all  $z$ -positions.

[208] After test images are captured from all z-positions, the process proceeds to 960 for analyzing the test images. For example, the processing unit analyzes the test images to determine the test image with the best focal length. The camera is moved to the z-position corresponding to the image with the best focal length at 970. At 980, the setup process is repeated for the second inspection system at the second inspection station. For example, 920 to 970 is repeated. The setup process is completed after the second inspection system at the second inspection station is set up. Once setup is completed, inspection (production inspection) commences at 970.

[209] The process, as described, may be applied to the HSTM of Fig. 7 with two inspection systems at two inspection stations, each performing 2-sided inspections of two distinct pairs of internal die sidewalls. Other configurations of inspection systems may also be employed by the HSTM. For example, 1-sided inspection systems can be employed. In such an embodiment, the HSTM includes 4 inspection systems at 4 inspection stations, each imaging one distinct internal die sidewall. Providing an HSTM with a combination of 1-sided and 2-sided inspection systems may also be useful. The setup process flow may also be applied to non-HSTM.

[210] The inventive concept of the present disclosure may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments, therefore, are to be considered in all respects illustrative rather than limiting the invention described herein. The scope of the invention is thus indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are intended to be embraced therein.

What is claimed is:

#### CLAIMS

1. A die inspection system comprising:  
an inspection module, the inspection module includes  
an illumination module for generating collimated illumination to  
illuminate a region of interest (ROI) at an internal die sidewall of the die, the  
ROI includes a grooving kerf and a die seal ring surrounding core circuitry of  
the die, wherein the illumination has an inspection bandwidth which is  
transparent to a substrate of the die,  
an image capture module,  
an optical sub-system for  
directing the collimated illumination from the  
illumination module through an inactive surface of the die at an  
angle  $\theta$  with respect to an orthogonal axis of the inactive  
surface of the die to the ROI, and  
directing internally reflected illumination from the ROI  
to the image capture module to image the ROI, and  
wherein the image detects the presence of and extent that cracks, if  
any, extend internally toward and beyond the seal ring of the die in the ROI.
2. The inspection system of claim 1, wherein the inspection bandwidth for a silicon die  
substrate comprises 1100-2500 nm.
3. The die inspection system of claim 1 wherein the angle  $\theta$  is about 35-65°.

4. The die inspection system of claim 1, wherein:  
the optical sub-system is configured to  
direct the collimated illumination to inspect first and second ROIs at  
first and second internal die sidewalls of the die, wherein the collimated  
illumination is through the inactive surface of the die at the angle  $\theta$  with  
respect to the orthogonal axis of the inactive surface of the die to the first and  
second ROIs;  
direct reflected illumination from the first and second ROIs to the  
image capture module to image the first and second ROIs in a single image  
capture, and  
wherein the image detects the presence of and extent that cracks, if  
any, extend internally toward and beyond the seal ring of the die in the first  
and second ROIs.
5. The die inspection system of claim 4, wherein the first and second internal die  
sidewalls are opposing internal die sidewalls of the die.
6. The die inspection system of claim 4, wherein the first and second internal die  
sidewalls are adjacent internal die sidewalls of the die.
7. A die inspection system comprising  
a first inspection module, the first inspection module includes  
a first illumination module for generating a first illumination  
a first image capture module, and  
a first optical sub-system, the first optical sub-system is configured to

direct the first illumination to inspect a first pair of first and second ROIs at first and second internal die sidewalls of a 4-sided die, through the inactive surface of the die at the angle  $\theta$  with respect to the orthogonal axis of the inactive surface of the die to the first and second ROIs, and

direct internally reflected first illumination from the first and second ROIs to the first image capture module to capture a first image the first and second ROIs in a first single image capture, and

wherein the image of the first and second ROIs detects the presence of and extent that cracks, if any, extend internally toward and beyond the seal ring of the die in the first and second ROIs; and

a second inspection module, the second inspection module includes

a second illumination module for generating a second illumination

a second image capture module, and

a second optical sub-system, the second optical sub-system is

configured to

direct the second illumination to inspect a remaining or second pair of third and fourth ROIs at the third and fourth internal die sidewalls of the 4-sided die, through the inactive surface of the die at the angle  $\theta$  with respect to the orthogonal axis of the inactive surface of the die to the third and fourth ROIs, and

direct internally reflected second illumination from the third and fourth ROIs to the second image capture module to capture a second image of the third and fourth ROIs in a second single image capture, and

wherein the second image of the third and fourth ROIs detects the presence and extent that cracks, if any, extend internally toward and beyond the seal ring of the die in the third and fourth ROIs.

8. The die inspection system of claim 7, wherein:

the first inspection module and second inspection module are deployed as separate first and second inspection stations on a High Speed Turret Machine (HSTM) where a plurality of pick-and-place (PNP) heads disposed at the periphery of a turret, the PNP heads are configured to each hold a die, the turret is configured to rotate to provide a series of dies sequentially to the first and second inspection module; and

where

at the first inspection station, the first pair of ROIs of the first and second internal die sidewalls of each of the dies on the turret are sequentially inspected by the first inspection module and then returned to the PNP for onward transport to the second inspection station, and

at the second inspection station, the second pair ROIs of the third and fourth internal die sidewalls of each of the dies are inspected by the second inspection module and then returned to the PNP for onward transport to other process stations.

9. The die inspection system of claim 8, wherein:

the first pair of ROIs inspected at the first inspection station are from the first and second opposing internal die sidewalls of the die at the first inspection station; and

the second pair of ROIs inspected at the second inspection station are the remaining third and fourth opposing internal die sidewalls of the die at the second inspection station.

10. The die inspection system of claim 8, wherein:

the first pair of ROIs inspected at the first inspection station are from the first and second adjacent internal die sidewalls of the die at the first inspection station; and

the second pair of ROIs inspected at the second inspection station are the remaining third and fourth adjacent internal die sidewalls of the die at the second inspection station.

11. The inspection system of claim 7 comprises:

a turret configured to rotate in a first direction around a z-axis, the turret comprises a plurality of pick and place (PNP) die holders disposed at a periphery of the turret, each PNP die holder is configured to hold a die;

the first inspection module is positioned below the turret at a first index position of the turret and the first inspection module is configured to inspect ROIs of the first pair of internal sidewalls of the die of the PNP die holder at the first index position;

the second inspection module is positioned below the turret at a second index position of turret, the second inspection module is configured to inspect ROIs of the second pair of internal sidewalls of the die of the PNP die holder at the second index position;

after an image of ROIs of the first pair of the internal sidewalls has been inspected, the die is returned to beneath the PNP die holder at the first index position for the PNP die holder to pick up the inspected die; and

while, at the same time, the second inspection module positioned below the second index position sequentially carries out the second inspection on the die of the PNP die holder at the second index position which has already undergone inspection by the first inspection module.

12. The die inspection system of claim 11 comprises a load station at a load index position, wherein the load station comprises a load pedestal, the load pedestal is configured to:

extend and retract in the x-y plane;

hold a die and extend under the PNP die holder at the load index position for pick up by the PNP die holder at the load index position; and

retract away from under the PNP die holder at the load index position.

13. The die inspection system of claim 11 wherein the first index position comprises a first inspection pedestal, the first inspection pedestal is configured to:

extend and retract in the x-y plane;

extend to under the PNP die holder at the first index position;

receive the die from the PNP die holder at the first index position;

rotate around a z-axis to correctly orient the die for inspection;

retract to the first inspection module for inspection; and

extend to under the PNP die holder at the first index position after inspection is completed for pickup by the PNP die holder at the first index position.

14. The die inspection system of claim 11 wherein the second index position comprises a second inspection pedestal, the second inspection pedestal is configured to:

extend and retract in the x-y plane;  
extend to under the PNP die holder at the second index position;  
receive the die from the PNP die holder at the second index position;  
rotate around a z-axis to correctly orient the die for inspection;  
retract to the second inspection module for inspection; and  
extend to under the PNP die holder at the second index position after inspection for pickup by the PNP die holder at the second index position.

15. The die inspection system of claim 11 comprises an unload station at an unload index position, wherein the unload station comprises an unload pedestal, the unload pedestal is configured to:

extend and retract in the x-y plane;  
extend under the PNP die holder at the unload index position, wherein the die of the PNP die holder at the unload index position has already been inspected by the first and second inspection modules;  
receive the die from the PNP die holder at the unload index position; and  
retract away after it has received the die.

16. The inspection system of claim 7 wherein:

the first illumination unit is configured to generate a first collimated illumination having an inspection band for inspecting the first and second ROIs;

the first optical sub-system comprises first filters configured to separate the first collimated illumination into first and second first illumination sub-bands within the first inspection bands to prevent crosstalk when inspecting the first and second ROIs;

the second illumination unit is configured to generate a second collimated illumination having the inspection band for inspecting the third and fourth ROIs; and

the second optical sub-system comprises second filters configured to separate the second collimated illumination into third and fourth second illumination sub-bands within the inspection band to prevent crosstalk when inspecting the third and fourth ROIs.

17. A die inspection system comprising:

a first inspection module disposed at a first inspection station of the inspection system; and

the first inspection module includes

a first illumination module for generating a first illumination for imaging first and second regions of interest (ROIs) at first and second opposing internal die sidewalls of a plurality of dies at the first inspection station arranged in a line, the first and second ROIs include a grooving kerf and a die seal ring surrounding core circuitry of the dies,

a first image capture module,

a first optical sub-system for

directing the first illumination from the first illumination module through an inactive surface of the dies at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the dies to the first and second ROIs of the dies, and directing reflected first illumination from the first and second ROIs to the first image capture module to produce a first image the first and second ROIs of the dies at the first inspection station, and

wherein the first image detects an extent that cracks, if any, extend internally toward and beyond the seal ring of the dies in the first and second ROIs.

18. The die inspection system of claim 17 further comprises a second inspection module disposed at a second inspection station of the inspection system; and

the second inspection module includes

a second illumination module for generating a second illumination for imaging third and fourth ROIs at third and fourth opposing internal die sidewalls of a plurality of dies at the second inspection station arranged in a line, the third and fourth ROIs include the grooving kerf and the die seal ring surrounding core circuitry of the dies,

a second image capture module,

a second optical sub-system for

directing the second illumination from the second illumination module through an inactive surface of the dies at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the dies to the third and fourth ROIs of the dies, and

directing reflected second illumination from the third and fourth ROIs to the second image capture module to

produce a second image the third and fourth ROIs of the dies,

and

wherein

the second image detects an extent that cracks, if any, extend internally toward and beyond the seal ring of the dies in the third and fourth ROIs, and

the first and second inspection modules of the first and second inspection stations complete inspection of first, second, third and fourth ROIs of the dies.

19. The die inspection system of claim 18 wherein:

first components of the first inspection station are configured to maximize throughput of the first inspection station by minimizing travel distance among the first components; and

second components of the second inspection station are configured to maximize throughput of the second inspection station by minimizing travel distance among the second components.

20. The die inspection system of claim 18 wherein:

the first inspection station further comprises

a first inspection platform with a plurality of first inspection pedestals in a first load region of a first inspection area, the plurality of first inspection pedestals can be extended and retracted in an x-y plane, wherein

when extended, the inspection pedestals are in a first load position of the inspection area for receiving the plurality of dies, and

when retracted the inspection pedestals are in a first inspection position of the first inspection area for inspecting the plurality of dies, and

the first pedestals are configured to rotate the dies around a z-axis to correctly orient the dies for inspection; and

a first gang pick-and-place (PNP) unit, the first gang PNP unit is configured to pick up the plurality of dies from a tray transported to a first inspection area of the first inspection in a first orientation, translate to the first load region to place the dies onto the pedestals,

pick up the dies from the first pedestals after inspection by the first inspection module, and

place the dies onto the tray transported to the first inspection station in tray positions from where they were picked up; and

the second inspection station further comprises

a second inspection platform with a plurality of second inspection pedestals in a second load region of a second inspection area, the plurality of second inspection pedestals can be extended and retracted in an x-y plane, wherein

when extended, the second inspection pedestals are in a second load position of the second inspection area for receiving the plurality of dies, and

when retracted the inspection pedestals are in a second inspection position of the second inspection area for inspecting the plurality of dies, and

the second pedestals are configured to rotate the dies around a z-axis to correctly orient the dies for inspection; and

a second gang pick-and-place (PNP) unit, the second gang PNP unit is configured to

pick up the plurality of dies from a tray transported to a second inspection area of the second inspection in a second orientation with is orthogonal to the first orientation,

translate to the second load region to place the dies onto the pedestals,

pick up the dies from the second pedestals after inspection by the first inspection module, and

place the dies onto the tray transported to the second inspection station in tray positions from where they were picked up.

21. The die inspection system of claim 18 wherein the first and second inspection stations are configured to operate independently in a continuous workflow to produce high throughput.

22. The die inspection system of claim 21 wherein the first and second inspection station are positioned along a same x-axis for streamlined tray movement without re-orientation of the tray from the first to the second inspection station.

23. The die inspection system of claim 21 wherein the continuous workflow comprises:  
the first inspection station is configured to inspect the first and second ROIs of the dies of a tray of dies;

a die holder holding the tray of dies after inspection is completed on the dies by the first inspection station is configured to transport the tray with dies inspected by the first

inspection station to the second inspection station for inspection by the second inspection station while a die holder holding a next tray of uninspected dies is transported to the first inspection station for inspection by the first inspection; and

repeating transporting an inspected tray of dies by the first inspection station to the second inspection station for inspection and a next tray of uninspected dies for inspection by the first inspection station.

24. The die inspection system of claim 23 comprises independent die holders for holding different trays for transporting the trays from one inspection station to another inspection station.

25. The system of claim 18 wherein:

the first illumination unit is configured to generate a first collimated illumination having an inspection band for inspecting the first and second ROIs;

the first optical sub-system comprises first filters of the first optical configured to separate the first collimated illumination into first and second first illumination sub-bands within the first inspection bands to prevent crosstalk when inspecting the first and second ROIs;

the second illumination unit is configured to generate a second collimated illumination having the inspection band for inspecting the third and fourth ROIs; and

the second optical sub-system comprises second filters configured to separate the second collimated illumination into third and fourth second illumination sub-bands within the inspection band to prevent crosstalk when inspecting the third and fourth ROIs.

26. The die inspection system of claim 20 wherein:

the first inspection platform comprises first pedestal dividers for separating adjacent first pedestals to prevent crosstalk from adjacent first pedestals; and

the second inspection platform comprises second pedestal dividers for separating adjacent second pedestals to prevent crosstalk from adjacent second pedestals.

27. A method for inspecting a die comprising:

generating illumination for imaging a region of interest (ROI) of a die at an internal die sidewall of the die, the ROI includes a grooving kerf and a die seal ring surrounding core circuitry of the die,

directing the illumination through an inactive surface of the die at an angle  $\theta$  with respect to an orthogonal axis of the inactive surface of the die to the ROI, and

directing reflected illumination from the ROI to an image capture module to image the ROI, and

determining from the image extent that cracks, if any, extend from internally toward and beyond the seal ring in the ROI.